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Shahriar Mahbub Alam
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STUDY AND ANALYSIS OF THE WATER QUALITY OF THE BLACKSTONE
RIVER WATERSHED

BY

SHAHRIAR MAHBUB ALAM

A DISSERTATION SUBMITTED IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY

IN
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UNIVERSITY OF RHODE ISLAND

1996

DOCTOR OF PHILOSOPHY DISSERTATION
OF
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1996

ABSTRACT

Wet weather water quality of the Blackstone River was analyzed. Three wet weather events were successfully captured for the wet weather program: Storm 1 (September 22-24, 1992), Storm 2 (November 2-5, 1992) and Storm 3 (October 12-14, 1993). Grab samples were collected at specific time intervals throughout the Blackstone River watershed. The concentrations and EMC's (event mean concentration) for different constituents were determined. Two types of violations were compared for fecal coliform in the Blackstone River: log mean > 200 md/100 ml and 10% of samples exceeding 400 md/100 ml. Acute and chronic criteria were compared with the concentrations measured for trace metals to determine violations. These criteria are used to protect the public health and the environment.

Concentration data and flow data were used to calculate mass loadings. EMCs and average flows were used to determine the value of EMM (event mean mass) at a particular station. A comparison of wet and total loadings were provided and tributary wet load rankings were determined. Net gains and losses per reach were calculated and major point sources and non point sources were compared.

Net pollutant changes in a reach help to identify locations of major pollutant sources. The results of this evaluation also provided insight into the relative importance of each reach through a system ranking. The ranking for each storm was calculated for both wet and total loads. The ranking, without point sources for the wet load, were also calculated for each storm. A comparison of wet and dry weather sources for different constituents was provided.

A procedure was developed to separate runoff and resuspension. This procedure was demonstrated for the reach between BWW07 and BWW08 (Rice City Pond). This reach appears to be a major source of resuspension. An estimate of annual loadings at the MA/RI state line and end of river (to Narragansett Bay) was provided. The annual loads were divided into two parts: contribution by dry weather and contribution by wet weather. Total loadings for a particular year were determined by adding wet loads with dry loads for that year.

The analysis of the concentration data showed that wet weather did impact the water quality of the Blackstone River. For UBWPAD there was no violation of maximum ammonia discharge during dry weather conditions but violations did occur in two out of three storms during wet weather (Storm 1 and Storm 3). During peak flow fecal coliforms from Worcester passed by UBWPAD without instream disinfection. This was due to the higher flows at the WWTF and the lower chlorine residual concentrations. Significantly more stations had fecal coliform violations under wet weather than dry weather.

Wet weather caused acute criteria violations. During the height of the storm, instream hardness drops resulting in lower acute criteria concentrations. The more stringent criteria typically coincided with maximum instream concentrations. The result is the possibility of short term violations. The cause of higher metal concentration may be resuspension of the bottom sediments due to high flow and velocity, runoff, or poor performance of treatment facilities subjected to increased flow during the storm.

Pollutants associated with wet weather may come from either new sources (runoff induced) or old sources (river sediments). It is important to note that the former may be

easier to control and regulate than the later. The data indicate clearly that with only minor exceptions more wet load entered the river during these periods than dry load.

The information collected during the wet weather sampling program provided insights into the behavior of the sources during varying storm conditions. A relationship was developed between rainfall and wet loadings using the data collected during the three storms and previous wet weather data available for the state line and end of river.

Regression plots were done for trace metals, nutrients and TSS. These equations were used to estimate the annual wet loading rates for the Blackstone River.

The dry weather data was sufficient to permit the calibration and verification of a model to describe trace metal transport as well as a model for dissolved oxygen. The dry weather models were used to estimate baseline mass loadings under steady state flow.

The relationships were developed and used to estimate the annual dry weather contributions at MA/RI state line (BWW13) and end of the river (BWW21). These dry weather loadings can be compared with the annual wet weather loadings. In the long run this is exactly what is needed to allow decisions into pollutant control.

ACKNOWLEDGMENTS

Every step towards progress is a culmination of the efforts of many people. Hence I take this opportunity to express my thanks to all the people who have directly or indirectly contributed in the creation of this dissertation. Few people who immensely contributed in many different ways are mentioned below.

I would like to express my profound gratitude and sincerest appreciation to my advisor Dr. Raymond M. Wright for his valuable counseling, continuous encouragement, constant guidance and patience throughout the course of this study. Whenever I saw his smiling face I forgot my tiredness and got refueled for next action. He will be a role model and mentor in my future life.

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I am very grateful to my family and to my wife's family for their encouragement and moral support. They have been a constant source of inspiration in my pursuit of learning and advancement.

Finally, I would like to thank my lovely wife, Tinku, for her love, support, cooking and cleaning during the period of the research. Hope finishing this dissertation would make her happy and end all her complains.

DEDICATION

I want to dedicate this dissertation to the memory of my beloved MOTHER:

“Late *Mrs. ZULEKHA BEGUM*” who died in 1993 due to Brest Cancer (May peace be on her and may Allah keep her in Heaven, which is the final destiny of all of us), for whom I pray and cry every day, every night, every moment and will be praying and crying for the rest of my life.

I wish to rest in final peace at the feet of my mother after my death. But, before that I want to do some good things in her memory which will be beneficiary to mankind (may Allah accept my wish).

I hope, wish and pray that no mother in the world dies due to *Brest Cancer* or any other disease leaving their child crying. Let all of us get together and do some good things in the memory of our mothers which will be beneficiary to mankind.

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CHAPTER 1

1.0 Introduction

The Blackstone River is an interstate waterway with its headwaters in Worcester, Massachusetts. It flows south through Pawtucket, Rhode Island into the Providence River and finally upper Narragansett Bay. The watershed area covers 480 mi² (1230 km²) and its length is approximately 48 mi (76.8 km). The major tributaries to the river are the Quinsigamond, Mumford, West, Branch, Mill and Peter's Rivers. Quinsigamond, Mumford, and West rivers flows in to the Blackstone River in Massachusetts, and Mill, Branch and Peters rivers in Rhode Island. Although Mill and Peters Rivers enter the Blackstone River in Rhode Island, the majority of their watersheds is in Massachusetts. The Blackstone River basin area is approximately 44 miles long and 12 miles wide and about two thirds of the basin area is in Massachusetts and the other one third is in Rhode Island. The Blackstone River flows south from Worcester through the Massachusetts towns of Millbury, Sutton, Grafton, Northbridge, and Uxbridge and through the Rhode Island towns of Woonsocket, Millville, Lonsdale and Pawtucket.

1.1 Significance of the Study

Narragansett Bay is Rhode Island's greatest resource where human activities include fishing and recreation. The Blackstone River, the second largest freshwater source to Narragansett Bay, is also the largest source of many pollutants. Wright et al. (1991) identified the Blackstone River as the major source of both nutrients and trace

metals.

The Blackstone River has a long history of pollution. The states of Rhode Island and Massachusetts are very interested in resolving the water quality problems of the river and ultimately improving its overall resource value. America's industrial revolution began here. Attracted to the water power that the river provided, Samuel Slater established the first successful water-powered textile mill in the United States in 1790. The historic Slater Mill is still there along the Blackstone River in Pawtucket, Rhode Island.

Subsequently numerous mills were built along the entire length of the Blackstone River. By 1800, Pawtucket alone contained 29 cotton mills (Kipp et al. 1992). The Blackstone averaged one dam for every mile of stream by 1830. Other industries also flourished along the Blackstone River, including textile machinery manufacturers, metal platters, tanneries, wire and steel mills, and woodworking companies.

The Blackstone provided another valuable function for industry: waste disposal. Toxic waste from fabric dyeing, leather tanning, manufacturing and metalworking were dumped in the river. In the mid-nineteenth century, complaints about the appearance and odor of the Blackstone River were being raised. In the late nineteenth and early twentieth centuries, the Blackstone River was called "the world's busiest river," due to the number of mills along its bank, many of which relied on the river for power. Another term used to describe the Blackstone River was "an industrial stream"; today, that term might be translated to mean "polluted stream". Sewage and wastes were inadequately regulated prior to the enactment of the Clean Water Act in 1972 and were usually discharged directly into the river in large quantities. The legacy of about two centuries of pollution is

still present in the river sediments and continued industrial discharge.

1.2 Water Quality Studies Performed on the Blackstone River

The Narragansett Bay Project (NBP) funded several water quality monitoring surveys to identify the water pollution problems in the Bay. Several of these studies included major tributaries, including the Blackstone River, at their mouths for monitoring numerous parameters including conventional and toxic pollutants (Wright et al. 1991; Pilson and Hunt 1989; Doering et al. 1989; Metcalf and Eddy 1991).

Quinn (1989) identified the Blackstone River as the major source of solids and petroleum hydrocarbons (PHCs), and a significant source of polycyclic aromatic hydrocarbons (PAHs) to Narragansett Bay based on the SINBADD cruises. Latimer (1989) also identified the Blackstone River as a major source of polychlorinated biphenyl (PCB).

Wright et al. (1990) examined three recent water quality surveys (SPRAY, SINBADD, and the wet weather study for the NBP) and identified the Blackstone River as a major source of most of the pollutants. The Blackstone River also ranked first or second for almost all pollutants (nutrients and trace metals) during the three wet weather events surveyed for the NBP project (Wright et al. 1991).

The Massachusetts Department of Environment Protection (MADEP) classified the Blackstone River as class B. Nearly the entire length in Massachusetts, is considered not to support the designated uses due to coliform, metals, dissolved oxygen (DO), and nutrients (MADEP 1990). The Rhode Island Department of Environmental Management

(RIDEM) classified its portion of the river as class C. The entire length in Rhode Island, is considered not to support the designated uses due to metals, nutrients and coliform (RIDEM 1990).

Wright (1988) and Quinn et al. (1988) found that levels of cadmium, copper, lead and PCBs were already exceeding RI freshwater aquatic life chronic criteria, where the river entered Rhode Island from Massachusetts. In addition, copper concentrations also exceeded the acute criteria. Wright (1988) also concluded that inputs from Rhode Island's discharges were relatively insignificant compared to loads coming from Massachusetts. Other studies have found water quality criteria to be violated throughout the Blackstone, in both states and during dry and wet weather conditions (Wright et al. 1991; RIDEM 1990; USEPA 1983; Save The Bay 1990).

There were 41 permitted dischargers (Point Sources) to the Blackstone River and its tributaries, 28 of these are industrial and 13 are municipal (Kipp et al. 1992). The municipal dischargers included 11 waste water treatment facilities (WWTF). Only two WWTFs have pretreatment programs (Upper Blackstone Water Pollution Abatement District (UBWPAD) and Woonsocket WWTF) and one (UBWPAD) provides seasonal nitrification.

Nonpoint sources to the Blackstone River may include agricultural and urban runoff, soil erosion and sediment resuspension, leachate from landfills, leaking underground storage tanks, hazardous waste sites, and effluent from failed septic systems. Usually wet weather exacerbates the loadings from these sources. Little data exists for nonpoint sources and associated pollutant loadings to the Blackstone but they are likely a

significant input. One study by EPA found that Lake Quinsigamond was experiencing eutrophic condition due to runoff of phosphorous, and bacterial pollution was widespread as a result of sewage contamination of storm drains via routes such as illegal connections and infiltration (USEPA 1983).

An estimated 2,180,00 cubic yards of contaminated sediments in the Massachusetts portion of the Blackstone River alone is reported by McGinn (1981). These sediments trapped behind current or former impoundments, have been identified as a potential major source of pollutants to the Blackstone River. During the period of rainfall or high flow conditions these sediments are resuspended and carried downstream, therefore contributing to water quality problems.

1.3 Objective of the Study

While some studies have been conducted on localized segments of the river, the lack of a comprehensive water quality survey for the entire river is identified as a hindrance to developing an understanding of the trends and kinetics of the pollutants in the river. As a result, the Blackstone River Initiative (BRI) was established by the U. S. Environmental Protection Agency (USEPA) with the Massachusetts Department of Environmental Protection (MADEP), Rhode Island Department of Environmental Management (RIDEM) and the Civil Engineering Department of the University of Rhode Island (CVE-URI). This study will be the first comprehensive watershed wide wet weather study.

BRI had two programs: one for dry weather and the other for wet weather. Three

surveys were done successfully for the dry weather program (July 1991; August 1991; and October 1991). Three storms were successfully captured for the wet weather program (September 1992; November 1992; and October 1993).

The goal of this research is to characterize the water quality of the Blackstone River watershed under wet weather and provide a comparison of results with dry weather conditions. The objectives included:

- 1) The determination of the impact of wet weather on the water quality of the Blackstone River;
- 2) The identification of the major pollutant sources and/or areas in the Blackstone River watershed and the development of system rankings; and
- 3) The determination of the relative importance between nonpoint and point sources and the development of annual loading rates for selected constituents.

CHAPTER 2

2.0 Literature Review

Millions of Americans make their living from the nation's waters. They fish and swim for recreation, or choose to locate their homes or businesses near waterways. The report, based on data collected in 1991-92, shows that America's waters are indeed in trouble. Approximately 40% of the waters are not suitable for simple activities such as fishing or swimming (Browner 1994). Polluted runoff (nonpoint source pollution) is the single greatest threat remaining to America's rivers, lakes, and estuaries. All pollution abatement efforts were aimed at controlling the point source pollution although more than 50% of the total water quality problems are nonpoint source related (Novotny and Chesters 1981).

Water bodies receive pollutants such as: silt, pesticides and fertilizer, whenever it rains. Pollutants are carried off farms, suburban lawns, industrial plants, and city streets into the rivers and lakes during the storm events. Controlling runoff from fields and streets is more difficult than controlling the pollution emitted from the end of a pipe (point source). Polluted water that flow from the land to streams is a problem that has long been neglected and has not been properly addressed. Nonpoint source pollution has increased in the U.S. and in the world. Mitchell (1996) found as much as 80% of water pollution is nonpoint source related and it has largely escaped the attention of regulators.

Water quality problems in rivers, lakes and continental shelves are widespread (Andersson and Rydberg 1988; Fransz and Verhagen 1985; Lancelot et al. 1987;

Rosenberg 1985; Rosenberg and Loo 1988; Wulff and Rahm 1988). Water quality in streams, rivers, lakes and coastal waters may change due to pollution. Watersheds are modified by alterations in vegetation, sediment balance, fertilizer use and the conversion of forests and grasslands to farms and cities (Aber et al. 1989; Borman and Likens 1979; Schlosser and Karr 1981; White et al. 1981).

About \$40.5 billion in federal money plus some \$25 billion more in state and local funds have been invested in the fight against water pollution (Taylor 1987). The quality of some 47,000 miles of monitored streams is markedly improved but 311,000 miles of water have worsened or remained unchanged. The cleaner the water becomes, the more attractive it becomes to the people to settle near it. The new development near the cleaner water starts the pollution cycle all over again. U.S. residents spent \$62.7 billion on pollution abatement and control (PAC) in 1983. This spending was for regulation and monitoring, pollution abatement, and research and development (U. S. Department of Commerce 1985). Regulation and monitoring is a government activity that stimulates and guides action to reduce pollutant. Pollution abatement directly reduces pollutant by preventing the generation of pollutant, recycling them, or treating them prior to discharge. Research and development supports abatement and helps increase the efficiency of regulation and monitoring.

Quantification of these watershed/water-quality relationships is important. Understanding the consequences of existing or potential watershed changes leads to the possibilities for preventing or remedial action.

2.1 Urban Runoff

The discharge of storm water into navigable waterways is recognized as a widespread problem. Urban runoff discharge is partially responsible for the degradation of U.S. waterways. A leading cause of water quality impairment is the pollution from diffuse, i.e. nonpoint sources (Skoch 1993). The stormwater pollution problem is difficult to solve primarily because it is easily created. A discharge occurs whenever rainwater falls on contaminated soils or piles of materials containing pollutants. This stormwater then carries the contaminants into waterways.

Analyzing pollutants in discharges at the end of the pipe were traditionally emphasized. A number of recent initiatives taken by EPA will change the direction of monitoring in general (Cook et al. 1994).

Combined sewer overflow (CSO) discharges pose a serious threat to receiving water quality in many urban drainage basins. Wright et al. (1992) studied the CSOs in Providence and modeled the impact of Providence sewer system to the Narragansett Bay in Rhode Island.

Cave and Roesner (1994) summarized previous stormwater monitoring programs and the Nationwide Urban Runoff Program (NURP). A comparison of the EMC values of selected constituents of NURP data collected in the early 1980s with the National Pollutant Discharge Elimination System (NPDES) data collected in 1991-1993 in the State of Michigan was presented by them. The constituents analyzed and presented by the study included total suspended solids (TSS), chemical oxygen demand (COD), biochemical oxygen demand (BOD), total phosphorous, dissolved phosphorous, total

Kjeldahl nitrogen (TKN), nitrite+ nitrate nitrogen, fecal coliform (FC), lead, zinc and copper. A comparison of EMC values of this study at an urban station (BWW00) with NURP studies are provided in Chapter 5 (Table 5.6).

Thomas and McClelland (1994) described a regional stormwater monitoring plan developed and implemented in the Atlanta Region to comply with NPDES rules. Similar studies were done in Dallas-Ft Worth, Texas (Brush et al. 1994) and Santa Clara Valley, California (Cooke et al. 1994). Brown et al. (1994) presented the methods and procedures developed by the City of Austin, Texas, Stormwater Monitoring Program to ensure the quality of stormwater monitoring data produced.

Turner and Rabalais (1991) studied the changes in the water quality of the Mississippi River. In terms of length, discharge, and sediment yield, the main river channel is the third, eighth, and sixth, respectively, largest river in the world (Milliman and Meade 1983). Water quality in the river has almost certainly changed this century as a result of the watershed changes and changes in fertilizer use. The authors studied three indicators of water quality: phosphorous (as total phosphorous), silicon (as silicate), and dissolved inorganic nitrogen (as nitrate). They used water quality data primarily from the Water Quality or Water Supply Papers series of the US Geological Survey and also data supplied by the New Orleans Sewerage and Water Control Board. They compared the mean concentrations of nitrate, silicate, and total phosphorous for four lower Mississippi River stations.

2.2 Law and Regulations

There was no major legislation dealing with nonpoint pollution until the U.S. Congress passed the Federal Water Pollution Control Act in 1972. The general population was not even aware of the problem until the late 1960s. The National Environmental Policy Act (NEPA) was designed to protect natural and environmental resources. Safe Drinking Water Act of 1974 was designed to protect the nation's drinking waters. Toxic Substances Control Act of 1976 is the primary legislative document controlling the toxic substance in the environment. The Federal Water Pollution Control Act with its 1977 amendments, known as "The Clean Water Act", recognized cleaning up nonpoint sources to solve the nation's water quality problem.

The Clean Water Act charges the Environmental Protection Agency (EPA) with policing the release of toxic chemicals into the nation's rivers, lakes and streams. By law, industrial firms may not release anything into these waters without first obtaining an EPA permit to do so. A new analysis by the General Accounting Office (GAO), a congressional watchdog agency, found that some 77% of the toxic pollutants discharged were not listed on their permits (Science News 1994). About 85% of the facilities, majority of the toxic pollutants discharged were not controlled through the permit process.

Need for the revisions for stormwater regulations provided under the Clean Water Act of 1977 were required to be able to address pollution problems more effectively and realistically (Tucker et al. 1995). Under the existing program, all municipal and local governments are required to obtain NPDES permits for rainwater runoff discharged into receiving water. This and other regulations have been found to create significant

budgetary problems for local officials throughout the U.S.

Urban stormwater runoff is receiving increased attention from the US EPA. It issued the final rule to implement Section 402 (P) of the Clean Water Act in 1990. This rule requires cities over 100,000 in population to obtain stormwater permits under the NPDES. The management of nonpoint sources of water pollution is often complicated. Defining the specific sources, pollutants, or both is difficult and costly task. A report to Congress By U.S. EPA (1984) identified five major categories of nonpoint pollution: agricultural; silvicultural; mining; construction; and urban. Nonpoint inputs from urban and industrial locations, forests, agricultural areas, and mining activities contain different types of pollutants and represent different transport patterns.

2.3 Sediment Erosion and Resuspension

Several studies were done in the past on modeling sediment transport and deposition (Arnolds et al. 1995; Cao et al. 1995; Mertes 1994). French (1995) proposed a new methodology to measure the maximum depth of deposition that occurs when a steep slope channel changes to a milder slope. Garbrecht et al. (1995) presented a new sediment transport capacity algorithm for measuring large scale propagation and redistribution of sediments in channel networks. The proposed algorithm uses existing sediment transport equations and generated consistent results for a wide range of flow and sediment characteristics.

Srivasta and Contractor (1992) evaluated the bed-load and suspended-load transport of sediments. Gomez (1991) reviewed the development of knowledge and

research into bedload transport during the past century. Particular emphasis was placed on the development of methods of predicting and estimating bedload discharge, and problems involved in using field data.

The amount of sediment moving into a part of the channel must equal the channel's capacity to move the sediment out of that channel segment. Otherwise sediment will either be deposited ultimately filling the channel or the force of the moving water will erode the channel banks and bed to restore the balance. Obtaining accurate measurements of sediment movement is very difficult. The complete understanding of bedload transport requires the development of reliable apparatus and techniques for predicting, measuring, and sampling bedload in rivers. The Agricultural Research Services (ARS) conducted some research in this field. Their engineers developed a sampling box for collecting coarse sediment and a sonar detection system for tracking sediment movement (Becker 1994).

A study done by Haster and James (1994) found different land surfaces contribute sediments differently. A better estimate of the total sediment load could be determined by representing each of the major land surfaces independently. They proposed a mathematical model for representing the washoff of sediments from small urban watersheds during storm events.

Universal soil loss equation (USLE) is the most widely used method of soil loss prediction. USLE was developed largely through the work of Wischmeier and Smith (1978). More than 8000 plot-years of erosion data were collected from 36 locations in 21 states and were used. Ease of application was a prime consideration in the development

of the USLE. This empirical method was originally developed for soil conservation work in cropland areas. The equation has since been adapted and interpreted for other erosion loss problems.

The USLE is the product of six factors:

$$A = RKLSCP$$

where A =calculated soil loss, R = rainfall erosivity factor, L=slope length, K = soil erodibility factor, S = slope gradient factor, C = crop management factor, and P = erosion control practice factor. The equation was free of some of the geographical and climatic restrictions of earlier methods of soil loss prediction. It was developed largely in the eastern two-thirds of the USA and so it is not necessarily applicable outside that area.

2.4 Best Management Practices

“Best Management Practice (BMP) means a practice or combination of practices that is determined by state (or designated area-wide planning agency) after problem assessment, examination of alternative practices, and appropriate public participation to be the most effective practicable (including technological, economic, and institutional considerations) means of preventing or reducing the amount of pollution generated by nonpoint sources to a level compatible with water quality goals” (Novotny and Chesters 1981).

BMP is an innovative storm-water-management program which involves the consideration of storm-water runoff as a potential resource rather than as a problem (Bou-Sabb 1993). BMPs are implemented to prevent future deterioration in the water quality

and to check existing pollutants in the water. The aim of the project is to control runoff at the surface instead of constructing expensive treatment plants at the discharge point.

Wetlands are valuable as sinks, sources and transformers of a multitude of chemical, biological, and generic materials. Wetlands are found to cleanse polluted waters, prevent floods, protect shorelines, and recharge groundwater aquifers and provide shelters for rare plant, fish and wildlife.

Inland wetlands function as basins in the watershed that retain and detain water at various flood stages. Retained water leaves the surface water via evapo-transpiration and the delayed release of flood water causes less damage in the downstream. Coastal wetlands protect fast lands from erosion and buffer coastal flooding and sea level rise. Wetlands remove nutrients and significant amounts of metals and reduce the sediment load transported in streams (Kibby, 1978). Wetlands act as a fish nursery, protect wildlife and sometimes add visual and aesthetic values.

Most stormwater permits require early action BMPs which include reduction of sources of pollutants through public education. One of the least costly and most effective ways to reduce nonpoint source pollution is storm drain stenciling. This approach addresses urban water pollution where it often starts, in the storm drain system of our communities. Storm drain stenciling is very simply, public education in the streets. It consists of volunteers painting, with a stencil, a pollution prevention message on the entrances to the drains throughout a city. While messages can vary, one study (Cobourn 1994) found it to be effective to state merely, "No Dumping; Drains to River."

Changes in rainfall/runoff characteristics of an area as affected by some management

practices such as livestock grazing can be estimated using rainfall simulation (Frasier et al. 1995). Streambank fencing is a management practice which keeps livestock and streams separated. This has the potential to decrease soil loss by preventing the mechanical breakdown of the streambank by livestock. It also serves as a vegetative filter to entrap soil lost from the surface of the grazed area as it moves toward the stream and prevents animals from defecating directly into the river. Owens et al. (1996) found average monthly sediment concentrations in the storm runoff were considerably lower after the stream was fenced away from grazing livestock.

A watershed rehabilitation program was undertaken for the Redwood National Park (Griffin 1990). Watershed rehabilitation consisted primarily of small- scale labor-intensive techniques. Channel water table control can improve water use efficiency within a watershed. It reduce demands on other water sources to facilitate irrigation; improve crop yields; and reduce the transport of fertilizer nutrients, in particular nitrogen, to sensitive receiving surface waters (Evans et al. 1992). The success of watershed-scale projects are influenced by several factors such as: soils, crops, and topography within the watershed; the percentage of the watershed area cropped; hydraulic properties of the watershed; seasonal rainfall; and management strategies.

2.5 Agricultural Runoff

Soileau et al. (1994) conducted a study to evaluate the effects of tillage on sediment, nitrogen, and phosphorous runoff losses from a representative watershed planted to cotton. Comparisons were made for three years of conventional tillage

followed by three years of conservation tillage. This study showed that for both tillage systems, sediment losses were less than 11,200 kilograms per hectare per year and a cotton residue cover during winter months was effective in minimizing total annual soil losses.

Isensee and Sadeghi (1993) studied the impact of tillage practice on runoff and pesticide transport. Comis (1992) found that no-till, an energy-saving method of planting without prior ploughing, keeps the surface flow and erosion to a minimum. It allows less topsoil and chemicals to reach streams, rivers, and lakes for contaminating the water.

Runoff and erosion are increased by decreased vegetative cover, increased soil compaction, and/or cutting of stream banks. Several studies were done to understand the impact of vegetation on runoff. Johnson and Blackburn (1989) found runoff produced with a rainfall simulator was two to three times greater from a bare treatment than from natural or clipped treatments. He also found the soil losses were about 20 times greater for a bare treatment than from natural or clipped treatments. The percent bare ground is the most important factor explaining soil loss, and as the ground cover increases, soil sediment in the runoff decreases (Hofmann and Ries 1991; Zobisch 1993; Costin 1980; Lang 1979).

A study done in Latvia showed that concentrations in river water increased 5-10 times that of background values as a result of fertilizer application and marsh land destruction (Tsirkunov et al. 1992). Greater flow velocity might be the reason for the bigger load transport during a storm event.

2.6 Computer Programs and Models Available

Some computer programs were developed in recent years to understand and model pollution and tracking pollution sources.

QUAL2E was developed by EPA and went through several revisions (EPA 1987). This program is used to simulate DO, BOD, temperature, algae as chlorophyll a, organic nitrogen as N, ammonia as N, nitrite as N, nitrate as N, organic phosphorous as P, dissolved phosphorous as P, coliforms, arbitrary nonconservative constituents and three conservative constituents. It allows for multiple waste discharges, withdrawals, tributary flows, and incremental inflow and outflow. QUAL2E operates in steady-state modeling conditions.

Wright et al. (1985) developed PAWTOXIC model to simulate the trace metal in the Pawtuxet River, Rhode Island. The successful calibration and validation exercise indicates that the model can be confidently used as a predictive tool. This model is extensively used by the RIDEM.

Agricultural Non-Point-Source (AGNPS) pollution model identifies watershed sites that could possibly carry pollutant such as pesticides, fertilizers or sediments (Comis 1995). The AGNPS divides watersheds into grids, each grid cell containing information such as soil type, topography, land use, chemicals applied, tillage method etc. The pollution potential is then calculated on a per-grid basis.

A model was developed to simulate the suspended transport of the fine-grained sediment, both cohesive and noncohesive, in the Pawtuxet River, Rhode Island (Ziegler and Nisbet 1994). The SEDZL modeling framework has been modified to include the

simulation of noncohesive suspended transport. The hydrodynamic and sediment transport models were calibrated and validated during a 33-day period, which included two high-flow events.

A computer-aided methodology was designed by Reinelt et al. (1988) to aid in the determination of water quality and ecological change resulting from nonpoint sources of water pollution. A case study example on the Stillaguamish River Basin in Washington State is provided also in the article.

An integrated rainfall-runoff and runoff-receiving water-quality modeling protocol was developed by Warwick and Edgmon (1988) to quantify the impact of combined sewer overflow events on in-stream dissolved oxygen concentration.

Storm Water Management Model (SWMM) was developed to simulate and design of combined or storm water sewer systems (EPA 1971). Its use for simulating nonpoint pollution processes and problems is limited. The program is large and requires an extensive amount of input data.

Storage, Treatment and Overflow Model (STORM) was developed for the U.S. Army Corps of Engineers (STORM 1975). This program can simulate quantity and quality of runoff from small urban watersheds. Nonurban areas can also be included in this program. Total and volatile particulates, biochemical oxygen demand (BOD), total nitrogen and orthophosphate can be modeled using STORM. It is a medium-sized program but requires a substantial amount of input data.

Nonpoint Simulation Model (NPS) simulates pollution from a maximum of five different land use categories in a single operation (Donigian and Crawford 1976). It

allows for simulation of runoff, water temperature, Dissolved oxygen (DO) and sediments.

The Overland Flow and Pollution Generation Model (LANDRUN) was primarily used for modeling effects of various land uses on the pollutant loading to the Great Lakes (Novotny et al. 1979). It is a medium sized program and can be run on a storm event basis or continuously.

2.7 Other Issues

The third world is counting heavily on water resource development to foster economic growth. Many nations also rely on hydroelectric development to reduce dependence on costly fuel oil. Many of the benefits of water resources development in the third world have been lost because of soil erosion, sedimentation and serious water quality problems have arisen (Southgate and Macke 1989). Sometimes pollution is a political and cultural problem in the third world countries. Alley (1994) described the impact of waste on the river Ganges in India and addressed the tensions played out in the community as government agencies developed the category of environmental pollution in official policy.

Sometimes, in the developed countries, opposition and various lobbyist groups can influence the release of documents by government agencies on pollution. One such case occurred in the United States. Due to the criticism from various quarters, the EPA has decided against the release of a report on sediment contamination point sources (entitled 'National Sediment Contaminant Point Sources Inventory: Analysis of Release Data for 1992'). This report ranks the importance of point sources in sediment contamination all

over the U.S. (Renner 1996).

2.8 Conclusions

A comprehensive wet and dry weather water quality study has not been done on an interstate river which has influence from both urban and rural areas. The Blackstone River Initiative (BRI) study will be the first of such a kind in the U.S. sponsored by the U. S. EPA. Wright et al. (1994) presented the summary of the field program for the wet weather studies of the BRI. A previous study done on Narragansett Bay identified the Blackstone River as the number one polluted river and as the major sources of both nutrients and trace metals (Wright et al. 1991) to the Narragansett Bay.

While some studies have been conducted on localized segments of the river, The lack of a comprehensive water quality survey for the entire river is identified as a hindrance to developing an understanding of the trends and kinetics of the pollutants in the river. So it is very useful and will be very interesting to study the pollution problems in the Blackstone River for wet weather conditions and to compare these results with dry weather.

CHAPTER 3

3.0 Program Description and Methodology

The Blackstone River Initiative was a joint effort between the EPA, MADEP, RIDEM and Civil and Environmental Engineering Department (CVE) at University of Rhode Island (URI).

The responsibility of the dry weather field program design and execution was headed up by the EPA. The field program was a joint effort by all groups. All samples were collected and analyzed under the control of CVE-URI with the exception of toxicity, which was handled by EPA-Lexington and fecal coliforms, which was analyzed by MADEP-Lawrence. The preliminary assessment of the dry weather data was completed by MADEP and expanded by CVE-URI. The modeling efforts were completed by the CVE-URI.

The responsibility of the wet weather field program design and execution was headed up by CVE-URI. The field program was a joint effort by CVE-URI, EPA, and MADEP. All samples were collected and analyzed under the control of CVE-URI with the exception of toxicity, which was handled by EPA-Lexington.

This dissertation details the result of these efforts as well as the collection and analysis of wet weather Storm 3 (October 1993) samples. The interpretation of the wet weather data (all three storms) and the integration of the results with the dry weather data (all three surveys) are also completed in this dissertation.

3.1 Water Quality Sampling

3.1.1 Water Quality Sampling Stations

There were a total of 21 river stations for the dry weather surveys and listing of the stations and a location map are provided in Table 3.1 and Figure 3.1. Fifteen of these stations were located along the Blackstone River and 6 near the mouth of the major tributaries. Dry weather stations are coded with the prefix BLK. In addition, 2 point source discharges were sampled, these included the UBWPAD and Woonsocket WWTF for both pre and post chlorination.

For the wet weather surveys stations are coded with the prefix BWW. A total of thirteen water quality stations were sampled along the Blackstone River, as well as six tributaries and five point sources discharges. These included from upstream to downstream three direct discharges to the Blackstone River including the combined sewerage overflow (CSO) facility in Worcester (BWW22) (between BWW00 and BWW01), UBWPAD (BWW23) (between BWW01 and BWW02), and Woonsocket WWTF (BWW24) (between BWW17 and BWW18), and two direct discharges to the Seekonk River below the mouth of the Blackstone River including Bucklin Point Narragansett Bay Commission Facility (BP NBC) (BWW25) (below BWW21) and the BP NBC by-pass (BWW26) (below BWW21). The NBC by-pass flowed over a weir at the northern end of the facility and received no treatment.

River mile points are listed from the mouth of the river starting with mile point 0. Only minor station modifications occurred between the dry and wet surveys. Stations were selected to isolate wet weather problem areas such as point sources, impoundments,

Figure 3.1 Sampling Station Location

Table 3.1 Water Quality Sampling Stations Location

Dry Weather	Wet Weather	River	Location	City
	BWW00	Blackstone	Greenwood St.	Worcester, MA
BLK01	BWW01	Blackstone	Millbury St.	Worcester, MA
BLK02	BWW02	Blackstone	McCraken Rd.	Millbury, MA
BLK03		Blackstone	Riverlin St.	Millbury, MA
BLK04	BWW04	Blackstone	Blackstone St. (Singing Dam	Sutton, MA
BLK05	BWW05	Quinsigamond	Millbury St.	Grafton, MA
BLK06	BWW06	Blackstone	Route 122A	Grafton, MA
BLK07	BWW07	Blackstone	Riverdale St.	Northbridge, MA
BLK08	BWW08	Blackstone	Hartford St. (Rice City Pond	Uxbridge, MA
BLK09	BWW09	Blackstone	Medon St. (Rte 16)	Uxbridge, MA
BLK10	BWW10	West	Centerville (Off Rte. 16)	Uxbridge, MA
BLK11	BWW11	Blackstone	Rte. 122 Bridge	Uxbridge, MA
BLK12		Blackstone	Rte. 122 (Near USGS Gage)	Milville, MA
BLK13	BWW14	Branch	Rte. 146A	Slatersville, RI
BLK14	BWW13	Blackstone	Bridge St. (State Boundary)	Blackstone, MA
BLK15	BWW15	Mill	Winter St.	Woonsocket, MA
BLK16	BWW16	Peters	Rte. 114	Woonsocket, MA
BLK17	BWW17	Blackstone	Hamlet Ave. (Rte. 122, 126)	Woonsocket, MA
BLK18	BWW18	Blackstone	Manville Hill Rd.	Cumberland, RI
BLK19		Blackstone	School St./Albion Rd.	Cumberland, RI
BLK20	BWW20	Blackstone	Lonsdale Ave.	Lonsdale, RI
BLK21	BWW21	Blackstone	Main St. (Slater's Mill)	Pawtucket, RI

combined sewer overflows and junk yards and to provide sufficient spatial detail in the system. The stations were compatible with previous water quality studies along the river. Station BWW00 was added to isolate the Worcester CSO outfall.

3.1.2 Dry Weather Field and Sampling Program

The dry weather program consisted of three 48 hour surveys: July 10-11, 1991 for Survey 1, August 14-15, 1991 for Survey 2 and October 2-3, 1991 for Survey 3.

Grab samples for dissolved oxygen (DO) were collected every six hours over the 48 hour period. Temperature, pH, and conductivity readings were taken in the field concurrently with the DO samples.

For the instream sampling, four sets of discrete grab samples were collected once every six hours over the first 24-hour period for each of the three surveys. The samples were analyzed for five-day carbonaceous biochemical oxygen demand (CBOD), total suspended solids (TSS), volatile suspended solids (VSS), chloride, total Kjeldahl-nitrogen (TKN), dissolved ammonia-nitrogen (NH_3), dissolved nitrate-nitrogen (NO_3), dissolved orthophosphorus (PO_4), total and dissolved metals (cadmium, chromium, copper, lead, and nickel) and hardness (calcium and magnesium).

Fecal coliform samples were collected during the 0400 run on the first day of each survey. Samples were also collected for chlorophyll *a* analyses, on the 0400 and 1600 river runs, on the first day of each survey period.

Samples were collected using teflon buckets, and pre-cleaned plastic bottles provided by the University of Rhode Island (URI). Samples were stored under ice for

transport. All samples were transported at the end of each survey run to the laboratory conducting the analyses. Chemical, nutrient, metal, and chlorophyll analyses were conducted by URI. Fecal coliform analyses were performed by the Massachusetts Department of Environmental Protection (MADEP). Dissolved oxygen determinations were performed by the MADEP and EPA field personnel.

3.1.3 Wet Weather Field and Sampling Program

3.1.3.1 Rainfall Criteria

Establishing rainfall criteria is critical to the success of the monitoring program and the interpretation of the data. Isolation of the effect of a discrete event to permit the characterization of runoff and the determination of the impact on receiving water quality was the basic objective. Rainfall criteria were set ahead of the field program and included:

- Minimum rainfall total of 0.5 inches
- Minimum rainfall duration of six (6) hours
- Minimum antecedent dry period (ADP) of three (3) days
- Minimum number of three (3) post-storm dry days

A rainfall monitoring network was established to cover the study area, consisting of six gages maintained by the National Weather Service, 4 URI gages and 2 gages maintained by municipal wastewater treatment facilities. Locations and rainfall details are provided in the next chapter.

The criteria is designed to sample storms associated with frontal systems that provide uniform rainfall over the watershed. Storm development and movement were

tracked by meteorologists with the final decision for the call of the storm provided by URI.

3.1.3.2 Field and Sampling Program

Three storms were successfully monitored on 09/22/92, 11/02/92 and 10/14/93, meeting all rainfall criteria with total rainfalls of 0.55 inches (14 mm), 0.92 inches (23 mm) and 0.8 inches (20.3 mm), respectively. The rainfall coverage for Storm 1 and Storm 2 were relatively uniform. Storm 3 ranged from 1.3 inches (33 mm) in the north at Worcester, MA to 0.55 inches (14 mm) in the south. Rainfall characteristics and stream flow determinations are discussed in detail in Section 4.

A prestorm sample was collected 3-4 hours in advance of the storm to define the baseline dry weather loads. Initially, sampling was set at a higher frequency to identify the local storm water and first flush contribution to the receiving water. A total of 15 samples were taken for each location starting at 3 hour intervals from time 0 (observed runoff) and continuing through 12 hours (5 samples), followed every 4 hours for the next 36 hours (9 samples) with one sample on the third day to define the end of storm. Samples were transported to a field lab centrally located in the watershed for processing and distribution.

Each station was sampled at the surface. Field measurements included temperature, pH, conductivity and dissolved oxygen. Laboratory chemical analysis included TSS, VSS, BOD, chloride, sodium, NH_3 and NO_3 as N, PO_4 as P, total trace metals (cadmium, chromium, copper, lead, nickel and zinc), hardness (calcium and magnesium), fecal coliform and *E. coli*.

Samples were collected using teflon buckets, and pre-cleaned plastic bottles. Samples were stored in ice for transport. Chemical, nutrient, and metal analyses were conducted by URI. Fecal coliform analyses were performed by Biological Analytical Laboratories (BAL).

Samples at the two WWTFs, UBWPAD and Woonsocket, were collected at the same frequency as the instream samples and analyzed for the same set of constituents given above.

3.2 Methods and Methodologies

To determine the impact of wet weather on the water quality of the Blackstone River the following was accomplished:

The samples were collected prior to the storm, during the storm and for several hours after the storm. These data coupled with stream flows allow for the calculation of mass loading curves. These then may be interpreted to estimate dry weather baseline conditions from prestorm data and, for comparison, wet weather loads from integration of the mass curves. In addition to this, the trace metal data allow for a comparison between observed in stream concentrations and acute and chronic criteria violations.

To identify the major pollutant sources and/or areas in the Blackstone River watershed and the development of system rankings, the following was accomplished:

Pollutant sources associated with wet weather may come from either new sources (runoff induced) or old sources (river sediments). It is important to note that the former

may be easier to control and regulate than the latter. The sampling program and analysis of the data give the net gain and losses between the reaches. Gains identify the nonpoint sources and the analysis of data for the waste water treatment facilities (WWTF) provide the loadings from point sources. Arranging these according to the percent loading contribution lead to the system ranking.

To determine the relative importance between non-point and point sources and the development of annual loading rates for selected constituents, the following was accomplished:

The information collected during the wet weather sampling program provide insights into the behavior of the sources during varying storm conditions. This information is used to calculate empirical relationships between wet weather mass loadings and rainfall characteristics for individual reaches of the river. These relationships are used with historic rainfall records to estimate annual loading rates for wet load.

The dry weather data was sufficient to permit the calibration and verification of a model to describe trace metal transport as well as a model for dissolved oxygen. The dry weather models are used to estimate baseline mass loadings under any steady state flow. The models are then used to estimate the annual dry weather contributions at any location in the river. These then are compared with the wet load to provide a comparison between the annual wet versus dry weather loadings. In the long run this is exactly what is needed to allow decisions into pollutant control. Addition of dry and wet loads give the total annual load for a particular year.

CHAPTER 4

4.0 System Hydrology and Hydraulics

4.1 Wet Weather

4.1.1 Rainfall

Sampling was successfully completed for three events: Storm 1 - September 22-24, 1992; Storm 2 - November 2-5, 1992 and Storm 3 - October 12-16, 1993.

4.1.1.1 Rainfall Network

There were a total of 16 raingages in the rainfall network (Figure 4.1). Not all of these gages were available for each storm. Each station is coded by the following: R1N, where R = rainfall station; 1 = station identification numbered from north to south; and N = the group responsible for the gage (for instance, N = National Weather Service (NWS), U = URI, M = Municipal, S = State) (Table 4.1).

The National Weather Service (NWS) operates seven stations either in or just outside the watershed. Two of these stations which are located at major airports (R1N and R16N) and record precipitation continuously. The other five stations are managed by the NWS's Northeast River Forecast Center. The data at these stations are manually collected daily by 0900 and are reported as a total precipitation amount pertaining to the previous 24 hour period. Three of these stations are inside the watershed (R6N, R7N and R11N) and two are to the east (R5N and R8N). Three gages were maintained by municipalities at wastewater treatment facilities (WWTF) (R4M, R10M, and R13M) and

Figure 4.1 Raingages Location For Blackstone River Wet Weather Studies

Table 4.1 Precipitation Log of Three Storms for Blackstone River Wet Weather Studies

Gage Name	Location	Maintained By	Type	Rainfall in inch		
				Storm-1	Storm-2	Storm-3
R1N	Worcester Airport, MA	NWS	1	0.44	0.98	1.30
R2U	Westborough WWTF, MA	URI	1	NA	0.83	0.85
R3U	Millbury WWTF, MA	URI	1	NA	0.77	NA
R4M	Millbury WWTF, MA	WWTF	2	0.66	0.62	NA
R5N	Buffumville, MA	NWS	2	0.63	0.99	1.15
R6N	Northbridge, MA	NWS	2	0.54	0.94	0.69
R7N	West Hill Dam	NWS	2	0.53	0.89	0.90
R8N	Putnam, CT	NWS	2	0.63	0.84	1.15
R9U	Burrville WWTF, RI	URI	1	NA	0.85	NA
R10M	Burrville WWTF, RI	WWTF	2	0.74	NA	0.48
R11N	Woonsocket, RI	NWS	2	0.56	0.86	0.61
R12U	Woonsocket WWTF, RI	URI	1	0.46	0.78	NA
R13M	Bucklin Pt. WWTF, RI	WWTF	2	0.49	NA	NA
R14S	Providence, RI	DEM	2	0.51	NA	NA
R15U	Fields Point WWTF, Prov.,	URI	1	0.62	0.76	NA
R16N	TF Green Airport, Warwick,	NWS	1	0.62	0.80	0.27
R1N: R = Rainfall; 1 = Station ID; N = National Weather Service (NWS) (U = URI, S = State and M = Municipal); DEM = RI Department of Environmental Management; Type 1 = Continuous Recorder; Type 2 = Daily Total; NA = Not Available						

one station (R14S) by the RIDEM. These data were also daily totals typically collected by 0700 each day.

To complete the rainfall network, URI established five additional stations with automatic tipping bucket rain gages (R2U, R3U, R9U, R12U and R15U).

4.1.1.2 Rainfall Characteristics

A summary of the total rainfall records at each station is also given in Table 4.1. The temporal pattern of each storm has been represented by a series of hyetographs (Figure 4.2). The three gages presented on this figure include the most northern station (R1N), a central station (R12U) and the most southern station (R16N).

Each storm's distribution across the watershed is illustrated by total rainfall lines of equal precipitation (Isohyetal lines). These are presented in Figures 4.3 to 4.5.

4.1.1.3 Total Rainfall

The simplest approach to developing equivalent uniform depth of precipitation over an area is to approximate the depth with an average storm of all raingages. However, this procedure is not acceptable if the gages are not evenly spaced or if the precipitation is irregularly distributed over the drainage area. The Thiessen method provides a means of weighting the precipitation at gages in proportion to a representative area. Each gage is assumed to represent all points closer to it than to any other gage. These areas are determined by connecting adjacent gages by lines and then constructing perpendicular bisectors to these lines. The area contained in the resulting polygons are

Figure 4.2 Rainfall For Blackstone River Wet Weather Studies

Storm 1

Figure 4.3 Rainfall Watersheds Distribution - Storm 1

Figure 4.4 Rainfall Watersheds Distribution - Storm 2

Figure 4.5 Rainfall Watersheds Distribution - Storm 3

than determined and each gage reading is weighted by the area.

The Thiessen polygons developed for the three storms are given in Figures 4.6 to 4.8. The watershed weighted average is included in the storm summaries of Table 4.2. Each storm met the minimum rainfall criteria as described in Section 3. Storm 1 had the lowest watershed total rainfall of 0.56 inches. Storms 2 and 3 were similar with 0.88 and 0.81 inches, respectively, however the range and distribution of rainfall in the watershed was dramatically different.

Total rainfall was also determined as it relates to the direct drainage for each water quality station. First, subbasin areas were determined for each station and overlaid with the Thiessen polygons. Total rainfalls for these subbasins between stations were determined (Table 4.3). Second, the total rainfalls were determined for the cumulative drainage area from headwaters to the river mouth (Table 4.4).

Storm 1 had a relatively uniform distribution of rainfall ranging from 0.44 inches in the north to 0.74 inches at a location central to the watershed. The lowest rainfall total in a subwatershed was 0.46 inches in the watershed area between BWW01 and BWW02 and the largest was 0.72 for the area in the Branch River watershed above BWW14. In general, the cumulative rainfall totals increased as you proceeded down the watershed (0.49 to 0.56 inches).

The rainfall distribution for storm 2 was also uniformly distributed and ranged from a high in the north of 0.99 inches to the low in the south of 0.76 inches. The lowest rainfall total in a subwatershed was 0.78 inches in the watershed area between BWW01 and BWW02 and the largest was 0.96 in the headwaters above BWW01. In general, the

Figure 4.6 Thiessen Polygons - Storm 1

Figure 4.7 Thiessen Polygons - Storm 2

Figure 4.8 Thiessen Polygons - Storm 3

Table 4.2 Average Rainfall Characteristics

Characteristic	Storm 1	Storm 2	Storm 3
TR (inch)	0.558	0.881	0.809
D (hrs)	6	16	8.5
ADP (days)	11	8	8
PI (in/hr)	0.20 (R12U)	0.23 (R1N)	0.52 (R1N)
AI (in/hr)	0.09	0.06	0.1
TR = Total Rainfall Based on Thiessen Method; D = Rainfall Duration; ADP = Antecedent Dry Period; PI = Peak Intensity (R1N = Station ID); AI = Avg. Intensity;			

Table 4.3 Summary Table of Rainfall For Individual Subwatersheds

Station	Area Sq. Mile	Rainfall (inch)		
		Storm 1	Storm 2	Storm 3
BWW00	60.5	0.494	0.955	1.253
BWW01	15.5	0.440	0.857	1.300
BWW02	6.2	0.461	0.784	1.129
BWW04	16.7	0.534	0.792	0.864
BWW05	34.2	0.473	0.857	0.944
BWW06	16.5	0.540	0.848	0.713
BWW07	6.0	0.540	0.940	0.690
BWW08	6.1	0.533	0.907	0.827
BWW09	68.5	0.560	0.928	0.881
BWW10	37.4	0.535	0.899	0.827
BWW11	2.3	0.530	0.890	0.900
BWW14	93.1	0.723	0.850	0.513
BWW13	13.4	0.617	0.861	0.665
BWW15	23.0	0.525	0.883	0.820
BWW16	11.6	0.510	0.860	0.610
BWW17	20.0	0.510	0.860	0.603
BWW18	12.2	0.510	0.860	0.610
BWW20	13.6	0.495	0.860	0.610
BWW21	23.3	0.502	0.844	0.594

Table 4.4 Summary Table of Rainfall For Cumulative Subwatersheds

Station	Area Sq. Mile	Rainfall (inch)		
		Storm 1	Storm 2	Storm 3
BWW00	60.5	0.494	0.955	1.253
BWW01	75.9	0.483	0.935	1.263
BWW02	82.1	0.481	0.923	1.253
BWW04	98.8	0.490	0.901	1.187
BWW06	149.5	0.492	0.885	1.079
BWW07	155.5	0.493	0.887	1.064
BWW08	161.6	0.495	0.888	1.055
BWW11	269.8	0.517	0.900	0.978
BWW13	376.3	0.572	0.886	0.852
BWW17	430.9	0.565	0.884	0.832
BWW18	443.1	0.563	0.883	0.826
BWW20	456.7	0.561	0.883	0.819
BWW21	480.0	0.558	0.881	0.809

cumulative rainfall totals decreased as you proceeded down the watershed (0.96 to 0.88 inches).

In contrast, Storm 3 had within it several intense thunderstorms which affected the drainage area along the western boundary and the headwaters to the north in Worcester (Figure 4.5). As a result, rainfall totals ranged from 0.27 inches along the southern border in Providence to 1.3 inches in the headwaters. The lowest rainfall total in a subwatershed was 0.59 inches in the watershed area between BWW20 and BWW21 and the largest was 1.30 in the watershed area between BWW00 and BWW01. There was a significant decrease in the cumulative rainfall totals as you proceeded down the watershed (1.25 to 0.81 inches).

These rainfall characteristics, especially the quantity and time distribution of the precipitation, will be one of the factors in governing the rate and distribution of runoff.

4.1.2 System Flows

There are three permanent USGS gaging stations in the watershed. These are located on the Quinsigamond River at North Grafton, MA (upstream of BWW05), Branch River at Forestdale, RI (upstream of BWW14) and Blackstone River at Woonsocket, RI (BWW17).

USGS also established six temporary gaging stations for this study. These included four on the Blackstone River (BWW01, BWW04, BWW11 and BWW20) and two on tributaries (Mumford BWW09 and Peters BWW16). All flows observed during the water quality surveys fell within the range of flows used for the stage discharge

relationships.

For the remaining stations, reference points were established at each location for measurement of river stage. These reference points were monitored under a wide range of flow conditions. River flow profiles were developed for each measurement using the model, QUAL2E. The detailed procedure is described elsewhere in Wright et al. (1996). The flow estimates and river stages were used to develop stage-discharge relationships at these stations. All flows observed during the water quality surveys fell within this flow range.

During the wet weather surveys river stage was recorded at each station for each water quality sample. Flows were then determined from the USGS or URI stage-discharge relationships for each station. The flows are summarized in the Tables 4.5 to 4.7.

Flows from the two WWTFs and the Worcester CSO facility were obtained from facility personnel. These are summarized in Table 4.8.

In general, there are several rainfall and watershed characteristics which influence the shape of the hydrograph. These include but are not limited to: (a) rainfall distribution or pattern; (b) hourly intensity; (c) watershed time to concentration (including all variables impacting this calculation, i.e. watershed slope and percent impervious); and (d) upstream regulation.

The classic shape of a hydrograph includes a rising limb, peak flow and falling limb. Often times the hydrograph is directly a reflection of a dominant watershed characteristic. For instance, different types of flow regulation, such as river reservoirs,

Table 4.5 Blackstone River Flow Summary - Storm 1

Station Run	FLOW (cfs)									
	BWW00	BWW01	BWW02	BWW04	BWW05	BWW06	BWW07	BWW08	BWW09	BWW10
P	15.3	16.5	73.3	79.0	4.50	79.7	107	109	11.5	7.64
0	38.3	41.2	107	93.0	3.80	67.4	95.0	124	12.0	7.94
3	172	185	268	182	6.20	111	99.0	129	14.2	9.42
6	59.5	64.0	156	245	6.20	111	101	115	14.8	9.07
9	53.7	57.8	142	163	7.90	141	103	111	13.6	9.07
12	43.1	46.4	118	144	9.30	166	104	108	12.5	9.24
16	33.8	36.3	88.9	116	9.30	166	111	125	12.0	9.24
24	21.9	23.5	49.6	80.0	6.70	120	123	130	11.5	9.24
32	15.3	16.5	49.6	53.0	5.60	100	120	136	11.0	8.74
40	21.9	23.5	80.8	66.0	5.10	90.0	123	136	9.29	8.90

Station Run	FLOW (cfs)								
	BWW11	BWW13	BWW14	BWW15	BWW16	BWW17	BWW18	BWW20	BWW21
P	133	169	32.8	6.30	2.37	162	181	210	239
0	142	188	42.0	5.80	3.61	163	205	220	250
3	173	232	54.7	12.4	13.2	292	250	253	288
6	160	214	50.1	12.4	11.0	250	210	241	275
9	155	205	46.1	12.4	7.23	205	226	259	295
12	162	209	42.8	10.2	10.5	214	226	265	302
16	155	200	41.5	8.72	6.25	215	186	215	245
24	148	192	40.6	16.7	4.00	209	226	247	281
32	166	210	39.8	16.7	4.00	209	226	271	309
40	177	218	36.4	15.0	4.00	289	315	253	288

Table 4.6 Blackstone River Flow Summary - Storm 2

Station Run	FLOW (cfs)									
	BWW00	BWW01	BWW02	BWW04	BWW05	BWW06	BWW07	BWW08	BWW09	BWW10
P	72.0	77.4	107	108	2.41	111	100	206	33.6	12.8
0	72.0	77.4	107	108	2.55	153	100	160	33.6	13.0
3	62.0	70.5	130	135	3.01	175	120	106	33.6	13.2
6	172	185	245	220	4.09	194	149	139	44.4	14.4
9	228	245	453	320	7.60	240	225	171	60.8	17.9
12	163	175	264	380	10.7	286	302	211	76.7	19.4
16	193	208	268	320	13.7	334	367	269	86.1	21.0
20	116	125	222	273	15.3	286	339	393	104	20.0
24	118	122	177	231	15.8	245	250	437	96.5	20.7
28	128	138	150	202	15.8	217	235	287	104	22.0
32	126	135	142	172	15.8	179	221	283	104	22.7
36	126	135	142	142	15.3	141	215	287	104	23.4
40	181	130	156	142	15.3	141	205	283	104	25.2
44	121	130	156	165	14.8	179	200	287	100	26.8
48	113	122	177	191	14.8	245	208	269	92.9	27.2
72	57.0	61.5	103	108	15.8	126	183	279	73.8	28.8

Station Run	FLOW (cfs)								
	BWW11	BWW13	BWW14	BWW15	BWW16	BWW17	BWW18	BWW20	BWW21
P	252	321	67.6	9.82	6.20	259	295	327	294
0	207	274	66.2	9.44	5.91	286	272	302	311
3	177	221	68.4	9.82	5.62	282	265	294	302
6	208	273	74.2	11.5	8.27	288	272	302	208
9	258	352	101	19.7	29.9	310	451	500	410
12	331	408	99.4	21.6	27.5	328	395	438	458
16	410	482	105	20.1	27.5	365	500	554	458
20	482	635	116	16.1	19.6	445	451	500	446
24	568	676	121	18.0	21.3	529	526	583	564
28	576	541	127	21.6	17.9	675	597	662	684
32	562	540	129	24.0	17.9	693	767	851	890
36	530	545	129	24.0	16.4	663	712	790	820
40	506	545	130	23.2	16.4	640	712	790	820
44	479	546	130	30.7	13.7	660	730	810	799
48	482	519	128	20.8	11.5	600	628	697	956
72	477	497	113	18.0	10.9	569	568	631	702

Table 4.7 Blackstone River Flow Summary - Storm 3

Station Run	FLOW (cfs)									
	BWW00	BWW01	BWW02	BWW04	BWW05	BWW06	BWW07	BWW08	BWW09	BWW10
P	38.0	41.2	60.4	85.8	8.26	47.9	114	141	16.6	9.07
0	38.0	41.2	73.3	85.8	8.62	28.3	114	219	23.1	9.24
9	530	570	829	74.6	20.2	179	201	117	38.8	11.9
12	407	438	637	541	20.8	406	421	174	41.2	12.8
16	140	150	165	295	25.8	406	570	364	37.1	12.6
20	128	138	153	178	26.9	166	300	414	17.8	12.1
24	122	131	147	198	29.9	194	278	352	29.5	12.6
28	109	117	130	203	28.8	179	287	332	29.5	11.7
32	48.4	52.0	130	166	26.5	179	265	294	25.8	11.7
36	160	108	107	155	24.7	210	244	301	25.8	12.1
44	76.0	81.7	103	125	22.7	174	238	283	27.3	13.0
52	76.0	81.7	105	135	21.9	59.9	144	NA	25.1	NA
72	NA	NA	NA	NA	NA	NA	NA	NA	26.6	NA

Station Run	FLOW (cfs)								
	BWW11	BWW13	BWW14	BWW15	BWW16	BWW17	BWW18	BWW20	BWW21
P	232	278	40.6	1.87	1.61	165	140	255	155
0	179	227	43.2	1.80	1.52	172	180	300	200
9	402	473	62.1	7.60	6.51	204	118	231	131
12	173	236	58.2	5.10	4.39	246	180	300	200
16	218	278	54.4	4.20	3.58	207	136	250	150
20	371	428	48.4	NA	3.58	223	202	323	223
24	524	580	45.0	4.20	3.58	420	303	437	385
28	490	545	44.5	3.80	3.23	797	582	746	337
32	376	429	45.0	3.60	3.06	551	329	464	646
36	318	370	45.0	3.80	3.23	416	320	455	365
44	297	349	45.0	3.60	3.06	416	238	363	355
52	NA	NA	44.5	5.90	5.09	406	295	427	363
72	258	309	NA	NA	NA	280	NA	NA	327

Note : NA = not available

Table 4.8 Average Flow

Station	Average Flow (cfs)				
Survey	BWW22	BWW23	BWW24	BWW25	BWW26
Storm 1	NA	50.1	9.48	34.9	31.0
Storm 2	NA	51.9	10.0	35.6	38.6
Storm 3	246	49.6	9.91	32.8	34.2
BWW22 (WOOR CSO) flow average of 2.93 hrs. during the storm; BWW23 (UBWPAD BWW24 (WOON); BWW25 (BP NBC); BWW26 (BP NBC By-Pass)					

Note : NA = not available

leave an obvious imprint on the downstream flow profiles usually dampening the runoff hydrograph and extending the time of its impact. An unusual hydrograph response speed (fast or slow) would be a direct indication of the shape of the watershed and/or the percent of area that is impervious.

A summary of the hydrograph characteristics are given in Table 4.9 to 4.11. The base flow is the prestorm flows as indicated at the time of Run P sampling. The average flows are for the sampling period beginning with Run 0. The peak flows indicate maximum hydrograph flow. Several general observations can be made from the 3-dimensional flow plots (Figures 4.9 - 4.11) and individual hydrograph comparisons (Figures 4.12 - 4.14) made below:

- Storm 1 (Figure 4.9 and 4.12) - Storm 1 was a short (6 hrs), relatively light, well distributed rainfall (0.56 inches). The runoff from the headwaters in Worcester resulted in a classic hydrograph at BWW01 with flows increasing from baseline of about 15 cfs to a maximum of 185 cfs at run time 3 hours (Point A). The hydrograph at BWW06 was impacted by local direct drainage during run times 3 and 6 hrs. By run time 9 hrs the hydrograph from the headwaters had arrived at BWW06 although the peak flow had decreased and the hydrograph had been attenuated due to channel storage over the 7.5 miles. In Fisherville Pond between BWW06 and BWW07, the hydrograph from Worcester was completely attenuated, adding to the base flow of the river. The storm track placed the headwater flows between BWW07 and BWW08 at the end of the sampling period (Point B). The additional flows from the three major tributaries central to the

Table 4.9 Hydrograph Characteristics - Storm 1

Station	Peak Flow (cfs)	Time to peak (hrs)	Base Flow (cfs)	Wet Volume (M cft)	Total Volum (M cft)	N (hrs)
BWW00	172	3.50	15.3	3.63	5.77	36.2
BWW01	185	3.50	16.5	3.63	5.82	36.0
BWW02	268	4.50	73.3	4.07	15.5	37.3
BWW04	245	6.25	79.0	5.31	16.9	38.0
BWW05	9.30	14.3	4.50	0.43	1.03	34.2
BWW06	166	12.3	79.7	9.39	20.7	39.6
BWW07	123	24.3	107	5.36	27.0	39.8
BWW08	136	33.5	109	4.20	34.7	39.9
BWW09	14.8	6.25	11.5	0.10	1.63	36.6
BWW10	9.42	3.25	7.64	0.07	1.34	34.5
BWW11	173	2.00	133	1.37	24.4	42.0
BWW13	232	3.25	169	2.91	31.1	43.4
BWW14	54.7	3.25	32.8	1.46	6.45	37.8
BWW15	12.4	3.25	6.30	1.24	2.54	32.8
BWW16	13.2	3.25	2.37	0.44	0.80	30.7
BWW17	292	2.25	162	5.60	35.4	44.0
BWW18	265	1.25	181	3.43	36.1	44.1
BWW19	265	14.5	210	5.32	48.3	44.3
BWW20	302	14.5	239	6.41	56.1	44.5

Note: M cft = Million cu. ft.

Table 4.10 Hydrograph Characteristics - Storm 2

Station	Peak Flow (cfs)	Time to peak (hrs)	Base Flow (cfs)	Wet Volume (M cft)	Total Volume (M cft)	N (hrs)
BWW00	193	9.50	72.0	8.09	22.6	36.2
BWW01	245	9.00	77.4	8.66	23.9	36.0
BWW02	453	10.0	107	11.7	34.4	37.3
BWW04	380	13.5	108	15.0	39.4	38.0
BWW05	15.8	5.20	2.41	1.39	2.75	34.2
BWW06	334	18.0	111	17.4	44.5	39.6
BWW07	367	18.0	100	19.6	46.4	39.8
BWW08	437	24.5	206	26.1	62.1	39.9
BWW09	100	20.0	11.0	7.45	17.4	36.6
BWW10	21.0	17.0	12.8	NA	NA	34.5
BWW11	576	24.0	252	35.5	88.7	42.0
BWW13	676	22.5	321	43.1	116	43.4
BWW14	101	11.0	67.6	11.2	31.3	37.8
BWW15	21.6	13.0	9.82	2.75	5.57	32.8
BWW16	29.9	9.00	6.20	1.31	2.68	30.7
BWW17	693	31.5	259	49.7	145	44.0
BWW18	767	31.5	295	68.3	155	44.1
BWW20	851	32.5	327	75.3	172	44.3
BWW21	890	33.0	294	85.1	179	44.5

Note : NA = not available ; M cft = Million cu. ft.

Table 4.11 Hydrograph Characteristics - Storm 3

Station	Peak Flow (cfs)	Time to peak (hrs)	Base Flow (cfs)	Wet Volume (M cft)	Total Volum (M cft)	N (hrs)
BWW00	530	8.50	38.0	21.5	30.2	36.2
BWW01	570	8.00	41.2	22.7	32.5	36.0
BWW02	829	8.50	60.4	29.6	41.9	37.3
BWW04	746	9.00	85.8	30.4	53.6	38.0
BWW05	29.9	22.5	8.26	2.24	4.58	34.2
BWW06	406	15.0	47.9	27.0	47.5	39.6
BWW07	570	20.0	114	25.2	55.6	39.8
BWW08	414	24.0	141	23.7	65.2	39.9
BWW09	38.8	15.0	16.6	1.63	5.39	36.6
BWW10	13.0	15.5	9.07	0.27	1.91	34.5
BWW11	494	27.0	232	30.2	73.6	42.0
BWW13	580	26.0	225	31.2	90.7	43.4
BWW14	62.1	11.0	40.6	1.18	8.40	37.8
BWW15	7.60	10.0	0.87	0.26	0.63	32.8
BWW16	6.51	9.00	1.61	0.25	0.53	30.7
BWW17	797	28.5	165	39.0	91.6	44.0
BWW18	582	32.0	140	27.7	73.1	44.1
BWW20	750	31.0	250	28.3	107	44.3
BWW21	646	36.0	55.0	34.4	113	44.5

Note: M cft = Million cu. ft.

Figure 4.9 Spatial and Temporal Flow Profile Presentation - Storm 1 (Storm Track = Peak Signal Passage from Worcester)

Figure 4.10 Spatial and Temporal Flow Profile Presentation - Storm 2 (Storm Track = Peak Signal Passage from Worcester)

Figure 4.11 Spatial and Temporal Flow Profile Presentation - Storm 3 (Storm Track = Peak Signal Passage from Worcester)

Figure 4.12 Hydrograph Comparison - Storm 1

Figure 4.13 Hydrograph Comparison - Storm 2

Figure 4.14 Hydrograph Comparison - Storm 3

watershed (Mill, Peters and Branch) are observed at Point C. The hydrograph signatures below this station typically reflected local drainage area runoff. The most prominent of these is the runoff from the Woonsocket area identified as Point D. In most cases flows returned to prestorm conditions within the 40 hour sampling period.

- Storm 2 (Figure 4.10 and 4.13) - Storm 2 was a long (20 hrs), moderate, well distributed rainfall (0.88 inches). The peak flows and volumes steadily increase along the watershed. The flows from Worcester were highest between the 6-12 hour runs (Point A). The track of the storm can be seen arriving at BWW08 between 20-24 hours. The arrival of the headwaters flows at BWW21 were between 36-48 hours (Point B). Unlike Storm 1, baseflows remained high even in the post storm period. This was attributed to the storm's characteristics (long duration, moderate rainfall and, therefore, high infiltration). The influence of the central tributaries is again evident at Point C. The extended high flows beyond the storm track, are due to the longer, more gradual release of flows from the tributary watersheds. Local drainage runoff is again seen in the Woonsocket area as well as the downstream stations bracketing Central Falls and Pawtucket (Point D).
- Storm 3 (Figure 4.11 and 4.14) - Storm 3 was a convective storm with most of the rainfall occurring in a 5 hour period. It was not well distributed with the heaviest of the rainfall occurring in Worcester. This resulted in a runoff signal from the headwaters in Worcester (Point A) that dominated the runoff profiles throughout the entire length of the Blackstone. The Worcester signal appeared at BWW08

between hours 16-20. The peak flows arrived at BWW21 between hours 28 and 36 (Point B). The rainfall from the local drainage areas in the lower sections of the watershed were evident, especially between BWW11 and BWW17 (Point C), but had a relatively minor impact on the hydrographs.

Hydrographs have been compared at three key locations: headwaters BWW01; MA/RI state line BWW13 and mouth of the river BWW21 in Figures 4.15 to 4.17, respectively.

Several procedures are available for separation of the hydrographs into baseflow and direct runoff. These are well documented in hydrology texts (McCuen 1989; Viessman, Lewis and Knapp 1990; Wanielista 1990). The procedures include straight-line baseflow separation, constant slope baseflow separation, concave baseflow separation and the master depletion curve method. Caution must be used when interpreting direct runoff volumes in downstream reaches for as hydrographs are routed downstream, runoff flows become attenuated and some of the direct runoff volume will begin to appear as river baseflow.

The concave baseflow separation method was used in this study. An example of this method is given in Figure 4.18. The initial recession curve is projected downward from A to C, which lies directly under the peak flow. The curve is then extended from C to a point D on the falling limb of the hydrograph N days after the peak. The value of N is determined from an empirical relationship provided in the references listed above. It takes the general form of $N = 1.0 A^b$ where A is in square miles and b is a constant that may be

Figure 4.15 Hydrograph Comparison - Headwaters

Figure 4.16 Hydrograph Comparison - State Line

Figure 4.17 Hydrograph Comparison - Mouth of The River

Figure 4.18 Example of Concave Base Flow Separation

determined specific to the watershed. The default value for b is typically taken as 0.2, however, based on the response of the hydrographs in storm 1, b was set at 0.1. The results are summarized in Table 4.9 to 4.11 including the direct runoff volume (in millions of cubic feet) and the average baseflow during the period of direct runoff (in cubic feet per second).

4.2 Hydraulic Structures or Controls

Historically, the Blackstone River has been a river in constant demand for its ability to supply energy, water supply or waste transport. The result was the construction of major hydraulic structures to control the river flow on the order of one per mile. Today, many of these structures have been removed. The ones that remain today (Table 4.12) have an impact on the river's water quality.

4.2.1 Dams and Impoundments

Nearly 45 dams and impoundments once existed on the Blackstone River, today only 19 remain. Some of them are still utilized for hydropower generation, but the majority no longer serve their original purpose. Many of these dams are in poor condition.

Three of the major impoundments along the river are Fisherville (between stations BWW04-06), Rice City (between stations BWW07-08) and Rochdale ponds.

4.2.1.1 Fisherville Pond

Fisherville is located downstream of the confluence of the Blackstone and

Table 4.12 Dams and Impoundments on Blackstone River

No.	Name	River Mile	Code No.a	Storagea (acre-feet)	Height	Reference
1	McCracken Rd.	43.9	NA	NA	4	2
2	Millbury Electric Substation	41	MA00578	77	4	3
3	Singing Dam	39.8	MA01180	60	14	2
4	Wilkinsonville	39.2	NA	NA	4	3
5	Saundersville	38.7	NA	NA	4	3
6	Fisherville	36.5	MA00577	250	4	2
7	Farnumsville	35.6	MA00576	85	4	3
8	Riverdale	31.9	MA00942	88.5	10	2
9	Rice City Pond	27.8	MA00935	1762	10	2
10	Tupperware	17.8	MA00096	305	15	2
11	Blackstone	16.5	NA	NA	4	3
12	Thundermist	14.3	RI03902	300	18	2
13	Manville	9.9	RI00809	58	17	2
14	Albion	8.2	RI00808	495	6	2
15	Ashton	6.8	RI00807	NA	7	3
16	Lonsdale	4.1	RI01705	NA	4	1
17	Central Falls	2.0	RI00401	80	13	1
18	Pawtucket	0.8	RI00402	150	14	1
19	Slaters Mill	0.0	RI04270	NA	18	1

1 = Army Corps of Engineers (COE 1973); 2 = Personal Communication (MADEP 1992);
 3 = Field Survey; a = COE (1994); NA = Not Available

Quinsigamond Rivers. The pond has maximum storage of 1360 acre-feet and drainage area of 134 square miles and the dam was constructed in 1882. It was constructed mainly to supply water to the now-abandoned Fisherville Mill Complex. The earthen dam is 10 feet high and 650 feet long, with a 200 feet long stone masonry spillway. Blackstone Canal is connected to the pond by a diversion structure (no longer in operation)

The 185 acre pond was drained in 1982 and has not been reflooded. MADEP raised the question concerning the safety of the dam. Partial reflooding of the pond happens caused by the obstruction at the outlet due to floating debris. The sediments behind the dam are contaminated with metals and organics.

4.2.1.2 Rice City Pond

The original purpose of the Rice City Pond (RCP) dam was to impound water to supply the Blackstone Canal during low flow periods. The reservoir area is about 800 feet wide and 4000 feet long. The drainage area of the dam is 204 square miles and maximum pool storage is 1762 acre-feet.

The main spillway is about 6 feet high and 50 feet long and the second spillway is about 75 feet long and 5 feet high. The elevation of the RCP has dropped in recent years causing the historic sediments to be exposed.

RCP was created in 1865 by owners of the Stanley Woolen Mill. In 1917 RCP was dammed to its highest elevation and remained unchanged till 1955. The RCP was a major settling pond for raw sewage dischargers, textile mill, metal plating, wire manufacturing, orchard pesticides, soil erosion from poor agricultural practices, auto

graveyards and many other undocumented industrial and commercial wastes (Wright et. al., 1996).

Hurricane Diane of 1955 damaged the RCP severely. Flooding left about 200 feet wide breach. The dam was reconstructed afterwards with a lowering of dam height about 5 feet. The flood carried most of the contaminated sediments to downstream. With the lowering of the impoundment, the river has craved channels through the soft sediments. The result is a movement of this sediment into the water column and river even under average flow conditions. The impoundment has the potential for a significant non point source of any constituent either recently or historically deposited in the impoundment.

4.2.1.3 Hydropower Stations

The Farnumsville hydropower facility was constructed prior to Federal Energy Regulatory Commission (FERC) licensing. So it has no FERC oversight or any other regulatory control. It is located just upstream of the Riverdale impoundment and has influence on the daily fluctuation of the flow of the river.

The Riverdale facility is located in Northbridge, MA. FERC issued a 30 year licence to a wire manufacturer for power generation in 1987. The reservoir impounded is approximately 88.5 acre feet with 1400 feet of backwater. The steel and concrete dam is about 14 feet high and 142 feet long. No minimum flow appear to be in the permit.

The gross storage of the Thundermist Dam in Woonsocket, RI is 300 acre-feet (per FERC). The old dam was replaced with 40 feet high and 266 feet long concrete overflow Dam in 1960. The maximum flow diverted is 1000 cfs, according to EPA.

The Elizabeth Mill Dam also known as Pawtucket (RI) Dam is a granite masonry dam of 10 feet high, 156 feet long, with one foot flashboards on it. The gross storage of the dam is about 150 acre-feet and has a capacity of 670 kilowatts. The maximum diversion by the hydropower plant is 1060 cfs (per licence application).

4.2.2 Blackstone River Canal

The construction of the Blackstone Canal was finished in 1828. The Canal essentially channelized the Mill Brook from the basin at Central Street to the Blackstone River south of the Cambridge and Millbury Street intersection.

When the Canal was in operation the number of industries in Worcester increased as the transportation problems were diminished. The population increased by 37 percent from 1825 to 1830, and the value of manufactured goods expanded drastically.

The Canal had a significant influence on the cultural, social and industrial development of Worcester. The rapid growth of Worcester attracted many immigrants. Since Worcester was still a pedestrian city, the settlement of the immigrants was based upon the proximity to many companies, which were located on the Canal's vicinity.

Today the Canal is only watered for approximately 6 miles. A detailed description of the canal and its history is provided elsewhere (BRVNHC 1993).

CHAPTER 5

5.0 Wet Weather Water Quality Interpretation

The two flow charts presented in Figures 5.1 and 5.2 describe the method followed in interpreting the wet weather data. Chapter 5 includes a presentation of individual concentrations and event mean concentrations (EMCs). Chapter 6 deals with criteria and violations. Chapter 7 uses the concentration and flow data to develop the mass loadings and gains/losses. System rankings and hot spot identification are provided in Chapter 8. A method for separating resuspended and runoff loadings is described in Chapter 9. An estimate of annual loadings at the MA/RI state line and end of river is provided in Chapter 10. Summary and conclusions are drawn in Chapter 11.

Three wet weather events were monitored for this study: September 22-24, 1992 (Storm 1), November 2-5, 1992 (Storm 2) and October 12-14, 1993 (Storm 3). Specific characteristics of the storms were provided in Chapter 4. Grab samples were collected at specific time intervals throughout the Blackstone River watershed and analyzed for 14 constituents. Details of the sampling protocol were given in Chapter 3. A complete listing of all data is provided in Appendix A. Mass loadings for each constituent per station per storm were calculated using the stream flows of Chapter 4. Individual station concentration and mass loading curves were developed. About 1000 profiles were developed during the course of this analysis. A subset of them specific to lead for three storms are provided in Appendix C.

Figure 5.1

Flow Chart Describing Water Quality Evaluation of Wet Weather Concentration

Figure 5.2

Flow Chart Describing Determination of Runoff/Resuspension and Annual Loading Rate

5.1 Water Quality Concentration

5.1.1 Comparison Between Dry and Wet Weather Concentrations

5.1.1.1 Nutrients

Both the UBWPAD and Woonsocket wastewater treatment facilities are the major sources of nitrogen and phosphorous under dry weather conditions (Wright et al., 1996).

Advanced treatment (nitrification) is required for UBWPAD, as stated in their federal permit #MA0102369. The permit divides the year into three time frames: November 1 to May 15; May 16 to May 31; and June 1 to October 31. The maximum daily ammonia discharge allowed by the permit for the three time periods are, 12.5, 7.5 and 2.5 mg/l, respectively. The Woonsocket facility is a secondary facility and, therefore, typically discharges large quantities of ammonia and relatively low levels of nitrate. There are no permit levels for ammonia for Woonsocket.

Nitrate and Ammonia - The ammonia and nitrate profiles for Storm 2 are given in Figures 5.3 and 5.4, respectively. For ammonia points A and B represent the location of the UBWPAD discharge. Since nitrification was not occurring in the November storm, the high levels of ammonia occurred before, during and after the storm. Likewise, the nitrate profiles (points A-B) indicate nitrification was occurring in the reaches below UBWPAD. Both profiles clearly indicate the storm track (Peak Concentration/Flow Passage) from the headwaters in Worcester, though the results were quite different. The higher flows produced higher ammonia concentrations and extended these concentrations much further downstream to BW08 in Rice City Pond. Nitrate concentrations were smaller in this same path suggesting that nitrification, which would normally have been

Figure 5.3 3-D Flat Ammonia Concentration Presentation - Storm 2 (Storm Track = Peak Signal Passage from Worcester)

Figure 5.4 3-D Flat Nitrate Concentration Presentation - Storm 2

occurring in these reaches, was delayed due to the high flows and faster times of travel.

The ammonia and nitrate profiles for Storm 1 are given in Figures 5.5 and 5.6, respectively. For ammonia points A and B again represent the UBWPAD discharge point. However, unlike Storm 2 ammonia concentrations do not remain high in the post storm hours. This is as expected given that nitrification should have been occurring in the facility. What is striking about this profile, is the response of the facility to the storm hydrograph that passed through the facility. The result was poorer treatment at the facility causing the discharge of a high, short term spike of ammonia.

There was no violation of the daily maximum ammonia discharge of 2.5 mg/l during the dry weather surveys. The maximum concentrations discharged by UBWPAD for the three dry weather surveys of July, August and October 1991 were 1.1, 0.60 and 0.80 mg/l and the average concentrations discharged were 0.44, 0.25 and 0.40 mg/l.

By comparison under wet weather conditions violations of ammonia concentrations did occur in two out of three storms (Storm 1 and Storm 2). During Storm 1, 3 out of 10 samples collected at UBWPAD violated the maximum limit of 2.5 mg/l ammonia. These violations coincided with peak storm flows. During Storm 2 when no nitrification was required 10 out of 16 samples collected at UBWPAD violated the maximum limit of 12.5 mg/l ammonia. Again these violations coincided with peak flows and the period immediately after.

The maximum ammonia concentrations discharged by UBWPAD during the three storm events were 4.3, 20.6 and 2.1 mg/l for Storm 1, 2 and 3, respectively, and the average concentrations discharged were 2.21, 13.2 and 0.76 mg/l.

Figure 5.5 3-D Flat Ammonia Concentration Presentation - Storm 1 (Storm Track = Peak Signal Passage from Worcester)

Figure 5.6 3-D Flat Nitrate Concentration Presentation - Storm 1 (Storm Track = Peak Signal Passage from Worcester)

The maximum concentrations of ammonia discharged by Woonsocket during the dry weather surveys were 28.6, 16.8 and 15.8 mg/l and the average concentrations were 28.1, 13.1 and 11.1 mg/l. For wet weather the maximum concentrations were generally higher at 34.3 and 33.6 mg/l and the average concentrations were 24.3 and 26.0 mg/l for Storm 1 and 2, respectively. For Storm 3, the maximum and average ammonia concentrations were very low at 0.53 and 0.38 mg/l, respectively. The cause of this is unknown.

Two other significant increases of ammonia appear in these figures (Figures 5.3 and 5.5). Point C marks the reaches between BWV07-11 which encompasses the reaches above, within and below Rice City Pond. The earlier peak between hours 3-6 is related to local drainage area runoff or reach resuspension. The later peak at about hour 12 is more reflective of the storm track from the Worcester headwaters. Point D marks the Woonsocket WWTF discharge. The signal is consistent in space and time and supports the finding in dry weather survey (Wright et al. 1996) that Woonsocket is a major source of ammonia.

The nitrate profile for Storm 1 (Figure 5.6) shows a high ridge line between points A-B, which is a result of the UBVPAD discharge. The increase of nitrate (instream nitrification) between BWV04-08 at hours 6-16 (Point C) coincides with the ammonia loss during the height of the storm.

At point D in Figure 5.6 concentrations of nitrate decline. This is due to both dilution from the 3 tributaries coming in between BWV08 and BWV13, as well as the nitrate uptake associated with plant productivity.

The ridge of higher concentrations at E occurs between BWW18 and BWW20 and is a direct result of instream nitrification of Woonsocket's ammonia load. In both Figures 5.5 and 5.6 the storm track from the headwaters in Worcester and the UBWPAD are evident. Storm 3 profiles are similar to Storm 1.

Phosphate - Similar to dry weather, under wet weather conditions dissolved orthophosphate profiles are dominated by the two point sources, UBWPAD and Woonsocket. An example of the phosphorous profile is presented in Figure 5.7 for Storm 1. The most striking feature of this figure is the ridge line of high concentrations at UBWPAD between stations BWW01 and BWW02 (Points A and B). The high discharge of phosphorous from UBWPAD is continuous and independent of the storm events. In general, the phosphorous profile shows a reduction in concentration below Rice City Pond (BWW08), an increase due to the Woonsocket facility's discharge and then a decline to station BWW21. The decrease in concentration below Rice City Pond, as well as in the reaches below the Woonsocket facility, are related to dilution from incoming tributaries and uptake due to plant productivity.

There is no permit requirement for phosphorous for either UBWPAD or Woonsocket. The maximum concentrations discharged by UBWPAD for the three dry weather surveys of July, August and October 1991 were 3.0, 3.0 and 3.4 mg/l, respectively and the average concentrations discharged were 2.30, 2.36 and 3.03 mg/l. In comparison the maximum concentration discharged during the three storm events were 2.09, 1.61 and 1.98 mg/l for Storms 1, 2 and 3, respectively, and the average concentrations discharged were 1.52, 1.16 and 1.35 mg/l. The lower concentrations

Figure 5.7 3-D Flat Phosphate Concentration Presentation - Storm 1

during the storm events are a result of dilution by higher facility flows.

The maximum concentrations discharged by Woonsocket for dry weather were 3.9, 4.9 and 4.2 mg/l and the average concentrations discharged were 3.3, 3.36 and 4.0 mg/l. The maximum concentrations discharged during the three storm events were slightly higher: 5.97, 7.16 and 6.86 mg/l, for Storms 1, 2 and 3, respectively, as were the average concentrations of 3.92, 4.43 and 5.21 mg/l.

5.1.1.2 Trace Metals

The UBWPAD was shown to be a major source of most metals to the Blackstone River under dry weather, steady-state conditions (Wright et al., 1996). The Woonsocket facility was also indicated as a significant source for several metals. A comparison between the two surveys (dry vs wet) for these two facilities has been made below. Data has been presented as survey average concentration and as a maximum concentration range. The average survey concentration was obtained by averaging all data from the three 1991 dry weather surveys to provide a single dry weather average concentration for each constituent. Similarly, all wet weather data from the three 1992/3 wet weather surveys were averaged to provide a single wet weather average concentration for each constituent. The maximum concentration range includes the maximum concentrations reported for each survey.

UBWPAD - For the UBWPAD several metals were influenced by the higher storm flows through the facility. The following general observations can be made based on the comparison of averages: under storm flows chromium concentrations doubled; copper

and nickel concentrations did not change significantly and cadmium and lead concentrations decreased (Table 5.1).

A comparison of maximum wet weather and dry weather concentrations lead to the following observations: for chromium the wet weather range was significantly higher; for lead, copper and nickel the wet weather maximum concentration ranges were slightly lower and for cadmium the wet weather range was significantly lower (Table 5.1).

Woonsocket - For the Woonsocket WWTF several metals were influenced by the higher storm flows through the facility. The following general observations can be made based on the comparison of averages: under storm flows copper and lead concentrations increased significantly; chromium concentrations did not change significantly and cadmium and nickel concentrations decreased (Table 5.2).

A comparison of maximum wet weather and dry weather concentrations lead to the following observations: for cadmium, copper and lead the wet weather ranges were significantly higher; for chromium the dry and wet weather maximum concentration ranges were similar and for nickel the wet weather range was significantly lower (Table 5.2).

Based on these comparisons, and the fact that no record or data support that metal loadings have changed between 1991 and 1993, one possible cause of the relatively high metal concentrations observed at UBWPAD (chromium) and the Woonsocket WWTF (chromium, copper and lead) may have been from sources in the system triggered under wet weather conditions. On the other hand, the decrease in some concentrations at UBWPAD (cadmium, copper, lead and nickel) and the Woonsocket WWTF (cadmium) may be more a result of the dilution from runoff. The exception to this was the unusually

Table 5.1 Comparison of Metals Between Dry and Wet Weather @ UBWPAD

Facility	Metal (µg/l)	Average Dry Weather	Average Wet Weather	Maximum Dry Weather	Maximum Wet Weather
UBWPAD	Cd	3.9	1.6	3.2-6.8	0.9-2.9
	Cr	4.5	9.1	2.7-7.5	6.8-31.5
	Cu	40	36	41.4-61.1	21.1-74.1
	Pb	4.4	2.7	2.4-8.6	3.4-5.7
	Ni	39	29	25.8-163	26.1-46.7

Table 5.2 Comparison of Metals Between Dry and Wet Weather @ Woonsocket

Facility	Metal ($\mu\text{g/l}$)	Average Dry Weather	Average Wet Weather	Maximum Dry Weather	Maximum Wet Weather
Woonsocket	Cd	2.9	1.5	1.7-5.9	2.7-11.5
	Cr	4.4	5.3	3.3-14.7	6.7-8.0
	Cu	31	51	20.0-46.2	61.9-97.1
	Pb	7.2	16	6.0-21.0	21.6-31.4
	Ni	160	5.4	79-256	5.6-10.6

high post chlorination concentration of nickel at the Woonsocket facility in 1991.

River Profile - Under dry weather conditions the metal concentrations along the river were categorized into two general profiles (Wright et al., 1996). Under wet weather these same patterns appear similar but magnified. The first pattern generally describes cadmium, chromium, copper, nickel and zinc. It was consistent with the dry weather surveys in that the major increase occurred between BWW01-04. This reach includes UBWPAD and several other potential non point sources of metal pollution. The other consistent increase in metals occurred in the reaches above, in and immediately below Rice City Pond (BWV07-11) due most likely to sediment resuspension. Example figure for chromium for Storm 1 is provided in Figure 5.8.

The other pattern was specific to lead and showed a significant source of the metal in the headwaters above BWV00. Example figure for lead for Storm 1 is provided in Figure 5.9. The UBWPAD was not significant relative to the headwater source. A secondary source of lead was associated with resuspension in the river reaches surrounding Rice City Pond (BWV07-11). The source of lead in the headwaters is not known. Further investigation within the Worcester collection system is warranted.

The concentration profiles were developed for all trace metals per station per storms and a subset of them specific to lead is provided in Appendix B.

5.1.2 Wet Weather Event Mean Concentration (EMC)

Since wet weather concentrations are time-varying one way to represent the data is to develop event mean concentrations (EMCs). The EMC is used to represent a flow

Figure 5.8 3-D Flat Chromium Concentration Presentation - Storm 1 (Storm Track = Peak Signal Passage from Worcester)

Figure 5.9 3-D Flat Lead Concentration Presentation - Storm 1 (Storm Track = Peak Signal Passage from Worcester)

weighted concentration of any water quality parameter during a single storm event. EMCs for each station were calculated by summing the products of concentration and flow for each time interval and then dividing by the total flow. A watershed EMC for the Blackstone River was determined by averaging the EMCs for all stations. Tables 5.3, 5.4 and 5.5 represent the EMC values for Storms 1, 2 and 3, respectively, and Table 5.6 represents the EMCs for the entire Blackstone River watershed. Figures 5.10 to 5.15 show the spatial variation of EMCs for the 16 constituents for the three storms.

5.1.2.1 Nutrients

The EMC profiles in Figure 5.10 reflected the operation of UBWPAD with respect to nitrification. It was established earlier that nitrification was being provided at the facility during Storms 1 and 3. The instream data supported this with high nitrate EMCs below UBWPAD and comparatively low ammonia levels. The reverse was true for Storm 2 when nitrification was not being provided at the facility.

Instream nitrification was evident in all three storms, but particularly in Storm 2, where there was a decline in ammonia below BW02 with a resulting rise in nitrate. To a lesser degree instream nitrification was also seen in the reaches below the Woonsocket discharge.

The decrease of nitrate in the Storm 1 profile was most likely due to nitrate uptake by plants. Nitrate loss due to plant uptake was observed and documented in the two summer dry weather surveys in July and August (Wright et al., 1996). It did not occur in the third survey in October, since plant production was very low. Storm 1 occurred in

Table 5.3 Event Mean Concentration (EMC) For Storm 1

Station	Cd ug/l	Cr ug/l	Cu ug/l	Ni ug/l	Pb ug/l	Zn ug/l	TSS mg/l	VSS mg/l
BWW00	0.61	2.47	6.45	3.10	19.7	33.5	6.41	2.76
BWW01	0.35	4.08	9.36	3.89	14.2	46.4	13.1	5.10
BWW02	0.90	10.8	14.3	10.4	13.2	64.1	7.55	4.50
BWW04	1.26	8.99	38.3	21.4	10.1	55.4	16.0	6.88
BWW06	1.00	7.15	31.8	18.3	9.83	38.5	7.40	3.42
BWW07	0.81	5.11	24.5	16.1	8.28	30.3	7.28	2.93
BWW08	1.10	8.40	28.4	16.4	12.4	41.3	9.80	3.30
BWW11	0.71	4.89	17.1	11.3	7.12	26.8	5.47	2.61
BWW13	0.45	2.86	11.0	8.28	4.34	17.5	3.67	2.07
BWW17	0.39	2.98	10.4	7.61	6.36	22.8	5.04	2.39
BWW18	0.43	2.16	11.8	5.85	4.82	35.0	4.70	2.94
BWW20	0.33	1.69	10.5	4.80	3.87	25.8	2.74	1.86
BWW21	0.38	2.05	10.4	4.62	6.76	25.1	2.75	1.78

Station	EC md/100ml	FC md/100ml	NH3 mg/l	NO3 mg/l	PO4 mg/l	BOD mg/l	Cl mg/l	Na mg/l
BWW00	2690	6190	0.17	0.32	0.02	4.16	43.7	19.2
BWW01	3850	11400	0.22	0.43	0.02	5.42	84.3	34.8
BWW02	0.55	340	1.54	1.14	0.73	5.99	91.3	49.6
BWW04	88.5	735	1.04	2.14	0.80	5.25	86.6	48.1
BWW06	173	607	0.49	3.25	0.74	4.33	81.9	46.6
BWW07	182	784	0.81	3.00	0.65	2.48	82.0	46.6
BWW08	41.5	189	0.83	2.54	0.64	2.85	81.2	45.5
BWW11	105	228	0.31	1.77	0.37	2.24	69.7	38.5
BWW13	139	594	0.05	1.29	0.28	1.75	60.9	34.2
BWW17	958	2230	0.04	1.37	0.24	1.67	59.0	30.8
BWW18	49.1	394	2.42	1.33	0.41	1.73	83.8	49.0
BWW20	40.2	117	0.55	1.99	0.26	1.67	84.6	49.5
BWW21	319	2290	0.37	1.73	0.17	1.34	76.3	44.4

Table 5.4 Event Mean Concentration (EMC) For Storm 2

Station	Cd	Cr	Cu	Ni	Pb	Zn	TSS	VSS
	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l	mg/l	mg/l
BWW00	0.05	1.45	7.80	2.23	11.4	27.6	11.8	6.51
BWW01	0.09	3.27	10.6	4.60	11.9	45.3	13.6	6.32
BWW02	1.12	7.02	15.9	12.3	11.7	46.9	19.6	13.9
BWW04	1.85	9.07	23.0	13.9	15.9	56.3	17.8	11.8
BWW06	1.41	5.62	17.5	10.5	13.2	43.7	10.7	5.51
BWW07	1.20	3.93	14.1	9.72	7.36	41.6	6.05	3.09
BWW08	1.72	6.69	18.6	11.8	11.4	45.0	8.83	3.83
BWW11	1.23	6.91	17.2	7.68	10.6	41.1	11.4	4.24
BWW13	0.51	3.52	9.46	5.00	6.31	21.8	4.10	2.07
BWW17	0.54	2.49	8.68	5.39	5.21	19.3	4.11	1.76
BWW18	0.51	2.33	9.87	4.72	4.28	21.3	6.83	3.93
BWW20	0.48	1.85	8.73	6.05	4.79	24.6	7.04	4.05
BWW21	0.54	1.68	8.21	4.97	5.97	26.4	4.81	2.33

Station	EC	FC	NH3	NO3	PO4	BOD	Cl	Na
	md/100ml	md/100ml	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
BWW00	2780	4900	0.07	0.12	0.04	6.30	54.2	22.6
BWW01	3570	5800	0.17	0.24	0.03	7.19	77.4	31.2
BWW02	8160	22200	3.87	0.28	0.41	7.80	81.5	40.4
BWW04	4840	26100	3.21	0.43	0.47	9.13	78.5	27.9
BWW06	3500	17400	3.27	0.74	0.42	7.54	80.9	32.1
BWW07	1580	8350	2.75	0.94	0.43	5.37	78.7	37.2
BWW08	1250	7240	2.49	1.07	0.45	4.89	82.3	39.7
BWW11	350	3030	1.17	1.23	0.27	4.51	62.2	29.8
BWW13	328	764	0.79	1.50	0.18	2.62	56.9	25.5
BWW17	402	836	0.44	1.63	0.19	2.48	59.1	26.0
BWW18	215	895	1.20	1.45	0.28	3.31	65.3	31.7
BWW20	88.8	409	0.79	1.44	0.26	3.76	71.0	30.7
BWW21	516	2110	0.79	1.69	0.23	4	71.3	27.1

Table 5.5 Event Mean Concentration (EMC) For Storm 3

Station	Cd	Cr	Cu	Ni	Pb	Zn	TSS	VSS
	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l	mg/l	mg/l
BWW00	0.36	7.28	19.2	3.94	41.1	35.8	28.8	9.15
BWW01	0.40	6.12	19.1	5.35	33.5	91.6	28.5	8.33
BWW02	0.79	7.60	29.0	11.6	30.6	52.7	24.2	8.61
BWW04	0.50	4.41	14.9	8.32	10.4	22.6	44.5	15.5
BWW06	0.53	3.89	19.4	9.19	16.4	36.2	26.0	9.49
BWW07	0.46	4.06	19.3	10.6	11.7	32.6	10.3	5.61
BWW08	0.54	8.83	25.6	11.4	19.1	51.0	17.2	5.27
BWW11	0.57	5.93	20.0	9.74	16.8	41.7	14.5	7.35
BWW13	0.36	2.77	10.6	8.24	6.17	16.5	5.93	3.80
BWW17	0.25	2.34	10.4	7.84	8.17	17.2	7.79	3.71
BWW18	0.25	1.85	10.7	7.18	5.74	17.9	7.08	3.96
BWW20	0.21	1.74	11.9	6.61	6.41	16.7	10.5	3.61
BWW21	0.24	1.77	9.81	5.34	5.68	15.0	8.64	4.70

Station	EC	FC	NH3	NO3	PO4	BOD	Cl	Na
	md/100ml	md/100ml	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
BWW00	9120	22200	0.05	0.22	0.01	5.66	35.8	18.3
BWW01	5590	9850	0.06	0.34	0.01	6.60	41.6	26.6
BWW02	781	5910	0.35	1.35	0.28	7.19	57.6	36.8
BWW04	2040	5280	0.29	1.34	0.26	6.38	60.2	27.2
BWW06	1510	3170	0.18	1.61	0.35	4.21	63.4	38.2
BWW07	315	2350	0.18	1.72	0.31	4.36	68.5	40.2
BWW08	486	2250	0.17	1.64	0.30	4.13	68.1	39.8
BWW11	239	807	0.11	0.69	0.26	3.53	68.5	40.5
BWW13	120	201	0.06	1.81	0.30	2.02	66.6	40.8
BWW17	722	1490	0.03	1.87	0.06	2.12	68.4	40.9
BWW18	282	2460	0.21	2.44	0.39	1.98	77.2	48.4
BWW20	291	728	0.26	2.31	0.57	1.95	75.1	47.0
BWW21	1090	1480	0.11	2.27	0.40	1.79	74.0	46.5

EMC Plots for NO_3 and NH_3

Figure 5.10 EMC Plots for NO_3 and NH_3 for Storms 1, 2 and 3

EMC Plots for PO_4 , FC and EC

Figure 5.11 EMC Plots for PO_4 , FC and EC for Storms 1, 2 and 3

September and appears to be within the high productivity period, whereas Storm 2 and 3 were in November and October and were within the low plant productivity period.

The increase in ammonia EMCs between BWW17 and BWW18 were due to the Woonsocket WWTF discharge.

For phosphorous the headwater concentrations were generally very low. There were major increases in the EMCs between BWW01 and BWW02 and between BWW17 and BWW18 reflecting the two major treatment facilities (Figure 5.11). Elsewhere, the phosphorous concentration declined due to dilution and plant uptake. The phosphorous pattern was the same for all three storms.

In general, based on the EMC profiles, the nutrient concentrations were dominated by direct discharge from the two major point sources or instream nitrification resulting from their discharge.

5.1.2.2 Conventional

TSS and VSS EMC profiles are presented in Figure 5.12. In general, the headwater concentrations are significant, often with concentrations that are amongst the highest for the entire river. This was opposite to the findings of the dry weather surveys, evidence to the relative importance of urban runoff as a major source of solid loadings.

There is an interesting pattern between BWW01 and BWW02 which again supports the operation of nitrification in the UBWPAD. With nitrification providing a much higher retention time within the facility, solids removal is often better. During Storms 1 and 3 where nitrification was occurring, the TSS EMC profiles actually show a

EMC Plots for TSS, VSS and Pb

Figure 5.12 EMC Plots for TSS, VSS and Pb for Storms 1, 2 and 3

decline between BWW01 and BWW02. Storm 2 provides a different result reflecting the higher solids load from the UBWPAD when nitrification was not occurring.

Also of interest is the increase of solids for Storm 3 between BWW02 and BWW04. It is not clear what source or sources have caused this increase, but based strictly on the concentration profiles and the knowledge of this area discussed by Wright et al. (1996), resuspension of bottom sediments or a sloughing of materials off the bottom may be important. In Storm 2 this increase in concentration is not evident due most likely to the masking from higher concentrations from upstream reaches.

To a lesser degree increases in solids could also be seen between BWW07 to BWW11. This reflects the resuspension of bottom sediments from Rice City Pond described earlier.

Fecal Coliform (FC) and *E. Coli* (EC) concentrations in the headwaters (above BWW00) are some of the highest concentrations along the entire river (Figure 5.11). This was especially true in Storm 3. The sharp decreases in the instream FC and EC concentrations below the UBWPAD (between BWW01 and BWW02) for Storms 1 and 3 are most likely due to residual chlorine in the facilities effluent. This was not the case in Storm 2, where higher stream flows resulted in lower residual chlorine. In fact, FC and EC concentrations increased to their highest levels in the reaches immediately below UBWPAD. This impact could be felt as far downstream as BWW08.

Similar increases of FC and EC are evident in the Woonsocket area in the river reaches above, in and below the Woonsocket facility. Fecal Coliform are discussed in more detail in the section that follows.

BOD has a similar trend for all three storms. Generally it increases after UBWPAD discharge and decreases to the mouth of the river (Figure 5.15). BOD does not appear strongly influenced by the storm related sources but appears governed by the two major point sources.

The sharp increase in the instream chloride (Cl) and sodium (Na) concentrations below the UBWPAD (between BWW01 and BWW02) for Storms 1 and 3 are most likely due to residual chlorine and sodium in the facilities effluent (Figure 5.13). This was not the case in Storm 2 for Cl, where higher stream flows resulted in higher dilution and lower residual chlorine. The sharp decrease in concentrations below BWW08 for Storms 1 and 2 were due to dilution by the tributaries, Mumford, West and Branch Rivers. Storm 3 was different in nature as discussed in Chapter 4. It had a rainfall total of 1.3 inches at the headwaters and decreased to 0.27 inches at the southern border of Rhode Island. There was no sharp decrease of concentrations below BWW08 for both Cl and Na.

5.1.2.3 Trace Metals

Compared to the other metals, lead's major source appeared to be in the headwaters (above BWW00). In fact, the headwater concentrations were typically the highest concentration along the entire river (Figure 5.12).

Neither the UBWPAD or Woonsocket facilities appeared to have any impact on these profiles. A consistent increase of lead did appear between BWW07 and BWW08 in Rice City Pond and was probably due to sediment resuspension.

The other 5 metals (Cd, Cr, Cu, Ni and Zn) had similar profiles in that there

EMC Plots for Cl and Na

Figure 5.13 EMC Plots for Cl and Na for Storms 1, 2 and 3

appeared to be two distinct peaks (Figure 5.14 and 5.15). The first occurred in the reaches below UBWPAD and was associated with the wastewater facilities discharge and possibly other non point sources of metals. In addition, concentrations, on average, typically continued to increase through BWW04. This might reflect the resuspension or sloughing of material off the bottom that may be an end result of the process of luxury metal uptake under steady state conditions.

A secondary peak consistently occurred around BWW08, again the probable cause was sediment resuspension within Rice City Pond. Below BWW08 the profiles quickly decreased to BWW13. As the Blackstone River enters and passes through Rhode Island all the metal profiles were either flat or declining with only minor exceptions typically around the City of Woonsocket. Concentrations in Rhode Island were generally either equal to or slightly higher than the Worcester headwater concentrations. These data suggested that the metal EMC profiles in Rhode Island were governed by concentrations entering at the state line.

5.1.2.4 EMC Comparison With Other Rivers:

The data of this study have been summarized as average EMCs for the entire Blackstone River watershed in Table 5.6. For comparison, results from an earlier wet weather study on five tributaries to the Providence River, including the Blackstone River, are provided (Table 5.7). Although the rainfall characteristics were quite different between studies, the EMC's for the Blackstone are similar. Rankings are not provided with the EMC data, since concentrations are influenced by flow and rankings have more

EMC Plots for Cd, Cr and Cu

Figure 5.14 EMC Plots for Cd, Cr and Cu for Storms 1, 2 and 3

EMC Plots for Ni, Zn and BOD

Figure 5.15 EMC Plots for Ni, Zn and BOD for Storms 1, 2 and 3

Table 5.6 EMC's for Storm 1, Storm 2 and Storm 3 for the Blackstone River

Storm	Cd	Cr	Cu	Ni	Pb	Zn	BOD	EC	FC	NH3	NO3	PO4	TSS	VSS
	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l	mg/l	md/100	md/100	mg/l	mg/l	mg/l	mg/l	mg/l
Storm 1	0.61	4.28	16.1	9.48	7.60	32.3	2.58	372	1270	0.71	1.77	0.40	5.94	2.92
Storm 2	0.79	3.73	11.9	6.93	7.75	31.1	4.60	1430	5440	1.36	1.23	0.27	8.07	4.30
Storm 3	0.40	4.04	15.8	8.11	13.6	30.2	3.64	1380	3670	0.16	1.66	0.30	16.1	6.38

Table 5.7 EMC's for Blackstone, Moshassuck, Woonasquatucket, Pawtuxet and Ten Mile Rivers

Station	Code	Cd	Cr	Cu	Ni	Pb	NH4	NO3	PO4	TSS
		ug/l	ug/l	ug/l	ug/l	ug/l	mg/l	mg/l	mg/l	mg/l
Blackstone	a-1	0.60	4.00	14.6	8.20	9.60	0.70	1.60	0.30	10.0
Blackstone	a-2	0.40	1.80	9.50	5.00	6.10	0.40	1.90	0.30	5.40
Blackstone	b	0.94	6.82	12.5	10.7	8.25	0.25	5.42	0.67	10.1
Moshassuck	b	0.39	7.10	20.2	7.76	20.9	0.15	2.08	0.11	17.5
Woonasquatucket	b	0.31	3.39	8.98	6.13	8.06	0.10	3.26	0.22	10.5
Pawtuxet	b	1.06	4.43	11.9	12.7	7.53	1.04	4.03	0.52	21.0
Ten Mile	b	1.06	7.58	14.7	44.0	4.13	0.10	4.92	0.27	5.35

a-1: This study whole river; a-2: this study BWW21; b: NBP study Wright et. al. (1988)

meaning when presented as mass loads. This has been done in a later section.

5.1.2.5 EMC Comparison With NURP Studies

The EMCs at Worcester (BWW00) have been compared with National NURP, Michigan NPDES and Michigan NURP studies in Table 5.8. Worcester is an urban city, so comparison of its EMCs with the NURP studies is appropriate. All EMCs are found to be lower than the other NURP Studies. For example, BOD is found to be about two times lower than the National NURP data and about five times lower than the Michigan NPDES and NURP data and lead is about eight, two and four times lower than the National NURP and Michigan NPDES and NURP data. The values reported in Table 5.8 were obtained based on the values reported by Cave et al. (1994).

5.1.3 Hardness, Cl, Na, pH, Temperature and DO

Hardness concentrations (mg/l as CaCO_3) were determined specific to each sample taken for the three storms captured. Hardness-based equations (Table 6.2) were used to calculate the acute and chronic toxicity criteria of each trace metals in the next section. Concentration profiles of hardness along with chloride and sodium were developed per station per storm. The same profiles were developed for DO, temperature and pH. Example plots for selected stations are provided in Appendix B.

Generally the concentrations of hardness decreased at or near the peak flows and increased again with time. This was significant in the headwaters and upper part of the river for all three storms (Figure B.1). At and near the mouth of the river, the decrease in

Table 5.8 Comparison of EMCs of Blackstone River at Worcester (BWW00) with National NURP, Michigan NPDES and Michigan NURP

Constituents	Units	Worcester (BWW00)	National NURP	Michigan NPDES	Michigan NURP
BOD	mg/L	5.37	11.7	23.7	25
TSS	mg/L	15.7	149.7	103.3	139
Dissolved - P	mg/L	0.02	0.17	0.15	0.08
NO ₂ +NO ₃	mg/L	0.22	0.88	1.70	0.76
Lead, total	ug/L	24.1	177.0	56.8	96.4
Copper, total	ug/L	11.2	47.8	41.5	20.8
Zinc, total	ug/L	32.3	519.8	338.9	152.3

Note: National NURP, Michigan NPDES and Michigan NURP
EMC values are taken from Cave et al., 1994.

hardness concentrations at peak flows were not significant for two (Storms 1 and 2) out of three storms (Figures B.3 and B.6). Storm 3 had a significant decrease in concentrations near the mouth of the river (Figure B.9). The decrease in hardness due to dilution by high flows would lower the toxicity criteria of violations. Therefore, there may be more violations at and near the headwaters than at the mouth of the river. Also there might be more violations associated with wet weather rather than dry weather.

Chloride and sodium showed a similar trend to hardness, decreasing in concentration at or near the peak flows. We know that chloride is a conservative constituent, so the concentrations must decrease with increase in flows.

The pH did not vary significantly with time and stations. The value of pH was typically between 6.0 and 6.5 for all stations and storms. The profiles for pH were generally flat (Figure B.10).

Temperature varied according to the season and time. Storm 1 (September) had much higher temperatures than Storms 2 and 3 (November and October). The general pattern was higher temperature at the beginning of the storm and decreased with time with some noise.

The DO profiles generally showed a little decrease in DO concentrations at the peak high flows due to dilution and increased with time again with some noise in it. Reaeration, DO in incoming tributaries and algal photosynthesis are the sources of DO and the sinks include: CBOD, NBOD, SOD and algal respiration. Presence of nutrients and sunlight time controls the photosynthesis of algae thus affecting the DO system. The DO dynamics are complex and described in details elsewhere (Wright et al. 1996).

The impact of wet weather on DO is not significant. There was a small decrease in DO concentrations at or near the peak flows due to dilution. There were no violations of the DO criteria (5.0 mg/l) in the mainstem stations of the Blackstone River for all three storms observed for this study. Only tributary stations BWW05 had 1 violation (prestorm sample) out of 16 samples collected for Storm 2 and BWW15 had 2 violations out of 13 samples collected for Storm 3.

CHAPTER 6

6.0 Water Quality Criteria Violation

6.1 Fecal Coliform

The Blackstone River headwaters appear to be the major source of fecal coliform (FC) under wet weather conditions. Other notable increases in concentration occur at Fisherville Pond, Rice City Pond and some individual river reaches between stations BW11 to BW17. Figure 6.1 is an example of a 3-D FC profile. Residual chlorine from the UBWPAD appears to be an effective disinfectant in the reaches at and below its discharge (Point A to B) with one major exception. At peak flow between time 0 and 6 hours, fecal coliforms get by the UBWPAD without instream disinfection. This is probably due to the lower instream chlorine residual resulting from the higher flows in the river and in the facility.

FC concentrations increase between BW11 and BW17 (point C in Figure 6.1). The source appears to be independent of the storm occurring before, during and after rainfall. The high FC concentrations from the Branch River (BW14) and Peters River (BW16) may be responsible for this. The FC ranges for Branch River were: 280-6200, 60-400 and 230-5800 md/100ml for Storms 1, 2 and 3, respectively. The average FC concentrations were 2350, 249 and 1434 md/100ml for Storm 1, 2 and 3, respectively. The FC ranges for the Peters River were: 300-39000, 14000-79000 and 63-94000 md/100ml for Storm 1, 2 and 3, respectively. The average FC counts for the three storms were 9531, 42909 and 26757 md/100ml, respectively.

Figure 6.1 3-D Flat Fecal Coliform Load Presentation - Storm 1 (Storm Track = Peak Signal Passage from Worcester)

The dry weather data also indicated these two tributaries had relatively high FC concentrations. The average FC concentrations for Branch River were 160, 220 and 460 md/100ml for Surveys 1, 2 and 3, respectively. The average FC counts for the Peters River were 380, 1060 and 260 md/100ml.

Storm track of FC for Storm 1 (Figure 6.1) match perfectly with the storm track of the hydrograph for Storm 1 (Figure 4.9) returning to background concentrations at BWW08 at 40 hours. Maximum FC loads were typically seen along the storm track for all three storms.

Table 6.1 shows the criteria violation for Storms 1, 2 and 3. Two types of violations were considered: Violation A was the log mean > 200 md/100 ml; and Violation B was 10% of samples exceeding 400 md/100 ml.

Under dry weather conditions Type A violations occurred in the mainstem stations BWW01, BWW04, BWW06 and in the tributary stations Branch River (BWW14) and Peters River (BWW16) (Table 6.1).

Under wet weather all stations along the mainstem Blackstone River had violations of both Type A and Type B for all three storms with the exception of BWW02, BWW08, BWW11, BWW18 and BWW20 for storm 1 and BWW13 for storm 3. BWW11 and BWW18 had only Type B violations for Storm 1 (Table 6.1). The tributary stations BWW14 and BWW16 had both Type A and Type B violations. BWW09 had no violations at any time. Under wet weather no FC samples were collected at tributary stations BWW05 (Quinsigamond River), BWW10 (West River), and BWW15 (Mill River).

Table 6.1 Fecal Coliform Violation in Accordance With Class B Water Criteria for Dry and Wet Weather

Stration ID BWW/BLK	Violation-A		Violation-B
	Dry Weather	Wet Weather	Wet Weather
00	No Samples	1, 2, 3	1, 2, 3
01	1, 2, 3	1, 2, 3	1, 2, 3
02	No Violation	2, 3	2, 3
03	1, 2	No Samples	No Samples
04	1, 2, 3	1, 2, 3	1, 2, 3
06	1, 2	1, 2, 3	1, 2, 3
07	3	1, 2, 3	1, 2, 3
08	2	2, 3	2, 3
11	No Violation	2, 3	1, 2, 3
12	No Violation	No Samples	No Samples
13	No Violation	1, 2	1, 2
17	1, 3	1, 2, 3	1, 2, 3
18	3	2, 3	1, 2, 3
19	No Violation	No Samples	No Samples
20	1	2, 3	2, 3
21	1	1, 2, 3	1, 2, 3

TRIBUTARIES

05	No Violation	No Samples	No Samples
09	1	No Violation	No Violation
10	No Violation	No Samples	No Samples
14	2, 3	1, 2, 3	1, 2, 3
15	No Violation	No Samples	No Samples
16	1, 2, 3	1, 2, 3	1, 2, 3

Note: Violations A= Log Mean > 200 md/100 ml; Violations B= 10% of Samples Exceeding 400 md/100 ml 1, 2, 3 = Surveys (i.e. Dry Weather Surveys 1, 2, 3; Wet Weather Storms 1, 2, 3)

Significantly more stations had violations of both Type A and Type B for wet weather versus dry weather. This comparison is provided in Table 6.1. The high loading at the headwaters seems to be the main cause of the FC problems under wet weather conditions. The river receives benefit from high residual chlorine from UBWPAD during most time periods. The exception is at or near peak storm flow. There are more violations in Storm 2 and 3 than in Storm 1. This is probably due to the fact that Storm 1 was smaller than Storm 2 and 3.

6.2 Acute and Chronic Trace Metal Criteria

Acute and chronic toxicity criteria for metals are used to protect the public health and the environment. These criteria prevent the surface waters from becoming unsuitable for fishing, swimming and other beneficial uses. A comparison of concentration data to these criteria may be used to assess the degree of waste water treatment needed to meet water pollution control requirements, establish acceptable receiving concentrations and assess the suitability of environmental conditions for aquatic life.

EPA has developed acute and chronic toxicity criteria based on hardness numbers for total metal concentrations. The EPA's fresh water aquatic life criteria is listed in Table 6.2. Criteria used in the analysis to follow were calculated by using these hardness-based equations. The hardness concentrations were determined specific to each sample taken.

Individual pollutographs were plotted by station with the criteria for each metal. These plots provide insight into the question of whether wet weather causes acute criteria violations. Figure 6.2 is an example of a pollutograph and is an illustration of just such a

Table 6.2 Summary of EPAs Fresh Water Aquatic Life Criteria for Total Metal

Name	Acute ($\mu\text{g/L}$)	Chronic ($\mu\text{g/L}$)
Cadmium	$e^{(1.128 * [\ln H] - 3.828)}$	$e^{(0.7852 * [\ln H] - 3.49)}$
Chromium	$e^{(0.819 * [\ln H] + 3.688)} + 16$	$e^{(0.819 * [\ln H] + 1.561)} + 11$
Copper	$e^{(0.9422 * [\ln H] - 1.464)}$	$e^{(0.8545 * [\ln H] - 1.465)}$
Lead	$e^{(1.273 * [\ln H] - 1.46)}$	$e^{(1.273 * [\ln H] - 1.465)}$
Nickel	$e^{(0.846 * [\ln H] + 3.3612)}$	$e^{(0.846 * [\ln H] + 1.1645)}$

Note: H is the hardness ($\text{mg/L as CaCO}_3 = 2.497[\text{Ca}] + 4.118[\text{Mg}]$); The source of the equations is Water Quality Standards Handbook.

Figure 6.2 Example Figure of Pb Showing Acute and Chronic Criteria Violation for Storm 2 at Station BW00

violation. It shows all 12 samples violated lead chronic criteria but only 2 samples violated lead acute criteria for Storm 3 at BWW00. These violations occurred during the height of the storm, when instream hardness dropped resulting in lower acute criteria. The more stringent criteria typically coincided with maximum instream concentrations. Similar plots were developed per station for all trace metals (120 plots) during the course of this analysis. A subset of these specific to lead is provided in Appendix C.

The individual pollutographs can be combined for each storm in a single profile representing the entire storm and river in time and space. The violations can also be represented for the entire river in a similar manner. Examples of these figures for acute criteria are given in Figures 6.3-6.5. These figures represent the location, duration and magnitude of acute violations by constituent by storm. A complete summary of violations for wet weather is given in Table 6.3. Comparison between dry and wet weather violations is provided in table 6.4. Each metal is discussed individually below.

6.2.1 Lead

Chronic Criteria Violations - Chronic criteria violations occur at all stations for all three dry weather surveys and all three wet weather storms. Violations are greater at the headwater station and around Rice City Pond (Tables 6.3 and 6.4).

Acute Criteria Violations - The only violations under dry weather conditions occurred at two stations (BWW06 and BWW07) during the first survey in July 1991. For wet weather acute violations start typically at the headwaters in conjunction with runoff (peak hydrograph flow). The figure for Storm 3 (Figure 6.3) is an excellent

Figure 6.3 3-D Flat Acute Criteria Violations for Total Pb - Storm 3

Figure 6.4 3-D Flat Acute Criteria Violations for Total Cu - Storm 2 (Storm Track = Peak Signal Passage from Worcester)

Figure 6.5 3-D Flat Acute Criteria Violations for Total Cd - Storm 1

Table 6.3 Blackstone River Wet Weather Summary of Acute and Chronic Criteria Violations, Storm 1

STATIONS							
	Total	Cd		Cu		Pb	
		Acute	Chronic	Acute	Chronic	Acute	Chronic
	# Sample	# Violation	# Violation	# Violation	# Violation	# Violation	# Violation
BWW00	10	1	3	2	3	2	10
BWW01	10	0	0	1	3	0	10
BWW02	10	0	6	6	6	0	10
BWW04	10	1	10	10	10	0	10
BWW06	10	0	10	10	10	0	10
BWW07	10	0	5	10	10	0	10
BWW08	10	1	9	10	10	0	10
BWW11	10	0	5	10	10	0	10
BWW13	10	1	1	10	10	0	10
BWW17	10	0	0	10	10	0	10
BWW18	10	0	0	10	10	0	10
BWW20	10	0	0	9	10	0	10
BWW21	10	0	1	6	10	0	10

Tributaries

BWW05	10	0	0	0	0	0	2
BWW09	10	0	0	0	0	0	10
BWW10	10	0	0	0	0	0	6
BWW14	10	0	0	1	7	0	5
BWW15	10	0	0	1	1	0	10
BWW16	10	1	0	1	2	1	10

Note: Cr and Ni has no acute and chronic criteria violation

Table 6.3 Storm 2 (Continued)

		Cd		Cu		Pb	
STATIONS	Total	Acute	Chronic	Acute	Chronic	Acute	Chronic
	# Sample	# Violation	# Violation	# Violation	# Violation	# Violation	# Violation
BWW00	15	0	0	3	4	2	15
BWW01	16	0	0	5	7	2	16
BWW02	16	3	10	9	16	1	16
BWW04	16	3	12	9	14	2	16
BWW06	16	3	14	16	16	1	16
BWW07	15	1	15	16	16	0	15
BWW08	16	8	16	16	16	0	16
BWW11	16	6	16	16	16	1	16
BWW13	16	0	11	16	16	0	16
BWW17	16	1	7	15	15	0	16
BWW18	16	1	9	16	16	1	16
BWW20	16	0	7	10	15	0	16
BWW21	16	0	7	9	13	0	16

Tributaries

BWW05	15	0	0	0	0	0	10
BWW09	16	0	0	0	0	1	15
BWW10	16	0	0	0	0	0	16
BWW14	16	0	0	1	7	1	16
BWW15	16	0	0	1	2	0	16
BWW16	16	0	0	2	4	0	16

Note: Cr and Ni has no acute and chronic criteria violation

Table 6.3 Storm 3 (Continued)

STATIONS	Cd			Cu		Pb	
	Total	Acute	Chronic	Acute	Chronic	Acute	Chronic
	# Sample	# Violation	# Violation	# Violation	# Violation	# Violation	# Violation
BWW00	12	0	2	2	2	2	12
BWW01	12	0	4	5	6	3	12
BWW02	12	0	3	11	12	2	11
BWW04	11	1	3	9	12	3	9
BWW06	12	0	4	10	12	2	12
BWW07	13	0	1	13	13	1	12
BWW08	13	0	5	10	12	2	12
BWW11	13	0	4	11	12	2	11
BWW13	13	0	2	10	10	0	12
BWW17	13	0	0	12	12	1	13
BWW18	12	0	0	9	11	0	12
BWW20	12	0	0	11	11	0	12
BWW21	12	0	0	10	11	0	11

Tributaries

BWW05	12	0	0	0	0	0	6
BWW09	13	0	0	0	0	0	13
BWW10	13	0	0	0	0	0	11
BWW14	12	0	0	0	0	0	11
BWW15	13	0	0	0	0	0	12
BWW16	13	0	0	0	0	0	13

Note: Cr and Ni has no acute and chronic criteria violation

Table 6.4 Acute and Chronic Criteria Violations Comparison for Dry and Wet Weather

Stration ID BWW/BLK	Cd				Cu				Pb			
	Acute		Chronic		Acute		Chronic		Acute		Chronic	
	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
00	NS	1	NS	1, 3	NS	1, 2, 3	NS	1, 2, 3	NS	1, 2, 3	NS	1, 2, 3
01	NV	NV	3	3	3	1, 2, 3	1, 2, 3	1, 2, 3	NV	2, 3	1, 2, 3	1, 2, 3
02	1, 2, 3	2	1, 2, 3	1, 2, 3	1, 2, 3	1, 2, 3	1, 2, 3	1, 2, 3	NV	2, 3	1, 2, 3	1, 2, 3
03	1, 2, 3	NS	1, 2, 3	NS	1, 2, 3	NS	1, 2, 3	NS	NV	NS	1, 2, 3	NS
04	1, 2, 3	1, 2, 3	1, 2, 3	B	1, 2, 3	1, 2, 3	1, 2, 3	1, 2, 3	NV	2, 3	1, 2, 3	1, 2, 3
06	1, 2, 3	2	1, 2, 3	1, 2, 3	1, 2, 3	1, 2, 3	1, 2, 3	1, 2, 3	1	2, 3	1, 2, 3	1, 2, 3
07	NV	2	1, 2, 3	1, 2, 3	1, 2, 3	1, 2, 3	1, 2, 3	1, 2, 3	1	3	1, 2, 3	1, 2, 3
08	NV	1, 2	1, 2, 3	1, 2, 3	1, 2, 3	1, 2, 3	1, 2, 3	1, 2, 3	NV	3	1, 2, 3	1, 2, 3
11	3	2	1, 2, 3	1, 2, 3	1, 2, 3	1, 2, 3	1, 2, 3	1, 2, 3	NV	2, 3	1, 2, 3	1, 2, 3
12	3	NS	2, 3	NS	1, 2, 3	NS	1, 2, 3	NS	NV	NS	1, 2, 3	NS
13	3	1	1, 2, 3	1, 2, 3	1, 2, 3	1, 2, 3	1, 2, 3	1, 2, 3	NV	NV	1, 2, 3	1, 2, 3
17	NV	2	2, 3	2	1, 2, 3	1, 2, 3	1, 2, 3	1, 2, 3	NV	3	1, 2, 3	1, 2, 3
18	NV	2	2, 3	2	1, 2, 3	1, 2, 3	1, 2, 3	1, 2, 3	NV	2	1, 2, 3	1, 2, 3
19	NV	NS	2, 3	NS	2, 3	NS	1, 2, 3	NS	NV	NS	1, 2, 3	NS
20	NV	NV	3	1, 2	2, 3	1, 2, 3	1, 2, 3	1, 2, 3	NV	NV	1, 2, 3	1, 2, 3
21	NV	NV	3	2	2, 3	1, 2, 3	1, 2, 3	1, 2, 3	NV	NV	1, 2, 3	1, 2, 3

TRIBUTARIES

05	NV	NS	NV	NS	NV	NS	NV	NS	NV	NS	1, 2, 3	NS
09	NV	NV	NV	NV	1, 3		1, 3	NV	NV	NV	1, 2, 3	1, 2, 3
10	NV	NS	NV	NS	1, 3	NS	1, 3	NS	NV	NS	1, 2, 3	NS
14	NV	NV	NV	NV	1, 3	1, 2	1, 2, 3	1, 2	NV	NV	1, 2, 3	1, 2, 3
15	NV	NS	NV	NS	1, 3	NS	1, 2, 3	NS	NV	NS	1, 2, 3	NS
16	NV	1	NV	NV	NV	1, 2	1, 3	1, 2	NV	1	1, 2, 3	1, 2, 3

Note: 1, 2, 3 = Surveys (i.e. Dry Weather Survey 1, 2, 3; Wet Weather Storm 1, 2, 3); NS= No Samples; NV= No Violations

Ni and Cr has no Acute and Chronic Criteria Violation

example of violations coinciding with the track of the storm hydrograph from the headwaters in Worcester. The highest and most frequent violations occur at the headwater station (BWW00) decreasing downstream. The impact of the headwater peak storm flows are not limited to these upper reaches. Lead concentrations increase and the resultant violations occur in Rice City Pond due to resuspension associated with the arrival of the higher flows from Worcester (Figure 6.3).

6.2.2 Copper

Chronic Criteria Violations - The chronic criteria violations occur at all stations at all times for all surveys and storms (dry and wet weather) along the mainstem and the tributaries of the Blackstone River. The highest violations occur below UBWPAD and around Rice City Pond (Tables 6.3 and 6.4).

Acute Criteria Violations - In the dry weather surveys violations typically began with BWW02 (UBWPAD) and continued downstream reaching BWW18 or BWW21 (Table 6.4). The extent of the violations under wet weather conditions are similar, however, wet weather does increase the magnitude of the violation.

6.2.3 Cadmium

Chronic Criteria Violations - For all dry and wet weather surveys the chronic violations for Cd generally start directly below UBWPAD discharge. The reaches with violations typically extended at least to Woonsocket (Tables 6.3 and 6.4).

Acute Criteria Violations - Dry weather acute violations began at BWW02 and

typically continued downstream for 3 to 4 stations. The exception was for the dry weather survey 3 which also had several violation in the reaches below Rice City Pond (Table 6.4). Similarly, under wet weather conditions most of the violations for Cd also occurred directly below UBWPAD and extended for several stations downstream (Table 6.3).

6.2.4 Chromium and Nickel

Cr and Ni concentrations were well below the acute and chronic criteria violations for all the stations for all three storms under wet weather and all three surveys under dry weather on the mainstem of the Blackstone River.

CHAPTER 7

7.0 Wet Weather Pollutant Loadings

7.1 Mass Loading Estimates

The water quality data coupled with stream flows allow for the calculation of mass loading curves. About 1000 mass loadings profiles along with concentrations profiles were generated during the course of this analysis. A subset of these mass loading profiles specific to lead is provided in Appendix B. Each mass loading curve was integrated to obtain the total load (e.g. lbs) for each station for each storm. The total mass was divided by the time of the event to obtain the total loading (e.g. lbs/day) for that constituent for each station. Baseline loading rates (dry load in lbs/day) were estimated for each pollutograph from the initial (prestorm) sample and the final (post storm) samples. These rates were multiplied by the time of the event to obtain the total dry load for that station (lbs). The wet load (lbs) per station per constituent was determined by subtracting the dry load from the total load. Figure 7.1 illustrates the procedure for load calculations. Point sources loadings, including the CSO, were calculated using the average flow and average concentration during the event period.

7.2 Wet Weather Event Mean Mass (EMM)

The EMC data calculated in Chapter 5 were multiplied by the average flow of the corresponding stations and the correct multiplier to come up with the single mass value (lbs/day) for that station. Which will be referred as Event Mean Mass (EMM) from now

Figure 7.1 Example figure of Cr Showing Mass Loading Calculation for Storm 2 at Station BWW04

on. Figures 7.2 to 7.7 show the spatial variation of EMM for the 16 constituents for the three storms.

7.2.1 Nutrients

Figure 7.2 reflect the operation of UBWPAD with respect to nitrification. The instream data also supported the fact that nitrification was being provided at the facility during Storms 1 and 3 with high nitrate mass below UBWPAD and comparatively low ammonia mass. Storm 2 had high ammonia mass and low nitrate mass indicating that nitrification was not being provided at the facility.

A decline in ammonia below BWW02 and an increase in nitrate support the fact that instream nitrification was occurring during the storms and it was particularly evident in Storm 2 (Figure 7.2). Instream nitrification was also seen in the reaches below the Woonsocket discharge.

The increase in ammonia mass between BWW17 and BWW18 were due to the Woonsocket facility discharge.

The decrease in nitrate mass in the Storm 1 profile was most likely due to nitrate uptake by plants as discussed in the EMC Section (Chapter 5).

Phosphorous pattern was the same for all three storms with increases of mass after UBWPAD and the Woonsocket discharge (Figure 7.3). The headwater contribution of phosphorous was very low.

In general, based on EMM profiles, the nutrient masses were dominated by direct discharge from the two major point sources or instream nitrification resulting from their

EMM Plots for NO_3 and NH_3

Figure 7.2 EMM Plots for NO_3 and NH_3 for Storms 1, 2 and 3

EMM Plots for PO_4 , FC and EC

Figure 7.3 EMM Plots for PO_4 , FC and EC for Storms 1, 2 and 3

in fact, an increase in EC and FC mass below UBWPAD.

BOD appears to be governed by the two major point sources and does not appear strongly influenced by the storm related sources (Figure 7.7). BOD has a similar trend for all three storms, generally increasing after the UBWPAD discharge and decreasing to the mouth of the river. The Storm 2 mass profile showed an increase in BOD after the Woonsocket discharge.

Residual chlorine and sodium in the facilities effluent are most likely the cause of the sharp increase in the instream chloride (Cl) and sodium (Na) masses below the UBWPAD (between BW01 and BW02) for Storms 1 and 3 (Figure 7.5). This was not the case for Storm 2 Cl, where higher stream flows resulted in lower residual chlorine masses. As a result the Cl EMM profile slope, after the UBWPAD discharge for Storm 2, is less than that of Storms 1 and 3. There is an increase in chlorine and sodium masses after the Woonsocket WWTF discharge for all three storms.

7.2.3 Trace Metals

Lead's major source appeared to be in the headwaters (above BW00) and Rice City Pond (Figure 7.4). Storm 3 had the highest load coming from headwaters due to the highest intensity of rainfall at the headwaters as discussed in Chapter 4 of this report.

Neither the UBWPAD nor the Woonsocket facility appeared to have any impact on the Pb EMM profiles.

There appeared to be two distinct peaks (Figures 7.6 and 7.7) for the other five metals (Cd, Cr, Cu, Ni and Zn). All these metals had similar mass profiles. The first peak

EMM Plots for Cl and Na

Figure 7.5 EMM Plots for Cl and Na for Storms 1, 2 and 3

occurred in the reaches below UBWPAD. The wastewater facilities discharge and other nonpoint sources of metals was the probable cause of this peak.

There was a constant increase of masses up to BWW04 reflecting either the resuspension of sediments, the sloughing of material off the bottom, or Patriot Metals, which is located in the reach between BWW02 and BWW04.

Resuspension in Rice City Pond was the cause of the second peak around BWW08. All the metal mass profiles were either flat or declining with minor exceptions typically around the city of Woonsocket as the Blackstone River enters and passes through Rhode Island. The Woonsocket facility had no significant affect on the mass profiles. These data suggested that the metal EMM profiles in Rhode Island were governed by the mass entering at the state line.

7.3 Comparison of Wet and Total Loading

Mass loadings provide insight into the question of whether wet loads are a major source of metals during and immediately after storm events. The data indicate clearly that with only minor exceptions more pollutants entered the river during wet period than dry. One means of highlighting this is to compare wet and dry loadings. This has been done by representing each station's wet load as a % of total load (Table 7.1). These data represent the spatial variation for all constituents along the mainstem Blackstone River and its tributaries.

A simplification of these data are presented as an average across all stations for each storm in Table 7.2. This table illustrates the variation of wet load as a % of total load

Table 7.1 Blackstone River Wet Weather Wet Loading Summary, % Total Averaged Across All Storms

	Cd	Cr	Cu	Ni	Pb	Zn	BOD	EC	FC	NH4	NO3	PO4	TSS	VSS
Station	Wet Load	Wet Load	Wet Load	Wet Load	Wet Load	Wet Load	Wet Load	Wet Load	Wet Load	Wet Load	Wet Load	Wet Load	Wet Load	Wet Load
	% Total	% Total	% Total	% Total	% Total	% Total	% Total	% Total	% Total	% Total	% Total	% Total	% Total	% Total
BWW00	81.3	93.1	90.8	84.6	87.5	85.9	85.9	96.9	87.9	86.9	77.9	83.0	91.6	91.7
BWW01	84.9	74.3	84.3	69.7	88.1	80.4	86.9	96.4	81.0	64.9	56.3	81.2	93.6	81.8
BWW02	85.8	75.2	82.3	62.1	84.6	72.1	69.3	75.9	90.0	73.4	51.9	77.7	76.0	74.9
BWW04	73.1	81.2	75.2	48.8	88.9	69.9	80.8	90.2	84.9	80.6	43.7	62.8	94.3	91.4
BWW06	56.4	66.9	58.6	42.8	73.2	64.2	67.6	94.2	94.7	67.4	53.9	44.3	79.0	71.2
BWW07	38.6	59.1	50.1	37.2	63.3	54.9	58.2	88.4	87.7	67.4	34.5	47.2	69.3	65.5
BWW08	51.2	61.9	56.4	40.6	63.3	49.4	63.2	84.9	75.7	70.0	32.2	43.4	67.1	66.0
BWW11	54.0	60.2	56.8	43.2	67.0	59.1	58.4	88.1	82.1	81.6	45.9	39.2	66.9	72.7
BWW13	64.8	52.5	44.0	31.8	62.0	55.8	49.3	82.5	79.5	85.2	54.2	36.4	54.0	65.6
BWW17	52.6	51.5	52.3	40.9	56.2	54.2	60.0	95.9	85.9	82.1	40.5	42.1	72.7	74.4
BWW18	53.8	55.7	48.8	34.8	51.0	47.6	59.1	90.4	83.6	69.3	32.1	40.3	55.6	69.9
BWW20	49.0	61.4	51.0	50.4	55.2	55.5	59.4	93.0	77.3	62.4	38.0	52.7	71.4	72.9
BWW21	52.2	53.1	46.1	47.9	62.0	60.3	69.3	95.3	95.8	70.9	42.2	48.3	64.6	72.2

Tributaries

BWW05	71.1	82.7	69.3	72.4	72.7	56.4					36.4	65.6	58.4	73.9
BWW09	72.1	61.2	74.5	43.9	68.3	43.2	60.9	68.9	72.0	55.9	55.4	45.4	64.3	77.3
BWW10	44.3	71.7	54.9	48.0	57.9	34.3					47.4	50.2	69.0	83.9
BWW14	53.8	57.1	51.2	59.2	50.2	36.8	66.0	81.5	75.4	81.3	40.7	22.9	63.3	62.6
BWW15	63.4	60.9	57.1	44.0	58.3	35.1					47.9	50.0	73.3	77.3
BWW16	71.0	63.8	64.2	68.6	70.2	81.5	67.9	83.9	90.9	71.4	49.3	62.4	77.2	66.2

Table 7.2 Blackstone River Wet Weather Wet Loading Summary, % Total Averaged Across All Stations

	Cd	Cr	Cu	Ni	Pb	Zn	BOD	EC	FC	NH4	NO3	PO4	TSS	VSS
Station	Wet Load	Wet Load	Wet Load	Wet Load	Wet Load	Wet Load	Wet Load	Wet Load	Wet Load	Wet Load	Wet Load	Wet Load	Wet Load	Wet Load
	% Total	% Total	% Total	% Total	% Total	% Total	% Total	% Total	% Total	% Total	% Total	% Total	% Total	% Total
Storm 1	51.9	48.0	41.9	35.1	53.4	45.5	48.3	86.8	76.6	75.1	37.2	41.9	56.5	68.7
Storm 2	65.9	68.8	65.1	49.3	73.4	63.6	78.2	90.5	85.9	69.5	49.0	64.6	81.7	68.8
Storm 3	66.3	78.5	76.8	62.1	81.5	77.6	73.7	93.2	92.7	77.4	53.1	54.7	82.5	86.4
Average	61.4	65.1	61.3	48.8	69.4	62.2	66.7	90.2	85.1	74.0	46.4	53.7	73.5	74.6

with the change of rainfall. The same table summarizes the average wet loadings for each constituents under wet weather for the entire watershed. A comparison by constituent is provided below.

7.3.1 Nutrients

All the ammonia loading were above 50% and most of the nitrate loadings were below 50% for the mainstem and tributaries stations of the Blackstone River. Wet load as % total load for nitrate ranged from 78% at the headwaters to about 40 % at the mouth of the river. For ammonia the values were greater than 70% for the whole length of the river with the exception of BWW01 and BWW20 .

Orthophosphate wet loadings were above 50% at the headwaters but steadily declined to below 50% at the mouth of the river.

Wet loads as a percent of total loadings are summarized in Table 7.2 averaged for all storm across all stations. Wet loadings contribute more than 50% of the loadings for most of the constituents.

7.3.2 Conventional

With regards to the conventional constituents such as TSS, VSS, EC, FC, and BOD, all the mainstem and tributary stations of the Blackstone River had more than 50% wet load except BWW13 for BOD. The highest percentage occurred for TSS/VSS at BWW04 (94%). The trend of higher percent wet load as the storm intensity increases is true for all these constituents.

7.3.3 Trace Metals

In general, there are two observations which were consistent for all six metals. First, the highest percentage of wet load occurred at the headwaters. This reflects the importance of Worcester as a source of metals under wet weather conditions. The reduction in the percentage of wet load to total downstream is attributed to the higher more dominate point source loadings from the WWTFs, especially UBWPAD.

Second, either individually by station or based on the overall average for all stations by storm there is a positive correlation between the wet load percent of total and the rainfall intensity observed in the headwaters. This is logical and certainly supportive of the hypothesis that metal mobilization, whether by runoff or resuspension, is a function of the characteristics of the event.

A notable decrease in wet load % at Fisherville Pond (between BWW04 and BWW06) is seen for all metals. For example Cu declined from 75.2% to 58.6% wet load due most likely to settling. On the other hand, an increase in wet load % occurred in the Rice City Pond for all metals except for Zn due to sediment resuspension which occurred under the higher wet weather flows.

All the tributaries had greater than 50% wet load except for Zn and Ni. Other significant increases in % wet load which is an indication of a wet weather source occurred: Cd between BWW11-13, and BWW20-21; Cr between BWW02-04 and BWW18-20; Cu between BWW13-17 and BWW18-20; Pb between BWW18-20 and BWW20-21; Ni between BWW18-20; Zn between BWW18-20 and BWW20-21.

7.4 Net Gain and Loss Per Reach

Based on the interpretation of the mass loading curves, mass balance around each reach may be made providing an estimate of pollutant gain or loss. Net pollutant changes in a reach help to identify locations of major pollutant sources. The results of this evaluation also provides insight into the relative importance of each reach through a system ranking. The following decisions were made to establish the protocol for data evaluation.

The conditions between stations are dynamic. There are potentially multiple sources of each constituents in each reach which may function differently depending on the rainfall characteristics. Individual measurements within a reach were limited to a select group of the major point sources (UBWPAD and Woonsocket) and tributaries. Station comparisons, only provide net gains or losses of pollutants. Specific identification of a source requires a more detailed evaluation of each reach, which was beyond the scope of this project. However, reaches identified as a hot spot may undergo a more detailed evaluation. (An example of this is the identification of Rice City Pond (river reach BWW07-08) as a source of pollutant resuspension and the subsequent speciality study summarized in Section 4.6.3 of BRI report (Wright et al., 1996)). Potential sources are usually identified based on measured land use or observations (both past and present).

The UBWPAD and Woonsocket loads were subtracted from their respective reach mass balance. The other WWTFs in the watershed discharges were not considered in the balance and, therefore, their contribution remains as a part of the net gain in a reach.

The total load net gain and loss was calculated by reach by subtracting loadings

from consecutive stations along with other reach additions (point sources and tributaries).

For example:

$$\text{Gains/Loss} = \text{BWW02} - \text{BWW01} - \text{UBWPAD (BWW23)}$$

or

$$\text{Gains/Loss} = \text{BWW06} - \text{BWW04} - \text{BWW05 (Quinsigamond River)}$$

The wet load follows a similar procedure. An example of the net gain/loss profiles is given in Figure 7.8. Trends may be observed in these types of figures. For instance in Figure 7.8, a major gain for all three constituents (TSS, Cu and Pb) may be seen in the reaches BWW00-04 and BWW07-11 and a major loss may be seen in the reaches BWW04-07; and BWW11-17 with some rise and fall after station BWW17. The gains and losses from these figures are used to calculate the point and nonpoint sources in the next section.

7.5 Major Point Sources vs Nonpoint Sources

A point source is continuous and can be readily quantified. Nonpoint sources may be difficult to identify and quantify. Surface runoff and resuspension from bottom sediment are examples of non point sources. Sources were grouped for comparison in the following manner: Point Sources Loadings = UBWPAD + WOON + WOOR CSO and; Non Point Sources Loadings = Headwaters (BWW00) + Reach gains + Tributary load.

Figure 7.9 is an example of point source and nonpoint source comparisons. These types of figures indicate the importance of nonpoint sources during wet weather events. The summary of the point and nonpoint sources are presented in Table 7.3 and 7.4 for

Storm 2, Wet Load

Figure 7.8 Example figure of Wet Load Showing Gain and Loss for TSS, Cu and Pb for Storm 2

BLACKSTONE RIVER WET WEATHER STUDIES

Wet Load

Constituent: Pb

Figure 7.9 Example Plot of Wet Load Showing Point and Non Point Sources Comparison for Pb Storms 1, 2 and 3

Table 7.3 Blackstone River Wet Load Point Versus Nonpoint Percentages

Storm	Cd		Cr		Cu		Ni		Pb		Zn	
	PS	NPS	PS	NPS	PS	NPS	PS	NPS	PS	NPS	PS	NPS
1	32.7	67.3	55.8	44.2	53.9	46.2	69.6	30.4	13.2	86.8	48.3	51.7
2	15.0	85.0	15.1	84.9	16.2	83.8	28.9	71.1	4.38	95.6	15.0	85.0
3	20.9	79.1	9.53	90.5	28.0	72.0	35.6	64.5	4.38	95.6	14.3	85.7

Storm	BOD		FC		NH3		NO3		PO4		TSS	
	PS	NPS	PS	NPS	PS	NPS	PS	NPS	PS	NPS	PS	NPS
1	36.2	63.8	2.72	97.3	58.6	41.4	41.3	58.7	72.3	27.7	23.3	76.7
2	26.2	73.9	68.2	31.8	68.0	32.0	1.89	98.1	77.2	22.8	28.4	71.6
3	39.6	60.4	0.26	99.7	31.1	68.9	54.5	45.5	39.3	60.7	7.42	92.6

PS = Point Source ; NPS = Nonpoint Source

Table 7.4 Blackstone River Total Load Point Versus Nonpoint Percentages

	Cd		Cr		Cu		Ni		Pb		Zn	
Storm	PS	NPS	PS	NPS	PS	NPS	PS	NPS	PS	NPS	PS	NPS
1	18.8	81.2	40.2	59.8	35.7	64.3	41.7	58.3	6.11	93.9	24.9	75.1
2	15.3	84.7	12.8	87.2	11.6	88.4	29.7	70.4	4.87	95.1	13.9	86.1
3	15.3	84.7	6.29	93.7	18.8	81.2	30.3	69.8	1.97	98.0	8.66	91.3

	BOD		FC		NH3		NO3		PO4		TSS	
Storm	PS	NPS	PS	NPS	PS	NPS	PS	NPS	PS	NPS	PS	NPS
1	39.4	60.6	1.85	98.2	49.2	50.8	27.2	72.8	81.1	18.9	16.9	83.1
2	35.8	64.2	66.2	33.8	82.6	17.4	1.57	98.4	59.4	40.6	19.2	80.8
3	25.9	74.1	0.07	99.9	20.1	80.0	31.5	68.5	35.9	64.1	2.42	97.6

PS = Point Source ; NPS = Nonpoint Source

wet and total loads.

From Table 7.4, Pb has non point source contribution of 93%-98% for the storms observed and clearly nonpoint source governed. The high concentrations of Pb in the headwaters and Rice City Pond during wet weather events also support this. The data in Table 7.4 shows ammonia contribution for point sources was relatively higher for Storm 2 and lower for Storms 1 and 3, which supports that nitrification was occurring at UBWPAD during Storm 1 and Storm 3 and no nitrification occurred during Storm 2. It is clear from these tables that non point sources govern are higher for most constituents with the exception of ammonia and orthophosphate which are governed by point sources.

Point and non-point sources loads are summarized in Table 7.5 averaged for all storm across all stations. Non-point sources contribute more than 50% of the loadings for most of the constituents.

Table 7.5 Summary Average of Wet and Total Load Point Versus Nonpoint Percentages

Average	Cd		Cr		Cu		Ni		Pb		Zn	
	PS	NPS	PS	NPS	PS	NPS	PS	NPS	PS	NPS	PS	NPS
Wet	22.9	77.1	26.8	73.2	32.7	67.3	44.7	55.3	7.33	92.7	25.9	74.1
Total	16.5	83.5	19.8	80.2	22.1	78.0	33.9	66.1	4.32	95.7	15.8	84.2

Average	BOD		FC		NH3		NO3		PO4		TSS	
	PS	NPS	PS	NPS	PS	NPS	PS	NPS	PS	NPS	PS	NPS
Wet	34.0	66.0	23.7	76.3	52.6	47.4	32.6	67.5	62.9	37.1	19.7	80.3
Total	33.7	66.3	22.7	77.3	50.6	49.4	20.1	79.9	58.8	41.2	12.8	87.2

PS = Point Source ; NPS = Nonpoint Source

CHAPTER 8

8.0 System Ranking

A system ranking was made using the net gains for each reach and loads from the point sources, headwaters and tributaries. UBWPAD and Woonsocket were the only point sources considered for ranking calculations. The tributaries are grouped as BWW05, BWW09+BWW10, BWW14, and BWW15+BWW16. The ranking for each storm was calculated for both wet and total loads. The summary rankings for wet and total loads are provided in Tables 8.1 and 8.2, respectively.

The percent loadings for each reach tributary combination, the headwater station and each point source were averaged to get the contribution and ranking for all three storms.

A ranking, without point sources for the wet load, were also calculated for each storm and given in Table 8.3.

8.1 Nutrients (NO_3 , PO_4 , NH_4)

Wet and Total Load - UBWPAD is the most important source for nutrients for both wet and total load and delivers almost 1/3 of the total loadings for ammonia. The second most important source is Woonsocket. Normally treatment facilities has high ammonia loadings and in the previous section it was found that ammonia is mostly controlled by point sources (Table 7.5). From Table 8.1 and 8.2, 60% of this ammonia point source loading is coming from UBWPAD and about 40% from Woonsocket.

Table 8.1 Average Blackstone River Wet Weather Rankings, Wet Load

Ranking	Cd		Cr		Cu		Nj		Pb		Zn	
	Source	%Load	Source	%Load	Source	%Load	Source	%Load	Source	%Load	Source	%Load
1	UBWPAD	18.2	UBWPAD	25.7	UBWPAD	26.2	UBWPAD	42.7	BWW00	31.1	UBWPAD	16.0
2	BWW02-04	15.6	BWW01-02	15.1	BWW02-04	12.6	BWW18-20	12.5	BWW07-08	14.5	BWW00	14.2
3	BWW01-02	14.3	BWW07-08	14.1	BWW07-08	11.1	BWW07-08	10.8	BWW01-02	13.9	BWW00-01	13.2
4	BWW07-08	12.4	BWW00	13.7	BWW00	10.9	BWW13-17	7.22	BWW20-21	13.8	WOON	8.60
5	BWW20-21	7.64	BWW08-11	8.63	WOON	5.88	BWW01-02	6.94	BWW13-17	4.54	BWW18-20	7.90
6	BWW11-13	6.99	BWW02-04	6.58	BWW01-02	5.71	BWW00	6.13	BWW02-04	4.27	BWW07-08	7.73
7	BWW00	6.76	BWW13-17	4.31	BWW13-17	5.52	BWW02-04	5.08	BWW18-20	3.85	BWW01-02	6.58
8	BWW08-11	6.23	WOON	2.70	BWW08-11	5.37	BWW00-01	1.77	UBWPAD	3.64	BWW20-21	5.62
9	WOON	4.22	BWW18-20	2.03	BWW17-18	4.50	BWW08-11	1.43	WOON	3.38	BWW08-11	5.32
10	BWW13-17	3.32	BWW20-21	1.86	BWW20-21	4.12	WOON	1.42	BWW08-11	2.80	BWW02-04	3.36
11	BWW18-20	2.32	BWW00-01	1.33	BWW18-20	3.85	BWW06-07	1.14	BWW15+16	1.06	BWW13-17	3.02
12	BWW00-01	0.50	BWW06-07	0.98	BWW06-07	1.39	BWW15+16	0.66	BWW14	1.05	BWW04-06	2.05
13	WOOW CSO	0.49	BWW14	0.93	BWW00-01	0.79	BWW04-06	0.66	BWW09+10	1.00	BWW17-18	1.52
14	BWW9+10	0.40	BWW9+10	0.76	WOOR CSO	0.70	BWW05	0.51	BWW17-18	0.39	BWW09+10	1.44
15	BWW15+16	0.23	BWW17-18	0.65	BWW09+10	0.68	BWW14	0.42	WOOR CSO	0.35	WOOR CSO	1.30
16	BWW05	0.21	BWW15+16	0.30	BWW15+16	0.36	WOOR CSO	0.40	BWW05	0.33	BWW14	1.02
17	BWW14	0.19	BWW05	0.23	BWW14	0.33	BWW09+10	0.20	BWW00-01	0.06	BWW15+16	0.80
18			WOOR CSO	0.19	BWW05	0.09			BWW04-06	0.03	BWW06-07	0.25
19											BWW05	0.13

WOON = Woonsocket WWTF, WOOR CSO = Worcester CSO

Table 8.1 Wet Load (Continued)

Ranking	BOD		FC		NH3		NO3		PO4		TSS	
	Source	%Load	Source	%Load	Source	%Load	Source	%Load	Source	%Load	Source	%Load
1	UBWPAD	24.1	BWW00	32.69	UBWPAD	31.2	UBWPAD	26.2	UBWPAD	42.0	BWW02-04	24.2
2	BWW00	17.4	UBWPAD	16.24	BWW17-18	23.4	BWW11-13	21.1	WOON	27.7	BWW00	14.4
3	BWW01-02	10.6	BWW20-21	14.44	WOON	20.8	BWW20-21	12.2	BWW17-18	7.72	WOON	11.3
4	BWW20-21	9.74	BWW01-02	10.55	BWW01-02	9.83	BWW18-20	9.56	BWW07-08	5.06	BWW13-17	9.77
5	WOON	8.42	BWW13-17	8.73	BWW06-07	2.96	BWW04-06	7.29	BWW06-07	4.52	BWW08-11	7.68
6	BWW02-04	7.26	BW00-01	4.68	BWW02-04	2.89	WOON	6.27	BWW02-04	2.57	UBWPAD	7.12
7	BWW13-17	5.90	BWW15+16	4.12	BWW20-21	1.63	BWW02-04	4.57	BWW11-13	2.45	BWW07-08	5.96
8	BWW17-18	4.06	BWW02-04	3.73	BWW04-06	1.61	BWW08-11	3.00	BWW01-02	1.55	BWW01-02	5.30
9	WOOR CSO	3.73	BWW14	2.46	BWW00	1.34	BWW13-17	2.27	BWW18-20	1.29	BWW00-01	3.65
10	BWW07-08	2.73	WOON	1.05	WOOR CSO	1.25	BWW00	1.63	BWW13-17	1.23	BWW18-20	3.61
11	BW00-01	1.96	BWW06-07	0.82	BWW07-08	1.12	BWW07-08	1.31	BWW00	1.09	WOOR CSO	1.45
12	BWW14	1.82	BWW04-06	0.22	BWW14	0.86	BWW14	0.96	BWW08-11	0.99	BWW14	1.43
13	BWW09+10	0.91	BWW08-11	0.18	BWW15+16	0.41	BWW17-18	0.90	BWW20-21	0.63	BWW17-18	1.43
14	BWW08-11	0.80	BWW09+10	0.09	BWW08-11	0.38	BWW15+16	0.70	BWW14	0.45	BWW15+16	1.32
15	BWW15+16	0.69			BWW05	0.09	BWW00-01	0.58	WOOR CSO	0.35	BWW06-08	1.21
16					BWW13-17	0.07	BWW09+10	0.58	BWW15+16	0.18	BWW09+10	0.07
17					BWW09+10	0.07	BWW01-02	0.41	BWW09+10	0.14	BWW05	0.07
18					BWW00-01	0.06	BWW06-07	0.28	BWW05	0.05		
19							WOOR CSO	0.08				
20							BWW05	0.01				

WOON = Woonsocket WWTF, WOOR CSO = Worcester CSO

Table 8.2 Average Blackstone River Wet Weather Rankings, Total Load

Ranking	Cd		Cr		Cu		Ni		Pb		Zn	
	Source	%Load	Source	%Load	Source	%Load	Source	%Load	Source	%Load	Source	%Load
1	BWW02-04	15.1	BWW07-08	21.6	BWW02-04	22.3	UBWPAD	32.7	BWW00	38.9	BWW00	17.4
2	UBWPAD	14.5	UBWPAD	18.5	UBWPAD	17.8	BWW02-04	14.6	BWW07-08	15.3	BWW00-01	16.5
3	BWW07-08	14.0	BWW00	18.3	BWW00	17.1	BWW00	11.0	BWW01-02	11.1	BWW07-08	10.0
4	BWW00	12.8	BWW01-02	14.2	BWW07-08	11.6	BWW07-08	9.89	BWW20-21	9.26	UBWPAD	9.64
5	BWW01-02	11.2	BWW13-17	8.43	BWW01-02	8.46	BWW18-20	8.31	BWW13-17	4.95	BWW01-02	6.41
6	BWW11-13	8.14	BWW02-04	6.85	WOON	4.31	BWW06-07	5.36	BWW02-04	3.66	WOON	6.18
7	BWW20-21	7.40	BWW00-01	4.16	BWW08-11	3.59	BWW01-02	4.55	BWW04-06	3.56	BWW17-18	5.43
8	BWW18-20	5.20	BWW20-21	2.30	BWW06-07	3.55	BWW13-17	4.26	BWW18-20	3.42	BWW18-20	5.02
9	BWW13-17	3.34	WOON	1.92	BWW17-18	3.18	BWW00-01	2.79	UBWPAD	2.36	BWW20-21	3.65
10	WOON	3.28	BWW14	1.46	BWW18-20	2.33	BWW02-04	1.65	WOON	1.96	BWW02-04	3.26
11	BWW02-04	1.69	BWW09+10	0.90	BWW00-01	1.71	BWW15+16	1.33	BWW14	1.76	BWW08-11	3.21
12	BWW08-11	0.99	BWW18-20	0.63	BWW20-21	1.34	WOON	1.13	BWW15+16	1.29	BWW13-17	2.79
13	BWW14	0.73	BWW15+16	0.42	BWW14	1.11	BWW11-13	1.07	BWW09+10	1.27	BWW04-06	2.39
14	BWW09+10	0.55	BWW05	0.24	BWW09+10	0.70	BWW14	0.61	BWW08-11	0.85	BWW06-07	2.36
15	BWW00-01	0.48			BWW15+16	0.46	BWW09+10	0.33	BWW05	0.32	BWW14	2.29
16	BWW15+16	0.27			BWW13-17	0.41	BWW05	0.32			BWW09+10	2.02
17	BWW05	0.24			BWW05	0.07					BWW15+16	1.10
18											BWW05	0.33

WOON = Woonsocket WWTF, WOOR CSO = Worcester CSO

Table 8.2 Total Load (Continued)

Ranking	BOD		FC		NH3		NO3		PO4		TSS	
	Source	%Load	Source	%Load	Source	%Load	Source	%Load	Source	%Load	Source	%Load
1	UBWPAD	24.3	BWW00	40.1	UBWPAD	31.2	UBWPAD	16.3	UBWPAD	35.3	BWW02-04	28.3
2	BWW00	23.1	UBWPAD	21.6	BWW17-18	22.4	BWW11-13	11.1	WOON	22.8	BWW00	25.3
3	WOON	7.59	BWW20-21	11.2	WOON	19.4	BWW02-04	8.95	BWW18-20	10.0	WOON	8.48
4	BWW01-02	7.12	BWW13-17	7.55	BWW01-02	12.8	BWW18-20	8.45	BWW17-18	6.09	BWW00-01	6.64
5	BWW18-20	6.35	BWW00-01	7.07	BWW18-20	4.13	BWW20-21	8.16	BWW07-08	5.61	BWW07-08	6.49
6	BWW00-01	5.64	BWW15+16	4.77	BWW00	2.96	BWW11-13	7.69	BWW02-04	5.36	UBWPAD	5.50
7	BWW02-04	4.10	BWW14	2.09	BWW06-07	2.51	BWW13-17	7.64	BWW06-07	3.31	BWW01-02	5.09
8	BWW07-08	3.56	BWW02-04	1.93	BWW07-08	2.36	BWW04-06	6.40	BWW14	2.45	BWW13-17	4.62
9	BWW13-17	3.42	BWW02-04	1.28	BWW14	0.89	BWW06-07	5.25	BWW01-02	2.32	BWW14	2.09
10	BWW00-01	2.91	WOON	1.13	BWW15+16	0.69	BWW08-11	4.49	BWW11-13	2.20	BWW15+16	1.86
11	BWW14	2.78	BWW17-18	1.08	BWW00-01	0.40	WOON	3.64	BWW13-17	2.19	BWW18-20	1.64
12	BWW20-21	2.73	BWW09+10	0.12	BWW09+10	0.15	BWW00	3.50	BWW00	1.16	BWW06-07	1.50
13	BWW04-06	1.42	BWW06-07	0.07	BWW13-17	0.04	BWW18-20	2.47	BWW9+10	0.90	BWW9+10	1.31
14	BWW09+10	1.42	BWW07-08	0.03			BWW14	1.94	BWW15+16	0.22	BWW17-18	1.04
15	BWW17-18	1.14	BWW08-11	0.02			BWW07-08	1.50	BWW05	0.05	BWW05	0.12
16	BWW15+16	1.04					BWW00-01	1.07				
17	BWW06-07	0.91					BWW15+16	1.07				
18	BWW08-11	0.44					BWW09+10	0.31				
19							BWW05	0.05				

WOON = Woonsocket WWTF, WOOR CSO = Worcester CSO

Table 8.3 Average Blackstone River Wet Weather Rankings, Wet Load, without Point Sources

Ranking	Cd		Cr		Cu		Ni		Pb		Zn	
	Source	%Load	Source	%Load	Source	%Load	Source	%Load	Source	%Load	Source	%Load
1	BWW02-04	21.6	BWW01-02	22.7	BWW02-04	21.8	BWW18-20	25.3	BWW00	32.9	BWW00	18.9
2	BWW01-02	17.4	BWW00	17.4	BWW07-08	16.2	BWW07-08	17.6	BWW20-21	15.3	BWW00-01	16.6
3	BWW07-08	15.5	BWW07-08	15.6	BWW00	15.0	BWW01-02	12.0	BWW07-08	15.0	BWW01-02	12.4
4	BWW11-13	10.4	BWW08-11	10.3	BWW13-17	9.26	BWW00	10.9	BWW01-02	14.2	BWW18-20	9.27
5	BWW20-21	9.33	BWW13-17	9.86	BWW01-02	7.47	BWW13-17	10.6	BWW13-17	5.05	BWW07-08	8.66
6	BWW00	8.70	BWW02-04	7.85	BWW18-20	6.72	BWW02-04	10.5	BWW18-20	4.43	BWW20-21	6.53
7	BWW08-11	5.84	BWW18-20	4.59	BWW08-11	6.43	BWW00-01	2.61	BWW02-04	4.23	BWW08-11	6.32
8	BWW13-17	3.89	BWW00-01	2.72	BWW17-18	5.39	BWW04-06	2.12	BWW08-11	4.17	BWW13-17	5.78
9	BWW18-20	2.83	BWW06-07	2.24	BWW20-21	4.93	BWW08-11	2.01	BWW15+16	1.17	BWW02-04	3.96
10	BWW00-01	2.61	BWW20-21	2.22	BWW06-07	1.88	BWW06-07	1.73	BWW14	1.14	BWW17-18	2.95
11	WOOW CSO	0.61	BWW14	1.52	BWW00-01	1.58	BWW15+16	1.38	BWW09+10	1.06	BWW04-06	2.28
12	BWW9+10	0.49	BWW9+10	0.98	BWW09+10	1.10	BWW05	1.28	BWW17-18	0.44	BWW09+10	1.72
13	BWW15+16	0.29	BWW17-18	0.78	WOOR CSO	0.95	BWW14	0.98	WOOR CSO	0.36	BWW14	1.56
14	BWW14	0.27	BWW15+16	0.55	BWW14	0.60	WOOR CSO	0.62	BWW05	0.36	WOOR CSO	1.45
15	BWW05	0.26	BWW05	0.40	BWW15+16	0.56	BWW09+10	0.31	BWW00-01	0.06	BWW15+16	1.16
16			WOOR CSO	0.22	BWW05	0.13			BWW04-06	0.03	BWW06-07	0.29

WOON = Woonsocket WWTF, WOOR CSO = Worcester CSO

Table 8.3 Without Point Sources (Continued)

Ranking	BOD		FC		NH3		NO3		PO4		TSS	
	Source	%Load	Source	%Load	Source	%Load	Source	%Load	Source	%Load	Source	%Load
1	BWW00	25.5	BWW00	33.7	BWW17-18	44.1	BWW11-13	33.4	BWW18-20	20.7	BWW02-04	28.0
2	BWW01-02	15.5	BWW01-02	20.0	BWW01-02	19.2	BWW18-20	15.7	BWW17-18	19.1	BWW00	16.0
3	BWW20-21	14.6	BWW20-21	17.1	BWW02-04	9.32	BWW20-21	12.9	BWW07-08	18.2	BWW13-17	12.9
4	BWW02-04	10.6	BWW13-17	8.92	BWW06-07	6.01	BWW04-06	8.33	BWW02-04	9.06	BWW08-11	10.8
5	BWW13-17	9.47	BWW02-04	5.75	BWW20-21	5.26	BWW02-04	8.32	BWW06-07	6.60	BWW01-02	7.09
6	BWW17-18	5.73	BWW15+16	5.61	BWW04-06	5.20	BWW13-17	5.15	BWW01-02	5.03	BWW07-08	7.02
7	WOOR CSO	5.39	BW00-01	5.03	BWW07-08	2.78	BWW08-11	3.16	BWW13-17	4.57	BWW00-01	4.88
8	BWW07-08	3.99	BWW14	2.55	BWW00	2.33	BWW00	3.14	BWW00	3.93	BWW18-20	3.74
9	BW00-01	3.12	BWW06-07	0.83	WOOR CSO	1.76	BWW07-08	2.30	BWW08-11	3.91	BWW17-18	2.01
10	BWW14	2.66	BWW04-06	0.23	BWW14	1.74	BWW14	1.66	BWW11-13	3.58	BWW14	1.86
11	BWW09+10	1.30	BWW08-11	0.18	BWW08-11	1.01	BWW17-18	1.59	BWW20-21	2.48	BWW15+16	1.70
12	BWW08-11	1.10	BWW09+10	0.12	BWW15+16	0.63	BWW00-01	1.19	BWW09+10	0.99	BWW06-08	1.58
13	BWW15+16	1.00			BWW00-01	0.20	BWW15+16	1.11	BWW15+16	0.68	WOOR CSO	1.50
14					BWW13-17	0.15	BWW09+10	0.78	BWW14	0.54	BWW09+10	0.82
15					BWW05	0.13	WOOR CSO	0.52	WOOR CSO	0.50	BWW05	0.11
16					BWW09+10	0.11	BWW01-02	0.42	BWW05	0.15		

WOON = Woonsocket WWTF, WOOR CSO = Worcester CSO

Other important sources are reach between BWW17-18 and BWW01-02. There might be some nonpoint sources in those reaches, which are triggered by the high wet weather flows.

UBWPAD is again ranked first for nitrate loadings. Woonsocket does not appear within first 10 rankings for nitrate total load and appears in 6th position for nitrate wet load. The second important source for nitrate is reach between BWW11-13. EMC profiles also shows increase in nitrate concentrations and decrease in ammonia concentrations in that reach (Figure 5.10). So, there might be instream nitrification occurring in that reach and some other nonpoint source may be present also. Other important sources of nitrate are reach between BWW20-21, BWW18-20 and BWW04-06 (Fisherville Pond).

UBWPAD and Woonsocket are the most important sources and together delivers about 60% of the loadings for phosphate. BWW17-18, Rice City Pond (BWW07-08) and BWW18-20 are important for phosphate. Resuspension (specially in the Rice City Pond) and other non point sources are responsible for high phosphate loadings in those reaches. The headwaters are not important for nutrient loadings.

Wet Load Without Point Sources - If we delete the point sources from the system then the reach between BWW17-18 alone delivers 44% of the ammonia loadings and BWW01-02 delivers about 20%. Other important sources are BWW02-04, BWW06-07 and BWW20-21. These loadings are due to runoff and resuspension related.

BWW11-13, BWW18-20 and BWW20-21 have the major reach gains of nitrate with 62% of the total loadings together. Other important sources are BWW04-06,

BWW02-04 and BWW13-17. Instream nitrification and other nonpoint sources may be the cause for these increase.

BWW18-20, BWW17-18 and Rice City Pond (BWW07-08) are the major sources for phosphate without point sources and together delivers about 60% of the loadings. Other important sources are BWW02-04, BWW06-07 and BWW01-02. Resuspension and other nonpoint sources are responsible here.

8.2 Conventional (TSS, BOD, FC)

Wet and Total Load - BWW02-04, the headwaters (BWW00) and Woonsocket are the major sources for TSS delivering greater than 50% of the loadings together. Other sources are BWW13-17, BWW07-08, UBWPAD and BWW01-02. The EMC plot for TSS (Figure 5.12) shows high concentration in the headwaters and couple of reaches downstream. That high concentration, resuspension and other nonpoint and point sources are the cause of high TSS loadings in these reaches.

UBWPAD, BWW00 and BWW01-02 are the most important sources of BOD delivering more than 50% of the loadings together. Other important sources are Woonsocket, BWW18-20 and BWW13-17. The EMC plot for BOD (Figure 5.14) shows high concentration from the headwaters up to BWW04. This high concentration in headwaters and other nonpoint and point sources are responsible for high BOD loadings in those reaches.

The headwaters are the major source for FC delivering about 1/3 of the loadings. UBWPAD and BWW20-21 together delivers more than 30% of the FC loadings. EMC

plot for FC (Figure 5.11) shows highest FC concentrations at the headwaters and then sharp decrease downstream. As discussed in Section 6.1, the residual chlorine from UBWPAD was not effective to bring down the concentrations downstream due to poor performance and high flows during Storm 2, which is responsible for UBWPAD being the second highest contributor for FC loadings. Nonpoint sources mostly controls the FC loadings.

Wet Load Without Point Sources - The headwaters are the most important source for FC, BOD and second important for TSS when the point sources are not considered.

Other important sources for TSS are BWW02-04, BWW13-17, BWW08-11, BWW01-02 and Rice City Pond (BWW07-08). Reaches between headwaters to BWW04 together delivers about 60% of the total TSS loadings without point sources.

Other important sources for BOD are BWW01-02, BWW20-21, BWW02-04 and BWW13-17. Reaches between headwaters to BWW04 together delivers more than 50% of the total BOD loadings without point sources.

BWW01-02, BWW20-21, BWW13-17 and BWW02-04 are other important sources for FC. Reaches between headwaters to BWW04 together delivers more than 60% of the total FC loadings without point sources.

8.3 Metals (Pb, Cu, Ni, Cd, Cr, Zn)

Wet and Total Load - The headwaters and resuspension in the Rice City Pond are the most important sources of Pb and together responsible for about 50% of the loadings. UBWPAD and Woonsocket are not important for Pb. BWW01-02, BWW20-21 and

BWW13-17 are within first five position and together delivers about 30% of the loadings. EMC plots for Pb (Figure 5.12) also shows high concentration of Pb in those areas. Resuspension and other nonpoint sources are the cause of high Pb loadings. Table 7.5 also supports that Pb is nonpoint source governed.

UBWPAD is the major source for all trace metals except Pb for both wet and total loadings. Woonsocket is not important for Ni, Cd, and Cr and delivers less than 2% loadings, but is important for Cu and Zn. Rice City Pond and headwaters are important for all trace metals and appears within first five position. Resuspension is the cause of metal loadings at Rice City Pond.

BWW02-04 appears in first and second position for Cu and Cd and in 7th position for Ni. Patriot Metals is located in that reach of BWW02-04 which may be responsible for high Cu, Cd, and Ni loadings in this reach. BWW01-02 is important for Cd and Cr.

In general, point and nonpoint sources including resuspension in the Rice City Pond are the cause of high metal loadings.

Wet Load Without Point Sources - The headwaters are the major source of Pb for wet load without point sources. Other important sources are BWW20-21, Rice City Pond, BWW01-02, and BWW13-17.

Headwaters and resuspension in the Rice City Pond are the most important sources for all trace metals when point sources are not considered. BWW01-02 is important for all trace metals and appears within first five rankings for Loadings without point sources. BWW02-04 is important for Cu, Cd, Cr and Ni.

8.4. Comparison Between Wet and Dry Weather Rankings

The comparison between dry weather and wet weather rankings for trace metals, TSS, and nutrients for the top five position are provided in Table 8.4.

UBWPAD is responsible for 49% of the load for nitrate, 62% for phosphate and 5% for ammonia under dry weather and 16%, 35%, and 31% under wet weather, respectively. UBWPAD is in the first position for nitrate and phosphate under both dry and wet weather condition. For ammonia under dry weather, Woonsocket is in the first position with 68% and UBWPAD is not so important. Under dry weather, UBWPAD has high nitrate and low ammonia which supports that nitrification is on and the facility is performing well. Under wet weather, two out of three survey had nitrification on in the facility, but UBWPAD has low nitrate and high ammonia supporting poor performance of the facility under higher flows during the storms.

Headwater and Rice City Pond are not important sources of nutrients under either dry or wet weather. Nutrients are mostly controlled by point sources under dry weather and by point and non point sources under wet weather conditions.

UBWPAD is ranked for TSS under dry weather and Woonsocket is not. For wet weather the reverse is true. The headwaters is an important source for wet weather but not for dry weather and Rice City Pond ranked for both wet and dry weather.

Head water and resuspension in the Rice City Pond are the most important sources for Pb under wet weather. Resuspension in the section of river starting below Fisherville Pond (BWW07) and ending below Rice City Pond (BWW08) is the major source of Pb under dry weather. Mouth of the river (BWW20-21) is important for wet weather but not

Table 8.4 Average Blackstone River Wet and Dry Weather Rankings (Total Load)

Wet Weather

Ranking	Cd		Cr		Cu		Ni		Pb		NH4		NO3		PO4		TSS	
	Source	%Load	Source	%Load	Source	%Load	Source	%Load	Source	%Load	Source	%Load	Source	%Load	Source	%Load	Source	%Load
1	BWW02-04	15.1	BWW07-08	21.6	BWW02-04	22.3	UBWPAD	32.7	BWW00	38.9	UBWPAD	31.2	UBWPAD	16.3	UBWPAD	35.3	BWW02-04	28.3
2	UBWPAD	14.5	UBWPAD	18.5	UBWPAD	17.8	BWW02-04	14.6	BWW07-08	15.3	BWW17-18	22.4	BWW11-13	11.1	WOON	22.8	BWW00	25.3
3	BWW07-08	14.0	BWW00	18.3	BWW00	17.1	BWW00	11.0	BWW01-02	11.1	WOON	19.4	BWW02-04	8.95	BWW18-20	10.0	WOON	8.48
4	BWW00	12.8	BWW01-02	14.2	BWW07-08	11.6	BWW07-08	9.89	BWW20-21	9.26	BWW01-02	12.8	BWW18-20	8.45	BWW17-18	6.09	BWW00-01	6.64
5	BWW01-02	11.2	BWW13-17	8.43	BWW01-02	8.46	BWW18-20	8.31	BWW13-17	4.95	BWW18-20	4.13	BWW20-21	8.16	BWW07-08	5.61	BWW07-08	6.49

Dry Weather

Ranking	Cd		Cr		Cu		Ni		Pb		NH4		NO3		PO4		TSS	
	Source	%load	Source	%load	Source	%load	Source	%load	Source	%load	Source	%load	Source	%load	Source	%load	Source	%load
1	UBWPAD	39.6	BLK07-08	37.1	UBWPAD	34.5	UBWPAD	47.0	BLK04-06	22.2	WOON	67.9	UBWPAD	48.7	UBWPAD	62.2	BLK07-08	13.6
2	BLK07-08	10.5	BLK12-13	16.4	BLK07-08	17.3	BLK20-21	9.43	BLK06-07	16.4	BLK01-02	7.80	BLK20-21	8.64	WOON	19.9	BLK20-21	10.5
3	BLK01-02	8.18	UBWPAD	11.7	WOON	7.28	BLK01-02	8.49	BLK07-08	12.8	UBWPAD	4.93	WOON	7.20	BLK12-13	3.06	BLK06-07	10.2
4	BLK12-13	7.81	BLK01	8.02	BLK08-11	7.01	BLK12-13	6.50	BLK12-13	11.7	BLK03-04	4.33	BLK02-03	5.70	BLK02-03	2.69	UBWPAD	8.57
5	WOON	7.24	BLK08-11	7.25	BLK04-06	5.68	WOON	4.56	BLK08-11	7.91	BLK20-21	3.80	BLK06-07	4.00	BLK11-12	2.36	BLK12-13	8.17

WOON = Woonsocket WWTF

under dry weather for Pb. UBWPAD and Woonsocket are not important for Pb and does not appear within first five rank under both wet and dry weather.

UBWPAD is a major source for Cu, Ni, Cd, and Cr under both wet and dry weather. Woonsocket is a major source for Cu, Ni, and Cd under dry weather only and does not appear within first five position under wet weather. For Cr Woonsocket does not appear within first five rank under both dry and wet weather.

Resuspension in the Rice City Pond is an important source of all trace metals under both wet and dry weather and it is more important during wet weather, since volume and velocity of water is high and more resuspension occurs under wet weather condition.

Headwater is an important source for all trace metals under wet weather but does not appear within first five rankings under dry weather. BWW02-04 is a major source of Cu, Cd, and Ni under wet weather and does not appear within first five rankings under dry weather. Patriot Metals is located within the reach BWW02-04 and that may be the source for Cu, Cd, and Ni under wet weather. BWW01-02 is important for Pb, Cu, Ni, Cd, and Cr under wet weather but is only important for Ni, and Cd under dry weather. BWW08-11 appears 3 time out of five trace metals in the first five rankings under dry weather but does not appear at all in the first five rankings under wet weather.

8.5 Comparison of Load for Different River Systems

Five major rivers contribute flows and pollutant loadings to the Providence River and Upper Narragansett Bay. The first wet weather study conducted in 1988-89 for NBP provided a ranking for these rivers for several pollutants (Wright et al. 1991). A similar

ranking table is reproduced here (Table 8.5) using only the tributaries loadings.

Blackstone River ranked first for all the constituents except NH_4 , where it was second. In general, the rankings for the other rivers in descending order were: Pawtuxet, Woonasquatucket, Ten Mile, and Moshassuck. Blackstone River alone was contributing 41%-67% of the wet load delivered by the five tributaries.

Total rainfall for NBP studies for the three storms observed were in October 1988 - 0.90", May 1989 - 1.94" and June 1989 - 0.37" as compared to this study for September 1992 - 0.558", November 1992 - 0.881" and October 1993 - 0.809". The data from this study have also been summarized in Table 8.6. The wet load (lbs) were calculated using the EMC values from Table 5.5 and the corresponding flows for those rivers. The wet loads were divided by the effective runoff for each storm to obtain the lbs/million cu. ft (lbs/M-ft^3) values for each storm. The values were averaged for the three storms in each survey. The same flow ratios for the NBP study (BRSM : MOSH : PAWT : TENM : WOON = 1.0 : 0.0776 : 0.4091 : 0.15527 : 0.1024) were used to determine an estimate of effective runoff for the tributaries for the storms of this study. The wet loadings were then calculated using these runoff values (Table 8.7).

A ranking table, similar to the NBP study has been prepared and presented in Table 8.7. The 1992-93 data supports the earlier observation that the Blackstone River is the major contributor of trace metals, nitrate and orthophosphate. In general, the rankings for the other rivers in descending order are: Pawtuxet, Woonasquatucket, Ten Mile, and Moshassuck. Blackstone River alone is contributing 28%-64% of the wet load delivered by the five tributaries.

Table 8.5 1988-89 NBP Tributary Wet Loads and Rankings

NBP Wet loads, Total of Three Storms

Station	Cd	Cr	Cu	Ni	Pb	NH4	NO3	PO4	TSS
	lbs	lbs	lbs	lbs	lbs	lbs	lbs	lbs	lbs
BRSM	36.4	331	468	315	433	7160	127000	13700	684000
MOSH	0.84	29.5	45.7	30.7	46.2	419	5980	241	68900
PAWT	9.52	87.1	148	143	127	12100	32900	5070	643000
TENM	5.79	92.2	92.8	217	28.5	856	20200	1260	28800
WOON	1.72	18.6	51.0	47.0	67.7	650	6780	691	115000

NBP Rankings, Wet loads

Station	Cd	Cr	Cu	Ni	Pb	NH4	NO3	PO4	TSS
	Rankings	Rankings	Rankings	Rankings	Rankings	Rankings	Rankings	Rankings	Rankings
BRSM	1	1	1	1	1	2	1	1	1
MOSH	5	4	5	5	4	5	5	5	4
PAWT	2	3	2	3	2	1	2	2	2
TENM	3	2	3	2	5	3	3	3	5
WOON	4	5	4	4	3	4	4	4	3

NBP, Wet loads Percent

Station	Cd	Cr	Cu	Ni	Pb	NH4	NO3	PO4	TSS
	%	%	%	%	%	%	%	%	%
BRSM	67.1	59.3	58.1	41.8	61.6	33.7	65.9	65.3	44.4
MOSH	1.55	5.28	5.67	4.08	6.58	1.97	3.09	1.15	4.48
PAWT	17.5	15.6	18.3	19.0	18.1	57.2	17.0	24.2	41.8
TENM	10.7	16.5	11.5	28.8	4.06	4.03	10.5	6.01	1.87
WOON	3.17	3.33	6.33	6.24	9.64	3.06	3.51	3.30	7.49

BRSM = Blackstone River; MOSH = Moshassuck River; PAWT = Pawtuxet River; TENM = Ten Mile River; WOON = Woonasquatucket River [NBP study Wright et. al. (1988)];

Total rainfall for NBP studies for three storms observed were 3.21" (October 1988 - 0.90"; May 1989 - 1.94"; June 1989 - 0.37")

Table 8.6 1988-89 NBP Wet Loads for Blackstone, Moshassuck, Woonasquatucket, Pawtuxet and Ten Mile Rivers

Storm Average

Station	Flow	Cd	Cr	Cu	Ni	Pb	NH4	NO3	PO4	TSS
	M-ft ³	lbs/M-ft ³	lbs/M-ft ³	lbs/M-ft ³	lbs/M-ft ³	lbs/M-ft ³	lbs/M-ft ³	lbs/M-ft ³	lbs/M-ft ³	lbs/M-ft ³
BRSM	306	0.06	0.71	0.86	0.89	0.61	18.5	356	43.1	904
MOSH	23.7	0.03	1.02	1.82	0.64	1.63	12.0	119	9.67	2319
PAWT	125	0.08	0.31	1.05	1.36	0.54	105	226	47.9	2342
TENM	47.5	0.06	0.55	0.91	2.94	0.20	5.24	234	8.47	354
WOON	31.3	0.01	0.23	0.57	0.52	0.74	10.8	188	18.2	1414

BRSM = Blackstone River; MOSH = Moshassuck River; PAWT = Pawtuxet River; TENM = Ten Mile River;
 WOON = Woonasquatucket River [NBP study Wright et. al. (1988)]; lbs/M-ft³ = lbs/million cu. ft.

Table 8.7 1992-93 Tributary Wet Loads Estimates and Rankings

Storm Average											
Station	Code	Flow M-ft ³	Cd lbs	Cr lbs	Cu lbs	Ni lbs	Pb lbs	NH4 lbs	NO3 lbs	PO4 lbs	TSS lbs
BWW21	a	42.0	1.80	7.85	37.4	20.8	34.8	2600	6080	1050	21970
MOSH	b	3.26	0.10	3.33	5.94	2.10	5.29	38.9	388	31.5	7550
PAWT	b	17.2	1.45	5.29	18.1	23.3	9.26	1800	3880	823	40200
TENM	b	6.52	0.42	3.56	5.94	19.1	1.32	34.2	1530	55.2	2310
WOON	b	4.30	0.06	0.99	2.47	2.25	3.18	46.5	806	78.2	6080

Rankings, Storm Average											
Station	Code	Flow M-ft ³	Cd Rankings	Cr Rankings	Cu Rankings	Ni Rankings	Pb Rankings	NH4 Rankings	NO3 Rankings	PO4 Rankings	TSS Rankings
BWW21	a	42.0	1	1	1	2	1	1	1	1	2
MOSH	b	3.26	4	4	4	5	3	4	5	5	3
PAWT	b	17.2	2	2	2	1	2	2	2	2	1
TENM	b	6.52	3	3	3	3	5	5	3	4	5
WOON	b	4.30	5	5	5	4	4	3	4	3	4

Storm Average											
Station	Code	Flow %	Cd %	Cr %	Cu %	Ni %	Pb %	NH4 %	NO3 %	PO4 %	TSS %
BWW21	a	57.3	47.0	37.3	53.6	30.7	64.6	57.6	47.9	51.4	28.1
MOSH	b	4.45	2.64	15.9	8.50	3.10	9.82	0.86	3.07	1.55	9.66
PAWT	b	23.5	37.8	25.2	25.9	34.5	17.2	39.8	30.6	40.5	51.5
TENM	b	8.90	10.9	16.9	8.51	28.3	2.46	0.76	12.0	2.72	2.95
WOON	b	5.87	1.60	4.71	3.53	3.32	5.90	1.03	6.36	3.85	7.78

MOSH = Moshassuck River; PAWT = Pawtuxet River; TENM = Ten Mile River; WOON = Woonasquatucket River
a: this study BWW21 (EPA 1991-93) ; b: Estimates for other Tributaries Using Flow ratios of NBP study Wright et. al. (1988)
Total rainfall for NBP studies for three storms observed were 3.21" (October 1988 - 0.90"; May 1989 - 1.94"; June 1989 - 0.37")
Total rainfall for EPA studies for three storms observed were 2.25" (September 1992 - 0.56"; November 1992 - 0.88";
October 1993 - 0.81")

CHAPTER 9

9.0 Characterization of Non Point Loads - Runoff vs Resuspension

Loadings in a river can be divided into point and nonpoint sources. Nonpoint sources can be broadly classified into two categories: runoff and resuspension. Runoff is due to overland flow and resuspension is a result of high storm flows and velocities scouring the bottom sediments. The runoff characteristics for the pollutants is considered to be a function of total rainfall, intensity of rain, duration of storm and antecedent dry period. Land characteristics such as: land use, slope and width of catchment also influences runoff characteristics of pollutants.

A new look at an old issue, that is the reduction and/or regulation of pollutant loadings, is provided by the division of the pollutograph into its three components, baseline loadings, resuspension and storm water runoff. If significant evidence is shown as to its relative importance, management alternatives are now available to reduce runoff. Bottom sediments are a reflection of the watershed history and potential interactions of these sediments during wet weather is important.

The separation of wet load into its components becomes a regulatory concern since the management for each is quite different. The resuspended bottom sediments could account for a major portion of the loadings. A procedure is discussed in this section to separate runoff and resuspension. This procedure is demonstrated for the reach between BW07 and BW08 (Rice City Pond).

9.1 Previous Research

An attempt to assess the resuspension of materials in the Pawtuxet River due to wet weather was taken by Roy Chaudhury (1991). Wet weather contributions from surface runoff were evaluated using data collected during the 1988-89 NBP Wet Weather Study (Wright et al., 1991). The sampling occurred over a period of five days and the details of the sampling procedures and rainfall characteristics can be found in the literature cited above. The first attempt to assess the resuspension of material in the Pawtuxet River was made using the procedure proposed by Rayes (1987). The Pawtoxic model was used to develop the relationship between flow and concentration for the range of 0 - 450 cfs. Rayes suggested that if the assumption is made that these relationship are valid for higher flows, then the equations may be used to generate the mass of pollutant resuspension during a storm event. This attempt was not successful since when it was applied to flows > 450 cfs, the dry weather loadings were found to be greater than the wet weather loadings.

An attempt to predict flow and concentration relationships for dry weather flows ranging from 75 cfs to 1600 cfs was made using Pawtoxic, as an alternative to the approach by Rayes. This process involved using the average loadings from the treatment facilities and the calculation of the incremental reach flows. The details can be found in Roy Chaudhury (1991). For wet weather conditions, the prestorm sample concentration was assumed to be the equilibrium concentration. The increasing flows on the hydrograph were used to generate the baseline with resuspension mass by multiplying the flow at each sampling period by the prestorm or equilibrium concentration of the constituent. This

established a new baseline for the evaluation of runoff. Integration of the curves gave the wet weather components associated with wet weather flows - runoff and resuspension.

The distinction between runoff and resuspension should require water quality modeling under unsteady wet weather conditions. However, since unsteady-state water quality modeling is not yet state of the art and attempts at modeling have proven to be data intensive, complex and difficult to calibrate and validate, Roy Chaudhury et al. (1993) offered an alternative. They isolated runoff and resuspension loadings for TSS, Pb, Cu, and Cd for this same reach for Storm 2. Four nomographs flow to resuspended loads were generated for a range of flows using the steady-state model relating Pawtoxic developed by Wright and McCarthy (1985). The resuspended loads were estimated for the monitored flows using these curves for each wet weather sampling run. The difference between resuspended loadings at BWW07 and BWW08 provided an estimate of the reach resuspension for each sampling run. The increased resuspension load was achieved by integration of the temporal variation of this loading.

9.2 Blackstone River Application

In this section a similar procedure was followed but the base data set for flow was extended to the 1991-1993 USGS flow record for the Blackstone River. Both nomographs and regression equations for flow vs resuspension for each constituents were developed.

The Pawtoxic model essentially simulates the fate of solids and metals through adsorption/desorption coupled with bottom sediment resuspension and settling. This

model was calibrated and validated for the 1991 dry weather water quality surveys (Wright et al. 1996). For this application of the model, it was run for monthly average flow conditions for 3 year period. Incremental inflows were calculated based on the procedure discussed in Section 5 of BRI report (Wright et al. 1996). Concentrations and flows at BWW07 and BWW08 for Cr, Cu, Pb, Ni, and TSS were taken from the model output. Loadings at BWW08 and BWW07 were determined using the flow and concentration data. Loadings due to groundwater were also determined. The resultant increase or decrease in pollutant load in Rice City Pond was an estimate of resuspension:

$$\text{Mass resuspension} = \text{Mass at BWW08} - \text{Mass at BWW07} - \text{Incremental Groundwater Mass}$$

A regression was run on these data to determine a relationship for flow vs mass resuspended for each constituent (Cr, Cu, Pb, Ni, and TSS). Figure 9.1 is an example of these regression. The regression summaries are provided in Table 9.1.

The regression equations were then applied for the ranges of flows reported at the two stations over the 3 storms to obtain the resuspended loadings. The resuspended load was then added to the loading of BWW07 for each sample period to obtain the line of BWW07 plus resuspension (an example figure is shown in Figure 9.2). The area under each curve was integrated to determine the loadings. The difference between the load defined by BWW08 and that defined by BWW07 plus resuspension was equal to the estimate of runoff. This was done for all constituents for all three storms. Table 9.2 represents the resuspended and runoff loadings for each storm for Rice City Pond.

Table 9.1 Resuspended Loading Predictive Equations (Load vs Flow)

Constituents	n	a	b	R ²
Cd	36	0.02	0.60	0.85
Cr	36	0.013	0.84	0.86
Cu	36	0.54	0.39	0.63
Ni	36	0.10	0.50	0.67
Pb	36	0.0044	1.14	0.95
TSS	36	3.68	1.20	0.93

Constituent (lbs/day) = $a * [\text{flow(cfs)}]^b$

n = number of observation, R² = Coefficient of Determination

Figure 9.1 Example Plot of Regression Line of Pb for Resuspended Load vs Flow at Rice City Pond (BWW07-BWW08)

Figure 9.2 Example figure of Resuspended and Runoff Load Calculation of Pb for Storm 2 at Rice City Pond (BWW07-BWW08)

Table 9.2 Runoff and Resuspended Loads Between BWW07 and BWW08

Storm-1

Constituent	Loadings Between	Resuspension		Runoff	
	BWW07- BWW08, lbs	lbs	%	lbs	%
Cr	3.81	1.49	39.1	2.32	60.9
Cu	7.05	6.80	96.5	0.25	3.55
Ni	2.67	2.15	80.5	0.52	19.5
Pb	4.55	2.07	45.5	2.48	54.5
TSS	2500	2089	83.6	414	16.6

Storm-2

Constituent	Loadings Between	Resuspension		Runoff	
	BWW07- BWW08, lbs	lbs	%	lbs	%
Cr	11.8	4.32	36.8	7.43	63.2
Cu	25.3	14.69	58.0	10.64	42.0
Ni	13.4	4.34	32.4	9.04	67.6
Pb	22.9	7.91	34.5	15	65.5
TSS	10100	7390	73.2	2162	21.4

Storm-3

Constituent	Loadings Between	Resuspension		Runoff	
	BWW07- BWW08, lbs	lbs	%	lbs	%
Cr	18.8	3.80	20.2	14.92	79.5
Cu	25.9	12.08	46.7	13.76	53.2
Ni	13.0	5.0	38.6	7.47	57.6
Pb	36.7	7.33	20.0	29.32	80.0
TSS	29300	9049	30.9	20320	69.4

Resuspension of Cr varies between 20%-39%, Cu between 47%-96%, Pb between 20%- 46%, Ni between 32%-81% and TSS between 31%-84% (Table 9.2). On average the percent wet load associated with resuspension for each metal was: Cr - 32.0%, Cu - 67.0%, Pb - 33.7%, Ni - 51.0%, and TSS - 64.7%.

It was established in Section 6.2 that wet weather can cause acute criteria violations and the cause of higher metal concentration may be resuspension of the bottom sediments due to high flow and velocity and runoff. If we can identify the type and cause of the problem, then the regulatory agency can impose new regulations to solve the problem of pollution. This procedure, developed here, can be repeated for each hot spot identified in Chapter 8. The separation of the wet loads into runoff and resuspension components will provide us with the information whether the problem of pollution is new (runoff related) or old (resuspension of bottom sediments). The solution will be different for different cases. For example controlling the resuspension of Cu in Rice City Pond on average will reduce the concentration by 67%, which might bring down the concentration during storm events causing no violation to occur. It was thought before that wet weather problem is related to runoff only. But in this section it was proven that resuspension as well can be an important cause of the problem and controlling it may be a solution to the wet weather pollution problem. Several control alternatives may be considered, such as: dredging, cover the bad soil with new good soil, reduction of volume and velocity of water by creation of wetlands.

CHAPTER 10

10.0 Annual Loading Rates

Information developed in earlier Sections leads to the estimation of the annual loading rates. Determination of the annual loads will provide us with an idea how much pollutants are carried by the Blackstone River to Narragensett Bay each year. The annual loads were divided into two parts: contribution by dry weather flows and contribution by wet weather flows. Dry weather flow is defined as the base flow and wet weather flow is defined as the flow due to a rainfall event (flow above the base flow in the hydrograph). Annual loads were determined for the years 1991-92. USGS flow data were used for these calculations.

10.1 Dry Weather Estimates

The calibrated and validated QUAL2E Model (Wright et al. 1996) was run using the same database as in Chapter 9 (1991-1993 USGS data) for DO, NO₃, PO₄ and NH₄. The post audit of the model, by Carrelli et al. (1995), showed a very good fit for those constituents at MA/RI state line (BWW13) and end of river (BWW21) (Figures 10.1 and 10.2 shows the comparison figures for state line and end of river respectively).

The QUAL2E model was used to develop the regressions for NO₃, PO₄ and NH₄ at the MA/RI state line (BWW13) and at the end of river (BWW21). From each run of the model for a particular month and year, the flow and concentration data for each constituent at the state line and end of river were read from the output of QUAL2E.

Figure 10.1 Post Audit @ MA/RI State Line (BWW13)

Figure 10.2 Post Audit @ End of River (BWW21)

These data were regressed to find a relationship between flow and concentration. Log-log, semi-log, and arithmetic relationships were tried and with the most statistically significant results being with the log-log transformation. The results of the regression analysis is presented in Table 10.1.

The calibrated and validated Pawtoxic Model was run for trace metals with the same database as in section 9.2 (1991-1993 USGS data). Using the output of the model for BWW13 and BWW21, concentration vs flow relationship were developed, as described above, for both stations (Table 10.1). Again log-log, semi-log, and arithmetic relationships were tried and the log-log relationship was used which had the most statistically significant results.

A linear relationship of flows between Woonsocket USGS gage station and BWW13 and BWW21 was developed and compared with the measured flows at BWW21 and BWW13 during the three storm events. These relationship were developed to calculate the flow at BWW21 and BWW13 using the USGS flow gage at Woonsocket and later used in calculating the annual loading rate of the river. The relationships were as follows:

$$Q_{21} = 1.053Q_w + 20.384$$

and $Q_{13} = 0.815Q_w + 21.963$

Where Q_w = Measured Flow at Woonsocket USGS gage, cfs

Q_{21} = Calculated Flow at BWW21 (end of river), cfs

Q_{13} = Calculated Flow at BWW13 (MA/RI state line), cfs

Table 10.1 Dry Weather Predictive Equations (Concentration vs flow)

BWW21

Constituents	n	a	b	R ²
Cd	36	7.57	-0.35	0.92
Cr	36	1.04	0.14	0.48
Cu	36	45.7	-0.17	0.77
Ni	36	45.3	-0.36	0.91
Pb	36	1.17	0.21	0.86
NH4	32	2.89	-0.37	0.59
NO3	32	79.5	-0.73	0.88
PO4	32	7.36	-0.60	0.87

BWW13

Constituents	n	a	b	R ²
Cd	36	6.17	-0.31	0.91
Cr	36	0.81	0.21	0.69
Cu	36	39.2	-0.14	0.71
Ni	36	44.0	-0.35	0.90
Pb	36	0.81	0.29	0.91
NH4	32	1.67	-0.40	0.57
NO3	32	29.6	-0.60	0.96
PO4	32	3.77	-0.52	0.77

Constituent (ug/l) = $a * [\text{flow}(\text{cfs})]^b$; [for Pb, Cu, Ni, Cd, & Cr]

Constituent (mg/l) = $a * [\text{flow}(\text{cfs})]^b$; [for NO3, PO4, & NH4]

n = number of observation, R² = Coefficient of Determination

A relationship was developed by Nixon et al. (1991) for Pb, Cu, Ni, Cd, and Cr with data collected at BWW21 prior to 1990. He (Nixon) used the data collected previously by other people and relied mostly on SINBADD and SPRAY data. SINBADD data had 4 data points and SPRAY had 18 data points collected in 1985-1987. The flow vs concentrations relationships for the end of river (BWW21) were converted to flow vs load relationship (m^3/day vs kg/day) and compared with the relationships developed by Nixon et al. (1991) (Table 10.2). The model and Nixon's regression was pretty close as seen in Table 10.2, which again validate our model.

Model regression and Nixon's regression were plotted along with the six data points which were calculated using 1991 dry weather surveys (3 surveys), and base (dry) loadings for 1992-1993 wet weather surveys (3 storms). These plots suggests that our model is forecasting well. For example plot for lead is shown in Figure 10.3 and the 6-data points are closer to the line represented by the model and Nixon's regression is under estimating the Pb loadings. The Blackstone River flow may be changed due to abandonment of several dams which were active before, so the pollution pattern may change now and certain metals concentrations may increase due to resuspension of the bottom sediments at and near the old abandoned dams.

The relationships developed earlier (Table 10.1) were used to estimate the annual dry loading rates for the Blackstone River.

10.2 Wet Weather Estimates

Relationships were developed between rainfall and wet weather loadings using the

Table 10.2 Comparison Between Model and Nixon (1991) Regression @ BWW21

		Cd	Cr	Cu	Ni	Pb
MODEL	log(a)	-3.94	-6.47	-3.77	-3.12	-6.65
	b	0.65	1.14	0.83	0.64	1.21
	R ²	0.98	0.98	0.99	0.97	0.99
	n	36	36	36	36	36
NIXON	log(a)	-6.64	-6.6	-4.69	-3.07	-5.15
	b	1.09	1.15	0.94	0.7	0.93
	R ²	0.75	0.95	0.97	0.85	0.93
	n	#	#	#	#	#

Constituent (kg/day) = $\log(a) + b * \log [\text{flow}(\text{cu. m/day})]$; # = not known

Figure 10.3 Example Plot of Model Regression, Nixon Regression with 6-Real Data Points for Pb at End of River (BWW21)

data collected during the three storms (1992-93, EPA) and previous wet weather data available for the state line (BWW13) and end of river (BWW21) (Table 10.3). These data were taken from other two studies done by Wright et al. for Narragansett Bay Commission (NBC) (Wright et. al. 1991), and Narragansett Bay Project (NBP) (Wright et al., 1990). Those studies were done from 1987 to 1990. The rainfall characteristics were different for different storms and total rainfall ranged from 0.21" to 1.94". Log-log relationships were found to better represent the data than semi-log and arithmetic relationships. Regression plots were done for trace metals, nutrients and TSS. Summary tables for the regressions for BWW21 and BWW13 are presented in Tables 10.4 and 10.5, and example plots for copper are shown in Figures 10.4 and 10.5 for each station, respectively.

These equations were used to estimate the annual wet weather loading rates for the Blackstone River. The data available had a rainfall range from 0.21" to 1.94". The model equations are therefore most appropriately applied to storms within that range. If the rainfall is greater than 2", the equations will over predict the wet loadings. So, to apply the model beyond 2.0", further observations for rainfall in excess of 2.0 inches is needed to extend the predictive equations.

10.3 Determination of Annual Load

Annual loadings for 1991-92 were calculated using the equations developed in sections 10.1 (dry load) and 10.2 (rainfall events). The USGS flow data were used for these calculations.

Table 10.3 Wet load Regression Data for Rainfall vs Load for BWW21 and BWW13

BWW 21

Project	Date	Rainfall	Cd	Cr	Cu	Ni	Pb	NH4	NO3	PO4	TSS
		Inch	Lbs	Lbs	Lbs	Lbs	Lbs	Lbs	Lbs	Lbs	Lbs
EPA	Sep22, 1992	0.55	0.33	1.30	6.64	3.89	9.07	596	936	218	2170
EPA	Nov2, 1992	0.92	4.68	16.0	64.4	37.9	38.7	6970	12100	1390	4030
EPA	Oct12, 1993	0.80	0.77	5.85	30.3	14.9	21.2	374	5020	836	40700
NBP	May10, 1989	1.94	26.6	220	344	153	353	3500	60100	2630	590000
NBC	May29, 1990	1.41			144	61.3	63.9		7870	1400	223000
NBC	Jun29, 1990	0.21			0.77	0.97	4.82		167	25.5	612
NBC	Jul12, 1990	1.56			36	12.2	18.2		4400	912	22300

BWW 13

Project	Date	Rainfall	Cd	Cr	Cu	Ni	Pb	NH4	NO3	PO4	TSS
		Inch	Lbs	Lbs	Lbs	Lbs	Lbs	Lbs	Lbs	Lbs	Lbs
EPA	Sep22, 1992	0.55	1.12	0.73	2.70	2.08	2.28	92	845	72	2550
EPA	Nov2, 1992	0.92	2.24	18.9	44.9	9.77	33.6	6200	8150	673	15000
EPA	Oct12, 1993	0.8	1.36	11.5	33.2	22.8	21.1	338	4780	767	26900
NBP	May10, 1989	1.94	30.5	155	350	204	148	40600	46400	3600	207000

Table 10.4 Wet Weather Predictive Equations for BWW21 (Load vs Rainfall)

Constituents	n	a	b	R ²
Cd	4	2.93	3.55	0.92
Cr	4	16.3	4.06	0.99
Cu	7	42.1	2.53	0.90
Ni	7	21.1	2.02	0.80
Pb	7	35.3	1.52	0.67
NH4	4	1680	1.55	0.34
NO3	7	5700	2.25	0.82
PO4	7	769	1.97	0.90
TSS	7	38100	2.87	0.81

Constituent (lbs) = $a * [\text{rainfall}(\text{inch})]^b$

n = number of observation, R² = Coefficient of Determination

Figure 10.4 Example Plot of Model Regression for Load vs Rainfall for Cu at End of River (BWW21)

Table 10.5 Wet Weather Predictive Equations for BWW13 (Load vs Rainfall)

Constituents	n	a	b	R ²
Cd	4	3.78	2.79	0.93
Cr	4	15.9	4.00	0.92
Cu	4	43.0	3.63	0.93
Ni	4	21.6	3.45	0.91
Pb	4	26.7	3.10	0.90
NH4	4	1120	2.90	0.58
NO3	4	7520	3.06	0.96
PO4	4	718	2.85	0.88
TSS	4	26200	3.29	0.92

Constituent (lbs) = $a * [\text{rainfall}(\text{inch})]^b$

n = number of observation, R² = Coefficient of Determination

Figure 10.5 Example Plot of Model Regression for Load vs Rainfall for Cu at State Line (BWW13)

Flows at BWW21 and BWW13 were calculated using flow relationship developed in section 10.1. Spreadsheets were prepared to separate the base flow for each station for the whole year. For this purpose, monthly hydrographs were drawn for each year per station. These hydrographs were compared with the equivalent daily rainfall data to determine the influence of wet weather. During a storm period, the baseflow was separated using the equation:

$$N = 1.0 A^{0.10}$$

Where N = number of days from the peakflow

and A = cumulative drainage area, sq. mile

The equivalent rainfall was calculated by using Thesian Method (Chapter 4) for each day of the rainfall event for the entire watershed of the Blackstone River.

The equations developed in section 10.1 were applied to the base flow for each day of the year to calculate the dry load for that day. The sum of the loadings gave the annual dry load.

Rainfall data for all the NWS stations (Table 4.2) for the entire basin of the Blackstone River were available (Climatological Data of New England 1991-1992, NOAA). Most of the rainfall data available were daily, so daily equivalent rainfall was used. The calculated equivalent rainfall for the Blackstone River watershed was used along with the equations developed in section 10.2 to come up with the estimate of wet loadings for the event for that day. This was repeated for each day of the year which had rainfall records. All calculated wet loads for the year were summed to obtain wet load contributions for the year.

Total loadings for a particular year were determined by adding wet loads with dry loads for that year as calculated above. Table 10.6 represents the summary of the annual loadings for 1991-92.

10.4 Load at State Line and End of River

Annual wet weather loads as a % of the total load at the state line (BWW13) were: Pb - 22%-28%, Cu - 16%-24%, Ni - 23%-32%, Cd - 18%-22%, Cr - 31%-44%, NO_3 - 38%-46%, PO_4 - 21%-26%, and NH_4 - 30%-37%. Wet weather related loadings as a % of total load discharged to Narragansett Bay (BWW21) were: Pb - 18%-19%, Cu - 9%-11%, Ni - 13%-15%, Cd - 17%-25%, Cr - 30%-44%, NO_3 - 21%-25%, PO_4 - 14%-16%, and NH_4 - 17%-18%.

Percent wet load at BWW13 was higher than that at BWW21 for all constituents. Cr had highest % wet load followed by NO_3 and Ni at BWW13 for 1991, but NO_3 was followed by Cr and NH_4 for 1992. Cr had highest % wet load followed by Cd and NO_3 at BWW21 for 1991, but Cr was followed by NO_3 and Cd for 1992.

The determination of annual loadings is important. Estimation of the annual loadings at BWW13 gave us an idea of how much pollutants were delivered to Rhode Island border line by the Massachusetts portion of the Blackstone River. The estimated loadings at BWW21 provided us with the information of pollutants delivered to Narragansett Bay by the Blackstone River. The division of the annual loadings into dry and wet loadings provided the contribution by base loadings and the wet weather loadings. Percent wet load delivered by Blackstone River to the Narragansett Bay was less than

Table 10.6 Annual Mass Loading Forecast Summary for Blackstone River at State Line (BWW13) and End of River (BWW21)

Constituent	Year	Equivalent	BWW13		BWW21	
		Yearly	Dry	Wet	Dry	Wet
		Rainfall	Load	Load	Load	Load
		(in)	(%)	(%)	(%)	(%)
Cd	1991	49.2	78.1	21.9	74.7	25.3
Cr	1991	49.2	55.8	44.2	55.9	44.1
Cu	1991	49.2	76.4	23.6	89.3	10.7
Ni	1991	49.2	68.1	31.9	84.9	15.1
Pb	1991	49.2	72.0	28.0	81.5	18.5
NH4	1991	49.2	62.8	37.2	82.2	17.8
NO3	1991	49.2	53.5	46.5	75.3	24.7
PO4	1991	49.2	74.1	25.9	84.1	15.9
Cd	1992	47.3	82.4	17.6	82.6	17.4
Cr	1992	47.3	69.0	31.0	69.8	30.2
Cu	1992	47.3	83.9	16.1	91.1	8.9
Ni	1992	47.3	76.8	23.2	86.5	13.5
Pb	1992	47.3	77.7	22.3	81.8	18.2
NH4	1992	47.3	69.6	30.4	83.0	17.0
NO3	1992	47.3	62.2	37.8	78.8	21.2
PO4	1992	47.3	79.5	20.5	85.9	14.1

50% for all constituents but wet load is significant if we compare the number of the days of the year that wet weather events occur to the number of days in a year.

CHAPTER 11

11.0 Summary of Wet Weather Interpretation - Conclusions and Recommendations

Wet weather water quality of the Blackstone River was analyzed. The two flow charts presented in Figures 5.1 and 5.2 describe the procedure at a glance. Three wet weather events were successfully captured for wet weather program: Storm 1 (September 22-24, 1992), Storm 2 (November 2-5, 1992) and storm 3 (October 12-14, 1993). Grab samples were collected at specific time intervals throughout the Blackstone River watershed. In Chapter 5, the concentrations and EMC's (event mean concentration) for different constituents were determined. Chapter 6 deals with violations and toxicity. Two types of violations were compared for fecal coliform violations in the Blackstone River: Violations A (log mean > 200 md/100 ml) and Violations B (10% of samples exceeding 400 md/100 ml). Acute and chronic criteria were compared with the concentrations measured for trace metals to come up with the violations. These criteria are used to protect the public health and the environment.

Chapter 7 uses the concentration data from Chapter 5 and flow data from Chapter 4 to calculate the mass loadings. A comparison of wet and total loadings were shown and tributary wet load rankings were provided. Net gains and losses per reach was calculated and major point sources and non point sources were compared.

System ranking and hot spot identification is provided in Chapter 8 using the information from earlier chapters. A procedure is developed in Chapter 9 to separate runoff and resuspension. This procedure is demonstrated for the reach between BWW07

(Rice City Pond). This reach appears to be a major source of resuspension. An estimate of annual loadings at the MA/RI state line and end of river is provided in Chapter 10. Information developed in earlier chapters leads to the estimation of the annual loads carried by the Blackstone River to Narragansett Bay. For calculation purposes the annual loads were divided into two parts: contribution by dry weather and contribution by wet weather. Total loadings for a particular year were determined by adding wet loads with dry loads for that year.

11.1 Research Questions

Can wet weather impact the water quality of the Blackstone River?

Absolutely yes. The analysis of the concentration data collected prior to the storm, during the storm and several hours after the storm supports this. In Chapter 5 it was found that, for UBWPAD there was no violation of maximum ammonia discharge during dry weather conditions but violations did occur in two out of three storms during wet weather (Storm 1 and Storm 3). In Figure 6.1 during peak flow between time 0 and 6 hours, fecal coliforms get by the UBWPAD without instream disinfection. This is probably due to the higher flows at the WWTF and the lower chlorine residual concentrations. Significantly more stations had FC violations under wet weather than dry weather which is clear from Table 6.1.

Wet weather cause acute criteria violations. Figure 6.2 illustrates just such a violation. During the height of the storm, instream hardness drops resulting in lower acute criteria concentrations. The more stringent criteria typically coincided with maximum

instream concentrations. The result is the possibility of short term violations. The cause of higher metal concentration may be resuspension of the bottom sediments due to high flow and velocity, runoff, or poor performance of treatment facilities, subjected to increased flow during the storm. Acute and chronic criteria violations are summarized in Table 6.2. From the above discussion it is clear that wet weather can impact the water quality of the Blackstone River.

What are the major wet weather pollutant sources and/or areas in the Blackstone River watershed?

Pollutants associated with wet weather may come from either new sources (runoff induced) or old sources (river sediments). It is important to note that the former may be easier to control and regulate than the later. The water quality data coupled with stream flows allow for the calculation of mass loading curves. Each mass loading curve was integrated to obtain the total load (e.g. lbs) for each station for each storm. The total mass was divided by the time of the event to obtain the total loading for that constituent (e.g. lbs/day) for each station. Baseline loading rates (dry load in lbs/day) were estimated for each pollutograph from the initial (pre storm) sample and the final (post storm) samples. These rates were multiplied by the time of the event to obtain the total dry load for that station (lbs). The wet load (lbs) per station per constituent was determined by subtracting the dry load from the total. The data indicate clearly that with only minor exceptions more wet load entered the River during these periods than dry load.

Based on the loading estimates an estimate of pollutant gain or loss by reach was

made. Net pollutant changes in a reach help to identify locations of major pollutant sources. The results of this evaluation also provides insight into the relative importance of each reach through a system ranking. A system ranking was made using the net gains for each reach and loads from the point sources, headwaters and tributaries. The ranking for each storm was calculated for both wet and total loads. The percent loadings by each reach section, headwater and point sources were averaged to get the summary % loadings contribution and ranking was done again to come up with the summary rankings for all three storms. The ranking, without point sources for the wet load, were also calculated for each storm. The summary of rankings for wet load is provided in Table 8.1, total load in Table 8.2, and that of rankings without point sources in Table 8.3. These tables lists the major wet weather pollutant sources and/or areas in the Blackstone River watershed. A comparison of wet and dry weather sources for different constituents is provided in Table 8.4.

How to forecast the annual wet weather loading rates to the Blackstone River?

The information collected during wet weather sampling program provided insights into the behavior of the sources during varying storm conditions. A relation ship was developed between rainfall and wet loadings using the data collected during the three storms (1992-93, EPA) and previous wet weather data available for the state line (BWW13) and end of river (BWW21) (Table 10.3). Regression plots were done for trace metals, nutrients and TSS. Summary tables for the regressions for BWW21 and BWW13 are presented in Tables 10.4 and 10.5, and example plots for copper are shown in Figures

10.4 and 10.5 for each station, respectively.

These equations were used to estimate the annual wet loading rates for the Blackstone River. The data available had a rainfall range from 0.21" to 1.94". The model equations are therefore most appropriately applied to storms within that range. If the rainfall is greater than 2", the equations will over predict the wet loadings. So, to apply the model beyond 2.0", further observations for rainfall in excess of 2.0 inches is needed to extend the predictive equations.

How the dry and wet weather programs are linked together?

The dry weather data was sufficient to permit the calibration and verification of a model to describe trace metal transport as well as a model for dissolved oxygen (Wright et al., 1996). The dry weather models were used to estimate baseline mass loadings under steady state flow. The relationships developed in Table 10.1 were used to estimate the annual dry weather contributions at MA/RI state line (BWW13) and end of the river (BWW21). These dry weather loadings can be compared with the annual wet weather loadings. In the long run this is exactly what is needed to allow decisions into pollutant control. Addition of dry and wet loads will give the total annual load for a particular year.

11.2 Conclusions

The following conclusions were drawn from the results of this study:

Nitrification

- UBWPAD's ability to provide nitrification is inhibited under high storm flows. The

facility discharges significant levels of ammonia under these conditions.

- In reaches experiencing nitrification under dry weather steady-state condition, nitrification may be inhibited due to high storm flows.
- In reaches not experiencing nitrification under dry weather condition, nitrification may occur due to transient storm related ammonia loads which occur in upstream reaches.

Concentration

- Under high storm flows, high ammonia concentrations occurs in the reaches around Rice City Pond.
- UBWPAD had no violation of maximum ammonia concentrations discharge of 2.5 mg/l under dry weather surveys, but under wet weather conditions violation of ammonia concentrations did occur in two out of three storms.
- WOON has no permitted discharge requirement for ammonia.
- Phosphorous concentrations are dominated by the two point sources UBWPAD and WOON.
- There is no permit requirement for either UBWPAD or WOON for phosphorous.
- The two treatment facilities are major contributors of metals to the Blackstone River. For the UBWPAD several metals were influenced by the higher storm flows through the facility. A comparison of average concentrations between dry and wet weather conditions lead to the following observations: chromium concentrations doubled under storm flows; cadmium and lead concentrations

decreases under storm flows and copper and nickel did not change significantly.

- A comparison of maximum wet weather and dry weather concentrations lead to the following observations: for chromium wet weather was significantly higher; for cadmium dry weather was significantly higher and for lead, copper and nickel the ranges were not dissimilar.
- Since Woonsocket WWTF is located downstream of the river, so the flow in the river is much higher compared to the flow discharged by Woonsocket facility and the dilution is much higher also. As a result the high concentration discharged by Woonsocket get diluted and has less effect than UBWPAD on the river water quality.
- Headwaters have high concentration of Pb.

Event Mean Concentration (EMC) and Event Mean Mass (EMM)

- The EMC and EMM profiles reflect the operation of UBWPAD with respect to nitrification. It was established earlier that nitrification was being provided at the facility during storm 1 and 3. The instream data supports this with high nitrate EMC and EMM below UBWPAD and comparatively low ammonia levels. The reverse is true for Storm 2 when nitrification was not being provided at the facility.
- The increase in ammonia EMC and EMM between BWW17 and BWW18 are due to the Woonsocket WWTF discharge.
- For phosphorous the headwater concentrations are generally very low. There are major increases in the EMCs and EMMs between BWW01 and BWW02 and

between BWW17 and BWW18 reflecting the two major treatment facilities.

- There is an interesting pattern for TSS profiles between BWW01 and BWW02 which again supports the operation of nitrification in the UBWPAD. With nitrification indicating a much higher retention time within the facility solids removal is often better. During Storm 1 and 3 where nitrification was occurring the TSS EMC profiles actually show a decline between BWW01 and BWW02. Storm 2 provides a different result reflecting the higher solids load from the UBWPAD when nitrification was not occurring. In that TSS EMC's were the highest for Storm 2 just below the UBWPAD discharge.
- The sharp decreases in the instream FC and EC EMCs and EMMs below the UBWPAD (between BWW01 and BWW02) for Storms 1 and 3 are most likely due to residual chlorine in the facilities effluent. This was not the case in Storm 2, where higher stream flows resulted in lower residuals. In fact, FC and EC concentrations increases to their highest levels in the reaches immediately below UBWPAD. The impact could be felt as far as BWW08.
- Similar increases of FC and EC are evident in the Woonsocket area including the WWTF and just below it.
- EMCs and EMMs for BOD had a similar trend for all three storms. Generally it increases after UBWPAD discharge and decreases to the mouth of the river. BOD does not appear strongly influenced by the storm related sources and therefore appears governed by point sources.
- Compared to the other metals, lead's (Pb) major source appears to be in the

headwaters (above BWW00). In fact, the headwater EMCs and EMMs are typically the highest along the entire river. The most probable cause would be urban runoff from Worcester.

- A consistent increase of lead does appear between BWW07 and BWW08 in Rice City Pond and is probably due to sediment resuspension.
- The other 5 metals (Cd, Cr, Cu, Ni and Zn) have similar EMC and EMM profiles in that there appears to be two distinct peaks. The first occurs in the reaches below UBWPAD and is associated with the wastewater facilities discharge and possibly other non point sources of metals, such as Patriots Metals. A secondary peak consistently occurs around BWW08, again the probable cause is sediment resuspension within Rice City Pond.

Acute/Chronic Violation

- High flows moving through Rice City Pond cause violations in the reaches at and below the dam due to resuspension.
- Cu is continually violated both with respect to chronic and acute criteria in both dry and wet weather starting at station BWW02.
- Pb chronic violations are continuous violation with respect to both dry and wet weather.
- Cd violations are more limited but also begins in and around BWW02.
- Ni and Cr has no acute and chronic violations under dry and wet weather.
- More stations had violations under wet weather than dry weather

- More violations occurs if the storm event is bigger.

FC Violation

- The high loading at headwaters seems to be the main cause of problem of fecal coliform under both dry and wet weather. Loading may come from nonpoint source triggered by the wet weather. Further study of the collection system of Worcester is recommended.
- Residual chlorine from UBWPAD seems to perform poorly at peak flows under wet weather

Mass Loading

- Most of the constituents have more than 50% wet loadings except for Ni and NO₃.
- The trend of high wet load as the storm intensity increases is true for almost all the constituents except NH₄.
- Headwaters has high % wet loads for most of the constituents and the %wet load decreases as we move towards the mouth of the river.
- Blackstone River is the highest contributor of pollutants to the Narragansett Bay.

Point and Non-Point Sources

- NH₄ and PO₄ are dominated by point sources.
- Cd, Cr, Cu, Pb, Ni, Zn, TSS, FC, NO₃, and BOD are dominated by non-point sources.

System Rankings

- Major source of Pb in both wet and dry weather appears to reside in the headwater.
- First five rankings represents 70%-90% of the total loadings for both wet and dry weather except for dry TSS (51%), and wet NO₃ (53%).
- UBWPAD is the major source of Cu (35% for dry, 18% for wet), Ni (47% for dry, 33% for wet), and Cd (37% for dry, 15% for wet) for both dry and wet weather.
- Headwater is the major source of Pb for wet weather.
- WOON appears 3 times within first five rankings for 5 trace metals for dry weather but does not appear within first five rankings during wet weather.
- Head water is a major source of metals for wet weather but not for dry weather.
- Resuspension in Rice City Pond is a major source of metals for both wet and dry weather.
- TSS is mostly non-point source governed loadings.
- UBWPAD, and WOON are major sources of nutrients and WOON is responsible for 68% loads for NH₄ under dry weather.

Resuspension

- Resuspension is an important phenomena in Rice City Pond.
- Cu, Ni, and TSS have more than 50% resuspension in Rice City Pond during wet weather events.
- Cr, and Pb have less than 50% resuspension in Rice City Pond during wet weather

events.

Annual Loading Rate

- Log-log relationship represents the data better for both rainfall vs loadings for wet load and flow vs concentration for dry load.
- To apply the model beyond rainfall of 2.0", further observation data points for rainfall and loads needs to be added to the database and again predictive equations can be developed.
- When our model and Nixon's regression model were compared against 6-data points, our model was found to forecast better for trace metals.
- Post audit of the model tells that model is forecasting well for nutrients.
- Percent wet load at BWW13 is higher than that at BWW21.
- Percent wet load delivered by Blackstone River to the Narragensett Bay is less than 50% for all constituents.
- Wet load is significant if we compare the number of the days of the year that wet weather events occur to the number of days in a year.

11.3 Recommendation

- complete a study of the headwaters (above BWW00) in detail under wet weather conditions, specially for Pb, FC, EC and solids.
- complete a study to determine the sources in Worcester's stormwater collection system for Pb, FC, EC and solids under wet weather conditions.

- The reach between BWW02 and BWW04 should be studied in detail.
Contribution of the local metal processing operations, located in this reach, need further study to determine their role in the problem.
- UBWPAD effluent violates the discharge permit for ammonia during wet weather events. Nitrification and disinfection is not efficient during the height of the storm (peak volume passing through the facility). Further study to determine operational change at the UBWPAD during the wet weather events is needed.
- Similar studies, as done on Rice City Pond (Wright et. al. 1996) should be done on other impoundments.
- Wetlands may be created along the river to store the flood water and reduce the velocity of flow which might solve the problem of resuspension.
- Some of the tributaries may be further studied for wet weather events.
- UBWPAD effluents may be discharged further downstream where dilution is greater.

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APPENDIX - A

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Table A.1 Water Quality Data for Storm 1

Station	Run	Date	Time	Flow cfs	Temp deg C	pH	Cond umhos/cm	DO mg/L	BOD mg/L	TSS mg/L	VSS mg/L	Cl mg/L	Ca mg/L	Mg mg/L
BWW00	P	9/22/92	1142	15.3	18.5	6.84	255	8.4	3.8	2.4	1.6	59.6	22.1	3.35
BWW00	0	9/22/92	2348	38.3	20	6.76	182	8.3	2.95	1.3	0.7	65.5	20.9	3.52
BWW00	3	9/23/92	0250	172	20	6.12	132	8.4	6.6	3.4	1.8	45.5	12.1	2.31
BWW00	6	9/23/92	0540	59.5	18.8	6.6	101	7.9	4.9	15.4	6.4	27.5	9	1.67
BWW00	9	9/23/92	0816	53.7	18.2	6.17	97	8.4	3.95	11	4	30.1	9.5	1.75
BWW00	12	9/23/92	1115	43.1	18.3	6.24	124	9.1	1.8	7.4	3	35.1	12.8	2.29
BWW00	16	9/23/92	1536	33.8	19.2	6.47	154	8.8	0.5	6.8	2.8	44.3	18.2	2.9
BWW00	24	9/23/92	2319	21.9	16.5	NA	183	8.85	1.5	5.6	1.6	54.2	19.6	3.28
BWW00	32	9/24/92	0722	15.3	15	6.52	181	7.3	0.6	8	2.6	49.1	18.7	3.43
BWW00	40	9/24/92	1516	21.9	16	6.68	196	7.3	1.3	3.2	2.6	58.7	19.5	3.23
BWW01	P	9/22/92	1200	16.5	18.8	6.66	260	8.4	6.35	2.6	2.2	208	26.7	3.87
BWW01	0	9/23/92	0005	41.2	19.8	6.36	240	7.5	10.3	3.4	2.4	188	23.5	3.97
BWW01	3	9/23/92	0305	185	19.1	6.58	176	6.3	7.95	26.4	8.8	72.4	18.2	3.6
BWW01	6	9/23/92	0545	64	18.5	6.65	186	7.5	4.06	11.4	5.2	57.3	18.1	3.44
BWW01	9	9/23/92	0830	57.8	18.2	6	169	7.8	3.35	6	3.4	55.9	16	2.87
BWW01	12	9/23/92	1130	46.4	18.5	6.18	270	8.8	2.8	5.2	2.8	94.9	17.3	3.66
BWW01	16	9/23/92	1545	36.3	18.9	6.43	218	8.2	2.55	4	2.4	65.5	19.7	3.48
BWW01	24	9/23/92	2331	23.5	16.4	NA	238	8.15	1.5	2.8	0.6	70.2	22.6	3.87
BWW01	32	9/24/92	0733	16.5	14.8	6.56	242	7.2	1	3.8	1.8	74.1	23.8	3.89
BWW01	40	9/24/92	1531	23.5	16	6.66	328	7.2	2.45	2.2	2.2	82.1	25	4.01
BWW02	P	9/22/92	1216	73.3	20.8	6.45	440	7.7	8.7	9	4.5	131	25	3.66
BWW02	0	9/23/92	0025	107	20.4	6.48	333	7.3	7.95	4.2	3	136	26.2	3.47
BWW02	3	9/23/92	0330	268	20.5	6.18	240	6.8	8.3	7.8	5.6	87.4	23.6	3.56
BWW02	6	9/23/92	0615	156	19.5	6.54	271	7.1	7.1	14.2	5.6	95.4	21	3.52
BWW02	9	9/23/92	0848	142	19.8	6.26	258	7.5	6.3	7.2	4.4	77	19.6	3.14
BWW02	12	9/23/92	1150	118	20	8.11	230	8.3	2.4	5.4	3.8	67.3	17.2	2.85
BWW02	16	9/23/92	1545	88.9	20	6.15	251	7.8	2.7	5.8	3.4	75.7	17.4	2.82
BWW02	24	9/23/92	2346	49.6	17.5	NA	306	7.45	5.8	4.8	3.4	80.4	20.1	2.99
BWW02	32	9/24/92	0755	49.6	16.5	6.27	319	8	1.15	5.3	3.8	77.9	21.9	3.47
BWW02	40	9/24/92	01545	80.7	18.2	6.45	332	8	2.45	5.8	4.2	93.6	23.9	3.38
BWW04	P	9/22/92	1238	79	20	6.84	455	8.65	8.3	5	4.2	106	23.7	3.59
BWW04	0	9/23/92	0059	93	20.7	6.7	313	8.15	1.75	33.8	11.6	110	23.3	3.37
BWW04	3	9/23/92	0400	182	20	6.7	310	8.6	8.55	35.8	15.2	104	18.5	3.07
BWW04	6	9/23/92	0655	245	19.2	6.65	277	8.3	7.85	23.6	8.8	78.8	19.9	3.05
BWW04	9	9/23/92	0915	163	19.4	6.95	255	9	6.2	10.2	5	81.6	19.3	3.02
BWW04	12	9/23/92	1215	144	20	6.52	270	9.2	1.05	7.6	4.8	79.3	19.9	3.2
BWW04	16	9/23/92	1630	116	20.8	6.49	252	8.6	3.45	3.8	1.8	74.6	19.9	3.1
BWW04	24	9/24/92	0008	80	17	NA	253	9.05	3.35	2.4	1.6	73.2	18	2.85
BWW04	32	9/24/92	0820	53	15.2	6.61	300	8.9	3.55	1.5	0.8	80.9	19	2.85
BWW04	40	9/24/92	1605	66	17.2	6.72	316	8.7	2.15	2.8	2.8	68.8	22.2	3.22
BWW05	P	9/22/92	1312	4.5	20.7	7.3	215	10.2	NA	1.5	1.5	70.6	19.3	3.37
BWW05	0	9/23/92	0147	3.8	19.8	6.61	182	7.15	NA	1.7	1.3	74.4	18.7	3.22
BWW05	3	9/23/92	0440	6.2	19.2	6.41	192	7	NA	1.4	1	75	18.9	3.33
BWW05	6	9/23/92	0725	6.2	18.5	6.52	199	7.2	NA	1.4	1.2	80.9	19	3.42
BWW05	9	9/23/92	0945	7.9	18.8	6.48	199	9.2	NA	0.8	0.6	70.2	19	3.43
BWW05	12	9/23/92	1245	9.3	19	6.4	202	9.6	NA	1.6	1	67.4	19.2	3.41
BWW05	16	9/23/92	1645	9.3	19.3	6.27	198	8.6	NA	1.4	1	63.3	18.9	3.44
BWW05	24	9/24/92	0038	6.7	17.5	NA	216	8	NA	0.5	0.5	66	18.8	3.37
BWW05	32	9/24/92	0855	5.6	16	6.31	209	8.5	NA	2.5	2.5	63.4	19.3	3.41
BWW05	40	9/24/92	1639	5.1	17.5	6.66	201	8.9	NA	2	2	70.6	19	3.44
BWW06	P	9/22/92	01257	79.7	19.8	6.66	380	8.3	4.85	3.8	1.8	89.2	22	3.22
BWW06	0	9/23/92	0119	67.4	20.5	6.68	303	7.8	8.4	7.5	5.3	105	21	3
BWW06	3	9/23/92	0440	110.8	20.5	6.58	304	7.7	6.05	11.4	6.8	78.8	21.5	3.07
BWW06	6	9/23/92	0715	110.8	19.2	6.49	313	7.8	2.9	9.8	3.8	75.9	21.3	3.01
BWW06	9	9/23/92	0935	141.3	19.2	6.31	316	8.5	5.3	9.4	3.8	95.9	20.8	2.83
BWW06	12	9/23/92	1230	165.7	20	6.34	289	8.4	4.2	8.4	3.6	83.4	19.9	2.89
BWW06	16	9/23/92	1700	165.7	20.1	6.54	262	8.7	3.85	7	2	73.4	19.7	2.76
BWW06	24	9/23/92	0020	120.2	17.5	NA	270	8.5	3.25	2.8	1.6	72	18.5	2.7
BWW06	32	9/24/92	0835	100	15.7	6.54	260	8.7	2.35	7	3.5	76.3	18.3	2.68
BWW06	40	9/24/92	1625	90	16.5	6.81	268	8.5	3.85	5.2	2.8	79.5	18.8	2.58
BWW07	P	9/22/92	1500	107	20.5	6.65	350	8.6	3.05	1.8	1.4	88.4	21.4	3.06
BWW07	0	9/22/92	0130	95	21	6.7	332	9.2	3.2	6.2	2.8	83.1	21.3	3.09
BWW07	3	9/23/92	0415	99	20.8	6.68	345	9.1	3.45	6.2	2.8	85.1	20.9	3.07
BWW07	6	9/23/92	0715	101	19.5	6.47	338	8.35	2.3	8.8	2.6	74.8	20.8	3.22
BWW07	9	9/23/92	1040	103	19.2	6.55	325	7.8	2.2	9.6	3.4	82.2	21.3	3.13
BWW07	12	9/23/92	1405	104	19.8	6.49	335	9.2	2.75	9	4.8	80	21.6	3.1
BWW07	16	9/23/92	1640	111	20	6.25	360	8.85	1.5	3.2	1.8	86.8	21.3	3
BWW07	24	9/23/92	0055	123	18.5	NA	330	9.4	2.1	12.4	4.8	89.9	20.1	3.09
BWW07	32	9/24/92	0850	120	18.5	8.41	290	8.1	2.2	11	2.4	78.9	20.2	3.05
BWW07	40	9/24/92	1735	123	17.3	7.06	292	8.4	2.35	4	2.4	71.4	19.3	2.8
BWW08	P	9/22/92	1440	109	21	6.74	338	9.9	2.95	6.2	2.6	90.3	19.6	3
BWW08	0	9/22/92	0110	124	20.5	6.45	322	7.7	3.65	11.8	3.8	67.2	19.5	2.92
BWW08	3	9/23/92	0350	129	20	6.79	315	7.1	5.2	18.2	6	83.2	18.9	3.05
BWW08	6	9/23/92	0700	115	19.5	6.62	310	7.55	3.55	17.2	4.4	72.8	17.5	2.7
BWW08	9	9/23/92	1005	111	19	6.35	320	7.65	1.85	11	3.6	80.1	20.3	3.16
BWW08	12	9/23/92	1320	108	20	6.45	330	9.25	2.45	4.8	1.4	81	19.8	3.13

Table A.1 Water Quality Data for Storm 1 (Continued)

Station	Run	Date	Time	Flow cfs	Temp deg C	pH	Cond umhos/cm	DO mg/L	BOD mg/L	TSS mg/L	VSS mg/L	Cl mg/L	Ca mg/L	Mg mg/L
BWW08	16	9/23/92	1620	125	20	6.41	312	9.3	2.1	3.4	1.9	77.2	20.6	2.99
BWW08	24	9/23/92	0040	130	17.5	NA	325	8.3	2.2	12.6	4.6	90.4	20.2	3.05
BWW08	32	9/24/92	0825	136	16	6.41	290	8.45	2.1	10	2.4	85.8	19.1	2.86
BWW08	40	9/24/92	1725	136	17	7.06	315	7.8	2.4	2.6	2.1	82.8	19.3	2.93
BWW09	P	9/22/92	1415	11.5	21	6.31	108	10.4	1.85	1.8	1.4	42.4	6.7	1.7
BWW09	0	9/22/92	0050	12.0	22	5.94	105	9.4	1.4	2	2	42	6.5	1.66
BWW09	3	9/23/92	0330	14.2	21.2	6.7	110	9.6	1	0.8	0.8	29	6.8	1.78
BWW09	6	9/23/92	0630	14.8	19.8	6.49	105	9.5	ND	ND	ND	24.4	6.7	1.78
BWW09	9	9/23/92	1025	13.6	19.5	6.73	95	9.5	ND	2	1	25.5	6.8	1.75
BWW09	12	9/23/92	1330	12.5	20	6.24	95	10.3	1.4	2	2	26.3	6.5	1.65
BWW09	16	9/23/92	1600	12.0	20.5	6.18	100	10.5	ND	1	1.2	21.2	6.4	1.67
BWW09	24	9/23/92	0022	11.5	18	NA	95	10.5	ND	1.4	0.6	27.2	6.6	1.71
BWW09	32	9/24/92	0815	11.0	16	6.22	90	10.2	ND	4.2	2.2	25.7	6.8	1.78
BWW09	40	9/24/92	1655	9.29	17	6.9	82	7.2	ND	2	1	27.2	6.4	1.65
BWW10	P	9/22/92	1430	7.64	19.5	6.28	170	9.6	NA	2.3	1.9	62.4	8.2	1.96
BWW10	0	9/22/92	0100	7.94	20	6.19	170	8.85	NA	4	3.5	47	7.9	1.93
BWW10	3	9/23/92	0340	9.42	19	6.83	160	8.85	NA	2.8	1.8	55.5	7.9	1.85
BWW10	6	9/23/92	0645	9.07	18	6.05	150	8.85	NA	0.8	0.8	47	8	1.92
BWW10	9	9/23/92	1010	9.07	17.5	6.89	140	8.9	NA	ND	ND	47	7.6	1.82
BWW10	12	9/23/92	1330	9.24	18	6.17	160	9.5	NA	3.8	2.2	51.6	7.9	1.93
BWW10	16	9/23/92	1550	9.24	18	6.01	150	10	NA	1.2	ND	45.6	7.7	1.88
BWW10	24	9/23/92	0030	9.24	16	NA	155	9.3	NA	9.2	2.8	51.7	8.3	2.06
BWW10	32	9/24/92	0825	8.74	14.8	6.22	150	9.4	NA	3.2	1	47.9	8.2	1.96
BWW10	40	9/24/92	1705	8.90	16.1	6.9	145	7	NA	1.5	1.5	58	8.2	1.95
BWW11	P	9/22/92	1400	133	20.2	6.56	285	10.4	6.1	2.8	1.8	87.7	17.4	2.79
BWW11	0	9/22/92	0040	142	21	6.81	252	8.65	2.25	6	2.2	64	16	2.81
BWW11	3	9/23/92	0315	173	20.5	6.57	265	8.6	2.15	7.6	2.8	71.9	16	2.89
BWW11	6	9/23/92	0615	160	20	6.58	265	8.45	1.95	11.2	3.6	59.1	15.7	2.6
BWW11	9	9/23/92	0950	156	19.2	6.44	245	8.7	1.05	4.2	2.4	66.3	16.3	2.57
BWW11	12	9/23/92	1310	162	20	6.52	260	9.7	2.45	6.4	3.8	65.6	16.5	2.6
BWW11	16	9/23/92	1540	155	20	6.24	255	9.7	1.8	3.6	2	63.6	16.3	2.75
BWW11	24	9/23/92	0010	148	18	NA	255	9.05	1.6	4.4	4	68	16.8	2.78
BWW11	32	9/24/92	0805	168	18	6.31	260	9.2	1.7	4.2	1	69.3	17.1	2.82
BWW11	40	9/24/92	1645	177	17	6.77	288	6.5	1.95	3.8	2.4	82.1	17.6	2.85
BWW13	P	9/22/92	1340	169	20.5	6.77	260	11	5.3	2.6	2.8	72	15.2	2.53
BWW13	0	9/22/92	0015	188	20.5	6.56	230	10	1.75	3.2	1.2	62.9	13.6	2.28
BWW13	3	9/23/92	0300	232	20	6.81	255	9.85	1.8	4.4	2.2	68.1	14.3	2.42
BWW13	6	9/23/92	0550	214	19.5	6.47	245	10.2	1.3	2.8	1	56.7	13.6	2.43
BWW13	9	9/23/92	0930	205	18.6	6.32	220	10.2	1.25	2.6	1.6	59	14.2	2.42
BWW13	12	9/23/92	1250	209	19.2	6.4	215	10.5	1.8	5.2	1.4	60.4	13.4	2.46
BWW13	16	9/23/92	1525	200	20.2	6.31	235	10.8	1.3	3.4	3.2	55.2	13.6	2.42
BWW13	24	9/23/92	2358	192	16	NA	220	10.1	1.15	4.2	2.6	56.6	13.2	2.38
BWW13	32	9/24/92	0850	210	16.5	6.2	190	10.6	1.25	4	1.6	50.6	12.6	2.24
BWW13	40	9/24/92	1625	216	18	6.74	258	8.6	1.25	4	3	68	15.9	2.62
BWW14	P	9/22/92	1530	32.8	21.6	6.59	102	10	ND	ND	ND	29.6	4.4	1.21
BWW14	0	9/22/92	0150	42	21	6.4	100	8.85	1.75	6	3.5	27.8	4	1.09
BWW14	3	9/23/92	0440	54.7	20.5	6.66	95	9.55	1.55	2.8	1.4	22.5	4.2	1.09
BWW14	6	9/23/92	0750	50.1	19.5	6.65	90	9.7	ND	1.6	1	22	4.2	1.13
BWW14	9	9/23/92	1100	46.1	19.5	6.64	85	10.1	ND	1	ND	23.9	4.2	1.12
BWW14	12	9/23/92	1430	42.8	19.8	6.13	85	10.4	ND	2.2	1.2	21.1	4.1	1.1
BWW14	16	9/23/92	1650	41.5	20.5	6.2	85	10.6	1.05	1	1	18.4	4.1	1.12
BWW14	24	9/23/92	0120	40.6	18	NA	90	9.8	ND	2.4	0.8	21.3	4.1	1.14
BWW14	32	9/24/92	0910	39.8	16.5	6.16	82	10.3	ND	4.4	1.6	20.1	4.3	1.15
BWW14	40	9/24/92	1755	36.4	17.2	6.32	84	6.2	ND	1	1	23.5	4.3	1.17
BWW15	P	9/22/92		6.30	22	6.81	165	8.4	NA	2	2.4	44.6	7.7	2.19
BWW15	0	9/22/92		5.80	21	6.51	160	7.9	NA	2.6	2	33.7	7.5	2.02
BWW15	3	9/23/92		12.4	20	6.66	150	8.6	NA	4.2	2.6	39.4	7.2	1.82
BWW15	6	9/23/92		12.4	21	6.14	150	8.7	NA	2.2	1.4	33.5	7.2	1.85
BWW15	9	9/23/92		12.4	19	6.56	150	8.8	NA	2.8	2.2	34.5	7.4	1.86
BWW15	12	9/23/92		10.2	20.5	6.18	162	9.4	NA	4	1.6	32.4	7.4	1.86
BWW15	16	9/23/92		8.72	19.5	6.7	150	8.3	NA	5.4	4	30.4	7.5	1.91
BWW15	24	9/23/92		16.7	17.9	NA	150	7.9	NA	NA	NA	39.1	7.4	1.88
BWW15	32	9/24/92		16.7	15.8	6.76	145	7.4	NA	3.5	3.5	32.9	7.5	1.9
BWW15	40	9/24/92		15.0	19	6.94	135	9.35	NA	4.6	3.8	36.9	7.2	1.86
BWW16	P	9/22/92	1400	2.37	20	6.24	180	6.4	3.3	15	4	45.2	10.4	2.58
BWW16	0	9/22/92	0000	3.61	20	6.31	180	6.4	3.35	16.2	5.8	37	10.3	2.33
BWW16	3	9/23/92	0245	13.2	20	6.47	100	7.2	3.65	17	6.2	22.6	4.8	1.84
BWW16	6	9/23/92	0625	11.0	18	6.1	155	7.3	0.5	2.8	1.6	29.7	9	1.98
BWW16	9	9/23/92	1020	7.23	18	6.09	132	7.6	1.15	4	2	30.7	6.5	1.9
BWW16	12	9/23/92	1400	10.5	19	6.04	140	7.9	1.05	3.6	2.2	24.2	7.6	1.74
BWW16	16	9/23/92	1830	6.25	18.5	6.44	120	6	1.55	6	3.5	20.2	6.6	1.47
BWW16	24	9/23/92	2350	4.00	16	NA	125	5.2	1.45	6.8	2.6	29.2	7.5	1.72
BWW16	32	9/24/92	0800	4.00	13.4	6.11	138	6	1	5.8	3.2	31.1	8.8	1.86
BWW16	40	9/24/92	1410	4.00	16.2	6.77	138	8.35	2	1.8	1.6	39.8	9.6	2.11
BWW17	P	9/22/92	1345	162	23	6.98	280	9.6	1	1.4	0.6	99.2	15.4	3.25

Table A.1 Water Quality Data for Storm 1 (Continued)

Station	Run	Date	Time	Flow cfs	Temp deg C	pH	Cond umhos/cm	DO mg/L	BOD mg/L	TSS mg/L	VSS mg/L	Cl mg/L	Ca mg/L	Mg mg/L
BWW17	0	9/22/92	2340	163	22	6.7	280	8.5	1.55	3.8	1.6	67.9	14.9	2.94
BWW17	3	9/23/92	0240	292	20	6.68	220	9.6	3.05	9.8	4	54.2	12	2.44
BWW17	6	9/23/92	0530	250	19.5	6.67	215	10.05	2.85	6.4	2.8	48.5	12	2.46
BWW17	9	9/23/92	0930	205	19	6.22	235	9.4	0.5	3	2	55.5	13.5	2.84
BWW17	12	9/23/92	1330	214	19.5	6.86	246	10.4	1	4.6	1.8	56	13.3	2.84
BWW17	16	9/23/92		215	19	6.7	232	8.3	1.1	6	2.4	47.2	12.4	2.5
BWW17	24	9/23/92	2345	209	17.5	NA	218	10.6	1.4	7.5	5	62.3	13.9	2.72
BWW17	32	9/24/92	1000	209	16	6.72	210	9.5	1.8	4.6	2.2	58.3	13.6	2.63
BWW17	40	9/24/92	1605	289	18	6.88	211	9.2	1.55	1.4	0.8	58.4	13	2.48
BWW18	P	9/22/92	1450	181	22	6.54	380	6.9	1.6	4.2	3	103	16.4	2.73
BWW18	0	9/22/92	0035	205	21	6.47	390	6.5	3.25	1.2	1	80.8	15.8	2.76
BWW18	3	9/23/92	0325	250	21	6.47	345	7.3	1.7	4.8	2.6	86.4	15.4	2.76
BWW18	6	9/23/92	0700	210	20	6.78	360	7.3	1.7	4	1.8	82.8	15.7	2.77
BWW18	9	9/23/92	1055	226	20	6.29	390	7.6	1.25	10.5	7	91.2	15	2.84
BWW18	12	9/23/92	1442	226	20.5	6.31	383	7.7	1.35	6	3.6	91.5	15.9	2.7
BWW18	16	9/23/92	1910	186	19.5	6.45	281	6.3	1.9	3.6	2	70.4	13.1	2.48
BWW18	24	9/23/92	0025	226	18.5	NA	292	6	1.7	5.2	3.6	72	12.3	2.35
BWW18	32	9/24/92	0820	226	17.9	6.59	260	7.85	1.8	4.8	2.8	78.6	13.3	2.41
BWW18	40	9/24/92	1645	315	18.2	6.72	255	7.1	1.35	2.8	2	82.5	14.3	2.51
BWW20	P	9/22/92	1520	210	22	6.59	325	9.1	1.15	1.3	0.7	101	16.1	2.78
BWW20	0	9/22/92	0100	226	21	6.36	355	6.7	2	1.6	0.8	92.8	16.1	2.78
BWW20	3	9/23/92	0345	253	21	6.52	335	6.1	1.45	1.2	1.2	79.4	15.8	2.75
BWW20	6	9/23/92	0720	241	19	6.49	315	6.7	1.85	2.8	1.2	68.8	15.7	2.71
BWW20	9	9/23/92	1120	259	19	6.17	315	8.7	1.45	2	1.8	77.9	15.8	2.62
BWW20	12	9/23/92	1515	265	20.5	6.38	345	9.9	1.65	4.8	3.6	82.4	16.2	2.67
BWW20	16	9/23/92		215	19	6.52	351	7.5	1.6	2	1.6	78.4	15.8	2.69
BWW20	24	9/23/92	0045	247	18	NA	391	5.85	1.7	3.6	2.6	88.7	15.5	2.85
BWW20	32	9/24/92	0845	271	16.8	6.56	290	6.8	1.6	4.6	2.6	83	15.6	2.58
BWW20	40	9/24/92	1710	253	18.5	6.74	317	8.35	2.2	2.8	2	96	15.6	2.52
BWW21	P	9/22/92	1540	239	23	6.63	320	9.1	0.5	5	4.5	76	15.6	2.64
BWW21	0	9/22/92	0125	250	22	6.78	310	8.8	1.9	1.3	0.7	68.6	15.9	2.77
BWW21	3	9/23/92	0420	253	21	6.61	320	8.1	2.05	2.8	1.4	73.2	16.2	2.87
BWW21	6	9/23/92	0745	241	19	6.52	280	9.1	1.6	4	2	70.6	15.3	2.66
BWW21	9	9/23/92	1155	259	20	6.25	310	9.6	0.5	2.6	1.4	71.4	15.2	2.68
BWW21	12	9/23/92	1545	265	21	6.22	323	9.8	1.05	2.6	2	75.4	15.4	2.59
BWW21	16	9/23/92	2005	215	19	6.72	313	8.9	1.65	2.8	1.6	73.9	15.4	2.7
BWW21	24	9/23/92	0145	247	18.7	NA	318	8.05	1.45	3	1.8	77	15.8	2.69
BWW21	32	9/24/92	0900	271	16.9	6.53	290	8.9	1.35	1.8	1.2	86.1	16.3	2.72
BWW21	40	9/24/92	1730	253	17.8	6.77	300	9	1.4	2	1.4	69.5	16.1	2.65
BWW23	P	9/22/92	1119		NA	6.24	480	NA	6.5	6.2	6.2	118	19.5	2.57
BWW23	0	9/22/92	2337		NA	6.23	371	NA	12	NA	NA	108	19	2.42
BWW23	3	9/23/92	0200		22.5	6.14	398	6.4	13.4	9.8	9.4	100	19.9	2.5
BWW23	6	9/23/92	0515		21	6.41	358	6.9	4.9	8.2	6.6	81.3	19.6	2.45
BWW23	9	9/23/92	0802		NA	5.94	322	NA	4.75	6.4	3.6	80.7	16.2	2.24
BWW23	12	9/23/92	1100		NA	5.97	267	NA	4.6	6.8	5.6	67.5	15.9	1.99
BWW23	16	9/23/92	1509		21	5.83	312	7.8	4.7	6.6	5	76.4	15.9	2.02
BWW23	24	9/23/92	2304		NA	NA	368	NA	5.85	6.8	5.8	88.3	15.7	2.15
BWW23	32	9/24/92	0703		20	6.14	402	NA	2.4	4.8	3.2	94	19.7	2.37
BWW23	40	9/24/92	1454		NA	6.14	435	NA	2.6	8.8	7.4	100	22.5	2.84
BWW24	P	9/22/92	1445		NA	6.91	782	NA	9.75	6.8	6.2	520	8.4	1.5
BWW24	0	9/22/92	0100		NA	6.7	820	NA	14	66	52	526	7.7	1.1
BWW24	3	9/23/92			NA	6.63	765	NA	12.5	24.6	18.2	483	8.6	1.3
BWW24	6	9/23/92			NA	6.52	777	NA	5.9	17.2	12	498	8.5	1.4
BWW24	9	9/23/92			NA	6.72	798	NA	3.7	9	6.5	500	8.1	1.42
BWW24	12	9/23/92			NA	6.93	825	NA	8.1	30.5	23	518	11.5	1.58
BWW24	16	9/23/92	1430		NA	6.88	752	NA	4.85	17	14	504	18.2	1.6
BWW24	24	9/23/92	0145		NA	NA	722	NA	3.9	30.5	23	509	16.8	1.57
BWW24	32	9/24/92	0845		NA	6.61	746	NA	3.85	42.5	31	500	16.3	1.65
BWW24	40	9/24/92	1815		NA	6.73	812	NA	4.75	3.4	2.6	492	23.7	1.79
BWW25	P	9/22/92	1605		24	6.56	100	3.5	8.75	18.7	12.7	156.2	14.7	1.99
BWW25	0	9/22/92	0140		23	6.65	510	3.2	15.3	21.3	20.7	171	18.3	2.27
BWW25	3	9/23/92			23	6.39	500	2.2	10.9	47.5	15.4	119	18.1	2.07
BWW25	6	9/23/92	0815		23	6.43	495	2.3	8.6	17.4	16.8	85.8	12	1.62
BWW25	9	9/23/92	1210		22	6.4	380	2.8	6.25	15.8	13.8	65	9.2	1.26
BWW25	12	9/23/92	1615		21	6.31	368	2.3	6.35	24.4	16.9	60.1	10.1	1.3
BWW25	16	9/23/92	2230		19.5	6.51	420	3.1	7.9	7.4	6.2	71.2	11.5	1.45
BWW25	24	9/23/92	0120		20.8	NA	481	1.81	4.7	17.5	15	85.1	11	1.4
BWW25	32	9/24/92	0930		20.4	6.5	450	2.3	3.85	17.8	15.6	91.3	11	1.52
BWW25	40	9/24/92	1747		21	6.47	390	2	4.15	18.4	17.1	103	15.8	1.86
BWW26	3	9/23/92	0440		21	6.08	125	7.1	39.4	75	57	26.7	9	0.2

ND = Not Detected
NS = No Sample
NM = Not Measured
NA = Not Analyzed

Table A.1 Water Quality Data for Storm 1 (Continued)

Station	Run	Na mg/L	Zn ug/L	NH3 mg/L	NO3 mg/L	PO4 mg/L	Cd ug/L	Cr ug/L	Cu ug/L	Ni ug/L	Pb ug/L	F.C. md/100mL	E.C. md/100mL
BWWW00	P	28	12	0.05	0.58	0.03	0.21	1.3	6	1.6	6.5	13000	410
BWWW00	0	25	15	0.08	0.28	0.03	0.24	1.3	4.8	1.6	7.3	3500	420
BWWW00	3	19	50	0.22	0.41	0.02	0.81	4.2	7.4	3.6	32.6	3000	500
BWWW00	6	13	34	0.31	0.38	0.02	1.12	2.2	6.4	7	22	18000	12000
BWWW00	9	13	45	0.05	0.29	0.03	0.82	1.7	11.3	2.5	17.3	12000	6800
BWWW00	12	17	18	0.06	0.18	0.02	0.17	1.4	5.4	2	10.4	4300	1700
BWWW00	16	22	16	0.11	0.15	0.03	0.15	1.1	4.7	1.5	8.9	2800	190
BWWW00	24	26	15	0.12	0.16	0.01	0.5	1.5	1.3	1.9	8.7	2500	370
BWWW00	32	26	16	0.05	0.16	0.01	0.16	1	3.6	1.1	6.9	1600	130
BWWW00	40	26	10	0.35	0.16	0.03	0.08	0.6	2.4	0.9	3.9	760	76
BWWW01	P	35	42	0.11	0.50	0.02	0.3	2.2	7.1	9.6	3.3	8300	150
BWWW01	0	34	43	0.42	0.61	0.06	0.43	4.9	1.3	3.5	11.8	11000	6800
BWWW01	3	34	55	0.2	0.36	0.01	0.5	5	14.8	4.3	21.6	17000	5800
BWWW01	6	29	38	0.24	0.48	0.02	0.27	2.4	10.4	3	11.1	13000	5700
BWWW01	9	28	40	0.2	0.45	0.02	0.23	2.7	8.1	3.2	14	9700	2900
BWWW01	12	51	54	0.27	0.53	0.02	0.31	5.4	8.4	4.6	13.9	6700	1700
BWWW01	16	35	50	0.09	0.43	0.02	0.22	3.8	6.2	2.7	7.1	5300	470
BWWW01	24	35	40	0.04	0.40	0.01	0.16	3.5	4.7	3.6	3.8	6600	370
BWWW01	32	37	24	0.08	0.35	0.01	0.17	3.4	2.8	2.9	3	880	270
BWWW01	40	41	27	0.45	0.39	0.01	0.19	3.6	3.4	2.9	6.4	1600	150
BWWW02	P	59	46	1.82	1.54	1.13	1.8	7.3	41.8	25.4	3.4	18	1
BWWW02	0	61	55	2.95	1.47	1.13	2.2	15.7	42.7	29.8	5.5	3	0.5
BWWW02	3	55	108	2.27	0.68	0.59	1.09	18.7	3.3	4.6	31.9	1400	0.5
BWWW02	6	44	58	1.73	0.78	0.74	0.14	8.3	1.8	2.7	13.4	4	0.5
BWWW02	9	42	45	1.2	1.94	0.82	0.08	8.5	2.2	2.7	11	17	0.5
BWWW02	12	37	41	0.52	0.97	0.74	1.14	5.9	11	10.6	4.6	7	0.5
BWWW02	16	40	51	0.56	1.21	0.82	0.13	5.1	11.7	2.9	5.3	28	0.5
BWWW02	24	52	57	0.8	1.30	0.90	0.15	12.4	2.8	3.4	8.6	28	0.5
BWWW02	32	53	40	0.005	0.97	0.27	1.01	6.2	24.2	19.3	2.6	4	1
BWWW02	40	57	59	1.22	1.34	0.27	1.52	5.7	41.7	25	3.8	5	0.5
BWWW04	P	62	41	0.81	1.75	1.11	1.09	8.2	43.6	23.8	3	810	4
BWWW04	0	56	46	0.97	1.62	1.11	1.28	5.6	44.5	21.4	7.3	360	59
BWWW04	3	56	86	1.16	1.80	1.15	2.6	17	69.1	32.2	18.2	1600	120
BWWW04	6	45	70	1.66	2.63	0.76	1.23	11.3	38.6	22	11.9	1400	190
BWWW04	9	43	58	1.61	1.87	0.58	1.15	8.1	30	17.8	14.2	580	130
BWWW04	12	44	44	1.43	1.87	0.67	0.92	5.9	27.5	17.5	8.4	150	23
BWWW04	16	44	32	0.2	2.23	0.78	0.79	5.1	27.4	17.7	5.6	230	21
BWWW04	24	38	40	0.005	2.86	0.67	0.69	4.8	24.7	16.2	7.7	220	60
BWWW04	32	49	44	0.1	3.40	0.76	0.8	8.9	28.3	19.9	3.4	200	12
BWWW04	40	51	34	0.005	1.70	0.36	0.68	5.2	24.4	18	2.9	160	23
BWWW05	P	32	ND	NA	0.22	0.02	ND	0.3	1.1	1.5	ND	NA	NA
BWWW05	0	30	14	NA	0.25	ND	0.17	ND	3.2	0.9	30.8	NA	NA
BWWW05	3	32	ND	NA	0.12	ND	ND	ND	3.1	1.2	2.7	580	550
BWWW05	6	30	ND	NA	0.18	ND	ND	ND	2.2	0.9	1.2	NA	NA
BWWW05	9	31	ND	NA	0.13	0.02	ND	ND	1.3	1	2	NA	NA
BWWW05	12	32	ND	NA	0.18	ND	ND	1.3	1	1.3	1	NA	NA
BWWW05	16	31	ND	NA	0.17	ND	ND	0.9	1.5	0.8	ND	NA	NA
BWWW05	24	31	ND	NA	0.11	ND	0.33	1	1	0.9	1.6	NA	NA
BWWW05	32	32	ND	NA	0.13	ND	ND	1	1	0.5	1.2	NA	NA
BWWW05	40	30	ND	NA	NA	ND	ND	1.1	0.8	0.8	1.1	NA	NA
BWWW06	P	46	32	0.36	3.36	0.77	0.86	4.9	30.2	17.5	7.5	60	10
BWWW06	0	53	47	0.37	3.40	0.89	1.26	8.2	43.9	20.7	33.5	330	170
BWWW06	3	51	32	0.44	3.34	0.94	0.91	7.1	41.2	20.1	9.3	980	530
BWWW06	6	52	40	0.5	3.58	0.90	1.06	7.6	38.1	20.1	8.6	560	430
BWWW06	9	52	51	0.83	3.75	0.94	1.21	10	40.2	22.1	10	990	230
BWWW06	12	48	39	1.01	3.64	0.88	1.22	9.2	30.4	19.5	8.9	1400	110
BWWW06	16	42	35	0.46	3.34	0.59	0.88	6.2	25.2	16.2	7.5	460	99
BWWW06	24	41	42	0.005	3.05	0.84	0.82	5.5	26	16	9.1	310	61
BWWW06	32	39	30	0.22	2.81	0.55	0.92	4.8	23	14.4	6.5	35	46
BWWW06	40	44	35	0.26	1.64	0.59	0.75	6.2	24.1	15.4	6.8	120	16
BWWW07	P	45	26	0.51	2.29	0.84	0.72	2.3	23.1	15.6	5.9	230	6
BWWW07	0	44	23	1.08	3.05	0.88	0.75	2.6	23.2	15	6.6	280	29
BWWW07	3	45	31	1.35	2.71	0.62	0.85	4	23.8	15.8	9.3	220	1700
BWWW07	6	47	34	1.13	2.86	0.84	0.73	3.5	21	14.7	7.8	5300	50
BWWW07	9	50	31	1.21	3.96	0.88	0.86	5.7	26	16.7	8.9	370	67
BWWW07	12	47	28	1.79	3.93	0.65	0.7	5.4	23.9	18.8	8	330	34
BWWW07	16	49	29	0.48	3.32	0.72	0.77	5.1	25	17	6.1	300	15
BWWW07	24	48	35	0.28	3.18	0.65	0.93	7.7	28.3	16.8	11.4	380	13
BWWW07	32	48	32	0.68	2.69	0.65	0.99	8.2	26.6	17.1	11	590	56
BWWW07	40	43	32	0.08	2.22	0.81	0.8	5.4	22.9	15.1	7.1	160	6
BWWW08	P	42	33	0.46	2.62	0.65	0.83	5.7	23.9	15.3	9	110	6
BWWW08	0	44	42	1.52	2.08	0.48	1.41	11.9	29.4	16.3	16.1	240	29
BWWW08	3	44	46	1.8	2.32	0.67	1.23	9.9	32.1	16.8	14.8	230	100
BWWW08	6	43	64	1.64	2.42	0.67	2.18	16.1	45.8	19.3	23.7	230	130
BWWW08	9	46	46	1.27	2.62	0.65	0.99	7.1	27.5	15.8	12.2	60	26
BWWW08	12	44	35	1.19	2.62	0.62	0.85	4.8	22.6	14.9	11.9	300	19

Table A.1 Water Quality Data for Storm 1 (Continued)

Station	Run	Na mg/L	Zn ug/L	NH3 mg/L	NO3 mg/L	PO4 mg/L	Cd ug/L	Cr ug/L	Cu ug/L	Ni ug/L	Pb ug/L	F.C. md/100mL	E.C. md/100mL
BWW08	16	44	31	0.72	2.89	0.61	0.65	3.5	19.2	13.5	5.5	120	30
BWW08	24	50	39	0.005	3.02	0.67	1.03	8.7	29.3	17.4	11.1	240	48
BWW08	32	49	42	0.08	2.66	0.70	1.02	9	30.1	18.1	11.7	200	18
BWW08	40	48	36	0.08	2.17	0.64	0.82	7	23.8	15.9	8.8	150	9
BWW09	P	10	ND	0.06	0.16	0.02	0.05	0.8	2.9	0.7	0.9	60	23
BWW09	0	11	ND	0.05	0.14	0.02	0.24	0.6	2	ND	0.8	96	22
BWW09	3	11	ND	0.06	0.14	0.02	0.19	0.7	2.6	ND	2.3	350	100
BWW09	6	10	ND	0.06	0.18	0.02	ND	0.9	1.1	ND	2	200	54
BWW09	9	10	ND	0.06	0.14	0.02	ND	0.7	1.2	ND	2.3	360	130
BWW09	12	9	ND	0.07	0.10	0.02	ND	0.7	1.6	ND	1	290	50
BWW09	16	10	ND	ND	0.74	ND	ND	0.7	1.1	ND	1.3	120	30
BWW09	24	10	ND	ND	0.86	ND	ND	0.6	1.3	ND	0.9	54	38
BWW09	32	11	ND	ND	0.65	0.02	NND	0.7	1.1	ND	1.9	79	39
BWW09	40	10	ND	ND	0.48	0.02	0.08	0.6	1.8	ND	0.9	14	56
BWW10	P	25	ND	NA	0.02	ND	0.05	0.3	2	ND	ND	NA	NA
BWW10	0	24	ND	NA	0.02	ND	0.14	0.4	4.3	0.7	1.4	NA	NA
BWW10	3	22	ND	NA	0.02	ND	0.05	0.3	1.7	ND	1.2	NA	NA
BWW10	6	24	ND	NA	0.02	ND	ND	0.3	1.4	ND	1.2	NA	NA
BWW10	9	22	ND	NA	0.05	0.02	ND	0.2	1.3	ND	0.8	NA	NA
BWW10	12	23	ND	NA	ND	ND	ND	0.3	3	ND	0.7	NA	NA
BWW10	16	22	ND	NA	ND	ND	ND	0.2	1.3	0.6	0.5	NA	NA
BWW10	24	25	ND	NA	ND	ND	ND	ND	1.8	ND	1.1	NA	NA
BWW10	32	23	ND	NA	ND	ND	ND	0.2	1.1	ND	ND	NA	NA
BWW10	40	21	ND	NA	ND	ND	ND	ND	1.5	ND	0.6	NA	NA
BWW11	P	37	22	0.09	2.32	0.36	0.63	3.8	15.5	11.4	4.8	90	10
BWW11	0	38	26	0.15	2.04	0.36	0.74	5.3	17.2	11.6	6.6	270	140
BWW11	3	38	30	0.19	1.85	0.34	0.8	6.3	18.7	11.6	8.6	500	310
BWW11	6	36	35	0.52	1.83	0.35	0.79	6.1	21.8	11.3	12.7	510	230
BWW11	9	38	28	0.7	1.22	0.36	0.67	3.9	15	9.9	5.9	160	190
BWW11	12	37	23	0.32	1.73	0.34	0.62	3.4	13.7	10.1	4.8	280	26
BWW11	16	36	23	0.31	1.75	0.35	0.6	3.4	13.8	11.1	4.9	120	29
BWW11	24	39	31	0.5	1.77	0.38	0.82	6.2	19	11.7	9.6	80	49
BWW11	32	40	23	0.08	1.80	0.42	0.78	5.6	18.4	12.2	8.9	100	28
BWW11	40	44	26	0.2	1.60	0.45	0.69	4.7	17.4	12.4	6.1	130	21
BWW13	P	38	17	0.005	1.79	0.33	0.47	3.5	13	8.9	4	270	25
BWW13	0	35	16	0.005	1.63	0.27	0.37	2.8	10.4	8.1	3.2	600	400
BWW13	3	36	23	0.04	1.58	0.28	0.53	3	11.7	8.7	6.4	740	380
BWW13	6	34	21	0.005	1.40	0.25	0.42	3	10.5	8.1	3.7	1900	80
BWW13	9	33	18	0.24	1.32	0.30	0.55	2.8	11	8.3	5	460	160
BWW13	12	33	13	0.005	1.18	0.28	0.42	2.8	10.4	7.8	6.6	710	110
BWW13	16	35	16	0.02	1.15	0.28	0.43	2.5	10.8	9.4	3.4	520	49
BWW13	24	31	19	0.05	1.07	0.28	0.4	2.6	10.3	7.6	3.5	380	75
BWW13	32	30	13	0.005	0.71	0.25	0.39	2.6	10	7	3.2	150	47
BWW13	40	37	18	0.1	1.10	0.31	0.47	3.2	12	8.9	3.9	90	30
BWW14	P	11	10	ND	0.45	0.03	0.06	0.8	2.9	1.3	ND	1100	100
BWW14	0	11	12	ND	0.46	0.03	0.13	1.4	3.8	1.2	1.6	6000	1200
BWW14	3	13	11	0.36	0.43	0.02	0.07	1	2.8	0.5	1.1	2100	1400
BWW14	6	12	15	0.12	0.38	0.02	ND	0.9	2.7	1.5	6.3	2000	550
BWW14	9	12	12	0.06	0.36	0.02	ND	0.7	2.6	0.8	1.2	6200	400
BWW14	12	12	12	ND	0.35	0.02	ND	0.7	2.5	1.1	0.9	2200	250
BWW14	16	13	12	0.09	0.34	0.02	0.06	1.1	2.1	0.7	1.4	880	260
BWW14	24	13	16	0.09	0.33	0.02	0.07	1.1	2.9	1.4	2.1	280	110
BWW14	32	12	10	0.05	0.32	0.02	0.14	1	2.3	ND	1	2400	99
BWW14	40	14	11	0.05	0.33	0.02	ND	1.1	1.9	1.1	1.2	330	110
BWW15	P	22	ND	NA	0.47	0.02	0.23	0.8	1.6	2	7.4	NA	NA
BWW15	0	20	17	NA	0.46	ND	0.41	0.8	2.2	1.1	5.6	NA	NA
BWW15	3	20	ND	NA	0.43	ND	0.05	0.5	1.3	0.7	1.3	NA	NA
BWW15	6	19	ND	NA	0.41	ND	0.07	0.8	1.7	1	1.8	NA	NA
BWW15	9	19	ND	NA	0.43	ND	0.07	0.6	1.4	1.1	1.9	NA	NA
BWW15	12	19	ND	NA	0.43	ND	ND	0.6	1.3	0.8	1.4	NA	NA
BWW15	16	20	ND	NA	0.41	ND	ND	0.4	1.4	1	1.6	NA	NA
BWW15	24	19	NA	NA	0.41	ND	NA	2.8	2.6	NA	NA	NA	NA
BWW15	32	20	ND	NA	0.41	ND	ND	0.5	1.8	2.4	2.9	NA	NA
BWW15	40	20	ND	NA	0.34	ND	ND	0.5	1.8	2.6	1.7	NA	NA
BWW16	P	23	20	ND	0.43	0.03	ND	1.1	4.8	2.9	5.4	5600	780
BWW16	0	12	18	0.26	0.88	0.02	ND	1.1	8.1	2.9	9.2	410	530
BWW16	3	22	37	ND	0.62	0.04	0.25	2	6.6	3.4	19	1700	2100
BWW16	6	19	10	ND	0.72	0.02	ND	0.8	2.1	1.7	3.7	3800	4400
BWW16	9	17	ND	0.06	0.64	0.02	ND	0.8	3.7	1	4	39000	1800
BWW16	12	15	10	ND	0.60	0.02	ND	1.2	3	ND	4.7	32000	830
BWW16	16	12	ND	ND	0.54	0.02	ND	0.9	2.7	2	4.9	7800	1600
BWW16	24	14	ND	ND	0.51	0.02	ND	0.8	2.9	2.9	3.7	3100	1500
BWW16	32	16	ND	0.07	0.51	0.02	ND	0.8	1.7	2	3.8	1600	1000
BWW16	40	18	ND	ND	0.51	0.02	ND	0.8	1.9	2	2.1	300	48
BWW17	P	40	18	0.005	1.57	0.27	0.34	2.6	10	9.5	5.3	420	22

Table A.1 Water Quality Data for Storm 1 (Continued)

Station	Run	Na mg/L	Zn ug/L	NH3 mg/L	NO3 mg/L	PO4 mg/L	Cd ug/L	Cr ug/L	Cu ug/L	Ni ug/L	Pb ug/L	F.C. md/100mL	E.C. md/100mL
BWW17	0	36	18	0.005	1.54	0.30	0.35	2.9	10.4	9.4	5.6	510	230
BWW17	3	28	32	0.005	1.39	0.26	0.51	4.1	12.6	8.9	10.2	8500	2800
BWW17	6	29	39	0.005	1.36	0.24	0.49	3.7	11.8	8.5	9.4	1700	4400
BWW17	9	31	16	0.08	1.36	0.23	0.39	2.8	9	6.8	5.3	810	400
BWW17	12	30	17	0.05	1.18	0.22	0.26	2.3	8.5	7.1	4	660	96
BWW17	16	28	19	0.005	1.18	0.21	0.31	2.3	7.8	5.7	5.2	620	70
BWW17	24	31	25	0.005	1.44	0.21	0.44	3.4	11.8	8.3	5.4	410	92
BWW17	32	31	19	0.12	1.44	0.22	0.38	2.5	9.5	6.6	4.3	5400	52
BWW17	40	29	18	0.09	1.34	0.26	0.38	2.7	10.8	6.1	6.4	720	32
BWW18	P	60	33	4.2	1.38	0.48	0.47	2	12.5	7	4.2	120	12
BWW18	0	51	34	1.8	1.41	0.36	0.64	2.7	11.3	7.1	4.7	120	8
BWW18	3	51	30	2.4	1.36	0.36	0.5	2	10.1	6.1	2.9	59	18
BWW18	6	53	32	3.2	1.36	0.41	0.4	2.2	12.3	7.3	4.4	140	54
BWW18	9	55	39	2.12	1.41	0.55	0.45	2.4	15.3	7	4.9	310	47
BWW18	12	55	33	1.96	1.46	0.56	0.4	1.9	12.9	6.2	3.6	420	80
BWW18	16	42	35	3.5	1.25	0.38	0.38	2.2	12.3	4	6	1700	190
BWW18	24	37	40	1.76	1.20	0.36	0.39	1.9	11.1	5.4	5.3	1300	110
BWW18	32	47	40	1.97	1.20	0.36	0.39	2.5	11	5.2	9.6	14	3
BWW18	40	43	34	2.13	1.31	0.30	0.35	1.9	10	4	3.4	58	4
BWW20	P	45	20	0.32	1.80	0.21	0.32	1.2	9.4	4.2	3.4	61	9
BWW20	0	47	25	0.54	1.90	0.19	0.28	1.2	9.5	3.5	4	48	24
BWW20	3	47	38	0.42	1.88	0.21	0.35	1.4	9.4	4	5.7	230	120
BWW20	6	48	23	0.58	1.83	0.26	0.29	1.4	10.3	4.6	3.2	270	160
BWW20	9	46	25	0.72	1.85	0.21	0.3	1.3	10	5.7	3.3	180	11
BWW20	12	51	26	0.92	1.95	0.26	0.3	1.3	10.3	5.2	4.3	87	12
BWW20	16	54	23	0.41	2.06	0.32	0.43	2.1	11.8	5.4	2.8	86	28
BWW20	24	52	27	0.62	2.10	0.28	0.36	2.3	11.7	4.8	3.7	77	13
BWW20	32	51	27	0.21	2.38	0.28	0.38	2.3	11.4	5.3	5.1	72	15
BWW20	40	54	22	0.74	2.10	0.38	0.33	2.3	11.8	5.1	2.8	51	10
BWW21	P	44	19	0.42	1.60	0.21	0.3	1.7	8.8	3.8	3.1	270	7
BWW21	0	43	22	0.41	1.57	0.17	1.23	2	9.1	3.9	5	180	110
BWW21	3	43	25	0.54	1.49	0.12	0.37	2.3	9.8	4.5	20.2	11000	1100
BWW21	6	40	42	0.5	1.42	0.10	0.26	2.2	10.8	5	16.8	8000	1800
BWW21	9	45	24	0.58	1.66	0.13	0.2	1.9	8.9	3.6	4.3	400	56
BWW21	12	45	21	0.36	1.79	0.16	0.21	1.7	9.2	4.2	3.9	580	36
BWW21	16	41	25	0.22	1.88	0.18	0.27	1.8	8.6	5.2	3.1	600	44
BWW21	24	44	24	0.11	1.47	0.18	0.26	2.1	10.5	5.5	3.8	1700	38
BWW21	32	49	25	0.08	2.28	0.23	0.35	2.2	11.1	5.7	4.4	210	22
BWW21	40	49	25	0.43	2.13	0.26	0.39	2.8	16.6	4.8	3	80	23
BWW23	P	68	47	1.34	4.75	1.97	2.22	9	68.2	45.4	3.9	120	<1.00
BWW23	0	68	60	4.32	5.09	2.04	2.49	9.7	71.9	46.1	4.3	7	<1.00
BWW23	3	66	60	3.46	4.53	2.09	2.41	20.9	74.1	46.7	3.3	2000	36
BWW23	6	59	54	4.12	2.67	1.97	2.25	12.3	60.1	40.2	2.4	56	<1.00
BWW23	9	53	57	1.8	3.43	1.54	2.07	10.7	55.8	33.9	5.7	110	<1.00
BWW23	12	46	50	1.5	3.37	1.40	1.46	8.6	47.9	30	2.3	14	1
BWW23	16	43	59	2.1	4.26	1.40	1.64	8.4	47.5	27.7	2.3	97	<1.00
BWW23	24	65	56	1.14	5.64	1.54	1.93	21.9	58.6	34.6	2.7	210	1
BWW23	32	75	61	0.46	4.42	0.68	2.11	10.6	48.9	38.9	2	36	<1.00
BWW23	40	69	68	1.86	4.15	0.54	2.37	7.4	55.7	39.4	2.4	43	<1.00
BWW24	P	343	90	34.3	0.64	4.21	1.66	4.8	33.2	5.2	9.4	5	1.00
BWW24	0	336	146	23.7	1.01	5.97	2.89	7.4	68.9	6.4	21.6	<1.00	<1.00
BWW24	3	320	145	30	0.43	4.39	2.91	7.4	71.2	6.3	21.3	<1.00	<1.00
BWW24	6	321	75	25.3	0.10	5.89	1.04	4.9	23.5	6.1	6.7	<1.00	<1.00
BWW24	9	318	69	20.3	0.32	5.27	1.16	3.9	22.2	4.8	5.8	<1.00	<1.00
BWW24	12	325	77	23	0.63	2.81	1.87	5.9	27.4	4.9	6.8	<1.00	<1.00
BWW24	16	330	81	31	0.36	2.45	1.66	5.2	23.6	2.7	5.3	14000	120
BWW24	24	322	89	16.3	0.45	2.45	1.65	6.4	32.4	4	9	2	<1.00
BWW24	32	318	92	17.7	0.88	2.28	2.41	6.5	49.7	3.4	12.3	<1.00	<1.00
BWW24	40	330	89	21.3	0.42	3.51	2.37	8	48.9	4	11.2	<1.00	<1.00
BWW25	P	108	82	2	2.40	6.25	0.17	5	15.7	97.2	5.2	47	<1.00
BWW25	0	111	130	3.2	1.33	5.49	0.46	6.3	26.5	128.8	9.7	210	8
BWW25	3	103	85	8.2	0.15	5.64	0.14	4.5	19.8	118.8	6.1	800	21
BWW25	6	79	70	6	0.04	5.03	0.17	4.3	19.2	95.6	7.4	5	<1.00
BWW25	9	62	58	7.2	0.03	4.27	0.14	3.4	17.4	78.3	6.7	80	<1.00
BWW25	12	57	68	1.8	1.44	3.67	0.19	4.6	18	69	10.6	76	4
BWW25	16	70	75	1.2	3.44	3.51	0.13	5.4	20.2	74.6	9.7	39	<1.00
BWW25	24	86	76	1.8	1.08	3.97	0.23	5.3	22.5	89.4	7.3	180	1
BWW25	32	96	78	0.4	2.26	3.51	0.13	5.1	18.9	86.1	7	350	4
BWW25	40	96	74	3.6	0.86	3.67	0.24	3.8	16	73.4	5.4	<1.00	<1.00
BWW26	3	18	62	8.9	0.20	1.38	1.83	48	112	118	36	790000	100000

ND = Not Detected
 NS = No Sample
 NM = Not Measured
 NA = Not Analyzed

Table A.2 Water Quality Data for Storm 2

Station	Run	Date	Time	Flow cfs	Temp deg C	pH	Cond umhos/cm	DO mg/L	BOD mg/L	TSS mg/L	VSS mg/L	Cl mg/L	Ca mg/L	Mg mg/L
BWW00	P	11/2/92	1510	72	7.2	6.68	181	11.8	1.2	1.8	1	55.2	17.48	1.59
BWW00	0	11/2/92	2315	72	6.3	6.52	190	10.8	NA	2.2	0.5	52	17.91	1.53
BWW00	3	11/3/92	0215	65	6	6.57	192	11.8	1.5	2.4	1.2	66.1	17.58	1.63
BWW00	6	11/3/92	0455	172	6	6.66	205	11.6	10.5	5.5	2.2	66.8	17.2	1.55
BWW00	9	11/3/92	0745	228	10.9	6.34	128	10.9	11.6	65	37	44.9	9.55	0.78
BWW00	12	11/3/92	1105	183	NA	6.5	105	NA	10.8	19.2	9.8	30.4	6.72	0.55
BWW00	16	11/3/92	1507	183	6.7	6.37	130	11.2	4.2	9.2	5.2	49.3	11.79	1.1
BWW00	20	11/3/92	1855	116	6.9	6.64	142	11.4	NA	3	1.8	55.6	12.1	1.39
BWW00	24	11/3/92	2250	113	6.8	6.44	158	10.8	4.6	1.6	0.5	60.9	13.6	1.38
BWW00	28	11/4/92	0245	128	6.8	6.4	164	10.9	NA	3.4	1.8	62.1	14.4	1.37
BWW00	32	11/4/92	0653	128	6	6.38	160	11.6	2.5	2.6	1.4	53.4	14.4	1.35
BWW00	36	11/4/92	1048	126	7	6.54	162	11.4	NA	2.2	1.2	61.1	11.6	1.22
BWW00	40	11/4/92	1446	121	8	6.59	160	10.9	2.2	2.4	1	57.2	14.9	1.12
BWW00	44	11/4/92	1842	121	8.5	6.96	158	9.9	NA	1.6	1.4	48.6	15.0	1.3
BWW00	48	11/4/92	2253	113	7.5	7.11	164	10.4	2.6	1.4	1	65.3	14.7	1.32
BWW00	72	11/5/92	1555	57	9.6	NA	364	7.4	ND	3.5	2.75	62.4	15.0	1.28
BWW01	P	11/2/92	1530	77.4	8	6.62	368	11	6.9	12.2	5	122	33.2	3.28
BWW01	0	11/2/92	2335	77.4	7.4	6.61	272	10.6	NA	5	2.8	102	24.3	2.51
BWW01	3	11/3/92	0230	70.5	7	6.55	262	11.6	4.6	5.6	3.6	106	22.5	2.3
BWW01	6	11/3/92	0515	185	7	6.93	202	11.5	11.1	21.2	18	98.8	17.2	1.77
BWW01	9	11/3/92	0820	245	NA	6.82	165	10.9	9.1	29.2	10	68.6	13.3	1.41
BWW01	12	11/3/92	1120	175	NA	6.53	135	NA	10.9	31.8	12	45.9	8.49	0.86
BWW01	16	11/3/92	1519	208	7	6.44	152	11.2	9.3	30.2	10.6	63.2	10.6	1.14
BWW01	20	11/3/92	1805	125	7.2	6.42	175	11.1	NA	11.6	8	68.7	12.8	1.46
BWW01	24	11/3/92	2305	122	7.2	6.48	180	10.6	5	2.8	0.5	67.5	14.8	1.64
BWW01	28	11/4/92	0300	138	7.3	6.5	202	10.7	NA	3.6	1.8	79.6	16.3	1.7
BWW01	32	11/4/92	0702	135	7	6.54	192	11	3	3.4	1	65.4	16.6	1.74
BWW01	36	11/4/92	1058	135	8	6.43	200	10.4	NA	3.8	2.2	76.7	16.6	1.74
BWW01	40	11/4/92	1500	130	8.1	6.61	194	10.6	2.7	3.2	1.8	75.4	17.3	1.74
BWW01	44	11/4/92	1900	130	8.5	6.83	223	9.6	NA	1.6	1.6	80.8	16.6	1.59
BWW01	48	11/4/92	2305	122	8	7.08	202	10.2	1.8	2.4	1.6	83.2	16.6	1.69
BWW01	72	11/5/92		61.5	9.6	NA	122	7	NA	3.7	3	85.7	17.6	1.72
BWW02	P	11/2/92	1553	107.4	11.3	6.71	390	9.4	4.1	9	6.8	117	25.2	4.41
BWW02	0	11/2/92	2355	107.4	11	6.61	370	8.9	NA	3.6	2.6	107	24.0	3.74
BWW02	3	11/3/92	0245	129.5	10	6.65	348	9.8	8.5	6.4	3	111	22.7	2.87
BWW02	6	11/3/92	0535	245.3	7	6.83	330	9.8	11.5	24	10.8	108	19.9	2.86
BWW02	9	11/3/92	0825	453.4	9.4	6.54	235	9.4	9.8	72.6	62.7	72.6	12.6	1.59
BWW02	12	11/3/92	1130	263.5	NA	6.83	190	NA	10.4	22.4	10.4	61.5	11.4	1.32
BWW02	16	11/3/92	1533	268.2	8.2	6.18	175	10	5.8	12.5	7.25	56.6	10.0	1.14
BWW02	20	11/3/92	1816	222.0	7.1	6.42	201	10.9	NA	14	7.6	68.3	11.5	1.52
BWW02	24	11/3/92	2320	177.2	9	6.53	211	10.5	9.6	6.6	3.2	69.7	13.7	1.63
BWW02	28	11/4/92	0310	150.2	8.4	6.52	220	9.5	NA	7.6	4	89	15.1	2.06
BWW02	32	11/4/92	0713	142.1	8	6.46	215	10	4.8	4.2	0.5	68.3	16.5	2.16
BWW02	36	11/4/92	1109	142.1	10	6.58	252	9.4	NA	5.2	3.4	83	17	2.12
BWW02	40	11/4/92	1520	155.9	10.5	6.61	240	9.3	4.9	3.4	2	82	17.9	2.28
BWW02	44	11/4/92	1920	155.9	10.4	6.89	225	8	NA	3	2.4	87.6	17.9	2.14
BWW02	48	11/4/92	2317	177.2	10.2	6.94	230	9.1	5.5	1.4	1.4	95.9	18.1	2.17
BWW02	72	11/5/92		103.4	11.1	NA	290	6.5	3.3	1.8	0.5	96.6	19.4	2.61
BWW04	P	11/2/92	1620	108	10	6.53	285	10.4	2.7	3.6	2	85.6	20.7	4.14
BWW04	0	11/3/92	0020	108	10	6.72	355	10	NA	3.4	2.4	114	24.7	4.5
BWW04	3	11/3/92	0305	135	9.5	6.59	352	10.2	6	5.6	2.8	120	23.8	4.05
BWW04	6	11/3/92	0605	220	9	6.83	342	11.5	12.6	22.8	9	122	23.0	4.52
BWW04	9	11/3/92	0850	320	10.2	6.73	305	10.2	10.5	73.9	64.3	102	14.2	2.85
BWW04	12	11/3/92	1155	380	NA	6.54	220	NA	10.4	37.7	16.7	70.3	9.51	2.02
BWW04	16	11/3/92	1553	320	8	6.52	174	10.9	10.8	7.8	5	66.8	11.7	2.31
BWW04	20	11/3/92	1993	273	8.2	6.45	171	11	NA	5.8	5.8	53.2	8.9	2.14
BWW04	24	11/3/92	2345	231	8.7	6.61	170	10.5	10.9	12.6	8.4	59.9	11.8	2.65
BWW04	28	11/4/92	0330	202	9	6.7	205	10.6	NA	6.6	6.4	72.8	13.8	2.58
BWW04	32	11/4/92	0738	172	8	6.67	210	11	7.9	6.8	3.4	62.4	14.9	2.78
BWW04	36	11/4/92	1127	142	8.5	6.71	208	11	NA	6.2	3	77.8	12.6	3.05
BWW04	40	11/4/92	1535	142	10.6	6.74	216	10.1	7.9	5	2.6	69.3	16.6	3.2
BWW04	44	11/4/92	1935	165	10.4	6.86	210	9.5	NA	3.2	2	38	16.2	2.7
BWW04	48	11/4/92	2338	191	10	7.04	222	9.8	6.1	3.8	2.8	89.1	17.2	3
BWW04	72	11/5/92		108	11.9	NA	252	7.8	4	1.4	1.2	88	17.6	3.28
BWW05	P	11/2/92	1655	2.4	6	6.66	202	1.6	NA	1	ND	66.6	19.4	2.6
BWW05	0	11/3/92	0100	2.6	6.6	6.74	210	9.5	NA	ND	ND	72.3	19.5	2.63
BWW05	3	11/3/92	0325	3.0	6	6.72	210	10.2	NA	ND	ND	71.6	19.3	2.71
BWW05	6	11/3/92	0625	4.1	6	6.93	199	10.6	NA	ND	ND	80.1	18.7	2.74
BWW05	9	11/3/92	0925	7.6	10	6.51	195	10	NA	8	3.4	76.2	18.2	2.58
BWW05	12	11/3/92		10.7	NA	6.35	203	NA	NA	ND	ND	82.4	18.4	2.52
BWW05	16	11/3/92	1807	13.7	6.9	6.65	212	11.1	NA	1.2	ND	90.6	16.5	2.44
BWW05	20	11/3/92	2000	15.3	6.5	6.71	195	10.8	NA	1.6	1.4	61.9	17.2	2.55
BWW05	24	11/4/92	0005	15.6	6.8	6.65	198	10.8	NA	1.6	1.8	78.8	17.5	2.44
BWW05	28	11/4/92	0355	15.6	6.8	6.7	201	10.4	NA	1.2	ND	85.6	18.3	2.45
BWW05	32	11/4/92	0805	15.6	6.5	6.66	200	11.2	NA	1	ND	89.2	18.0	2.25

Table A.2 Water Quality Data for Storm 2 (Continued)

Station	Run	Date	Time	Flow cfs	Temp deg C	pH	Cond umhos/cm	DO mg/L	BOD mg/L	TSS mg/L	VSS mg/L	Cl mg/L	Ca mg/L	Mg mg/L
BWW05	36	11/4/92	1154	15.3	7	8.53	198	10	NA	ND	ND	82.6	17.8	2.3
BWW05	40	11/4/92	1810	15.3	8	8.83	202	10.6	NA	1.4	1	82.3	18.6	2.5
BWW05	44	11/4/92	2010	14.8	8	8.94	208	9.8	NA	ND	ND	85.5	18.6	2.48
BWW05	48	11/4/92	2353	14.8	7.5	7.09	196	10.2	NA	ND	ND	86.4	18.4	2.57
BWW05	72	11/5/92		15.8	9	NA	182	7.2	NA	1	ND	81.8	18.6	2.42
BWW06	P	11/2/92	1637	111	8.9	6.59	282	10.3	2.3	3.2	2.4	81.8	20.0	1.85
BWW06	0	11/2/92	0040	153	9	6.68	355	9.8	NA	3.8	0.5	81.3	20.2	2
BWW06	3	11/3/92	0345	175	9.5	6.5	299	10.4	5.1	5.2	2.8	91.3	20.8	1.98
BWW06	6	11/3/92	0640	194	9	6.68	326	11.5	12.2	6.2	3.6	119	22.9	1.93
BWW06	9	11/3/92	0910	240	10	6.81	310	10	5.3	1.6	1.2	112	21.3	1.9
BWW06	12	11/3/92	1220	286	NA	6.68	295	NA	10.6	51.3	18	95.9	15.1	1.6
BWW06	16	11/3/92	1617	334	8.7	6.62	220	10.5	8	20.8	18.4	81.4	14.8	1.4
BWW06	20	11/3/92	1948	286	8.2	6.74	185	11	NA	5.8	4.2	63.5	11.7	1.27
BWW06	24	11/4/92	0020	245	8	6.7	178	10.4	NA	2	0.5	45	11.1	1.4
BWW06	28	11/4/92	0340	217	8.5	6.74	190	10.4	NA	11.4	5.2	65.8	12.0	1.53
BWW06	32	11/4/92	0757	179	8	6.48	200	10.8	8.7	6.6	3.4	59.5	13.7	1.4
BWW06	36	11/4/92	1142	141	8.5	6.48	198	10.6	NA	8.4	3.4	72.5	14.2	1.63
BWW06	40	11/4/92	1600	141	8.3	6.6	203	10.2	7.4	6.4	3	73.2	15.5	1.5
BWW06	44	11/4/92	1955	179	9.9	6.61	210	9.5	NA	8	2.2	81.4	16.3	2.03
BWW06	48	11/4/92	0005	245	9.8	7.04	225	9.2	8.9	2.8	1.6	86.8	16.9	1.63
BWW06	72	11/5/92		126	10.6	NA	230	7	4.2	1.4	0.5	84.7	16.5	1.66
BWW07	P	11/02/92	1730	100	7.4	6.75	255	8.5	2.7	3.4	2.4	83.3	19.6	1.38
BWW07	0	11/03/92	0005	100	7.5	6.8	250	12.2	NA	2.8	2	96.6	19.5	1.41
BWW07	3	11/03/92	0305	120	8	6.68	245	8.3	4.4	4	1.6	86.1	19.2	1.47
BWW07	6	11/03/92	0600	149	8	6.57	248	9.2	3	4.8	2.6	88.2	19.1	1.38
BWW07	9	11/03/92	0930	225	8.2	6.61	232	11.4	2.5	3	2.2	92.2	18.9	1.43
BWW07	12	11/03/92	1255	302	8.5	6.57	238	9.1	2.8	5.4	2.4	92.3	19.0	1.4
BWW07	16	11/03/92	1630	367	9.8	6.48	302	8.9	6.8	9	3.4	95.5	21.1	1.61
BWW07	20	11/03/92	1950	339	10	6.35	283	9.6	NA	3.8	2.6	93.9	19.4	1.07
BWW07	24	11/03/92	2345	290	9.8	6.87	230	8.8	7.9	3.4	0.5	67.6	14.9	1.22
BWW07	28	11/04/92	0400	235	9.2	6.57	190	8.4	NA	9.6	6.4	74.8	14.3	1.18
BWW07	32	11/04/92	0755	221	9.5	6.7	180	8.8	8.8	11	5.7	58.3	13.6	1.15
BWW07	36	11/04/92	1120	215	10	6.54	175	9.6	NA	7.4	3.2	62.4	12.6	1.1
BWW07	40	11/04/92	1430	205	10.8	6.65	180	8.5	7.8	4.2	2.8	62	12.6	1.11
BWW07	44	11/04/92	1955	200	9.9	6.72	183	NA	NA	11.4	6	48.1	14.0	1.16
BWW07	48	11/04/92	2315	208	10.3	6.72	205	9.8	5.9	4	2	74.1	14.0	1.15
BWW07	72	11/05/92	1845	183	11.2	NA	235	7.75	3.8	5.66	3	78.4	15.6	1.34
BWW08	P	11/02/92	1705	206	7	6.41	255	8.3	1.3	3.4	1.8	84.6	19.5	2.23
BWW08	0	11/02/92	2315	180	7.2	6.53	245	10	NA	7.5	2.5	92.6	19.3	2.22
BWW08	3	11/03/92	0245	105	7.2	6.55	238	7.8	2.6	1.2	0.5	86	18.6	2.13
BWW08	6	11/03/92	0545	139	7.5	6.48	220	7.7	3.4	7.8	3.6	97.4	18.4	2.14
BWW08	9	11/03/92	0815	171	8	6.65	230	12	2.5	6	2.4	96.6	18.3	2.08
BWW08	12	11/03/92	1225	211	8.2	6.84	232	10.1	3.4	7.8	3	94.8	17.8	2.1
BWW08	16	11/03/92	1600	269	8.9	6.35	268	9	6.5	19.8	8.2	83	16.3	1.99
BWW08	20	11/03/92	1935	393	9.4	6.48	292	9.4	NA	1.8	1.4	94.7	19.3	2.18
BWW08	24	11/03/92	2330	436	9.5	6.66	290	9.6	2.4	2.2	0.5	97.3	18.4	2.09
BWW08	28	11/04/92	0350	286	9.5	6.65	232	8.75	NA	22.2	7.4	86.6	16.1	1.9
BWW08	32	11/04/92	0745	282	9	6.69	202	8.7	8.8	12.4	5.2	86.1	14.7	1.66
BWW08	36	11/04/92	1110	286	10	6.51	190	8.6	NA	10.6	3.6	87.8	13.6	1.54
BWW08	40	11/04/92	1420	283	10.5	6.65	135	7.7	6.2	8.6	4.33	64.6	13.3	1.55
BWW08	44	11/04/92	1945	287	9.7	6.61	180	8.7	NA	11.6	3.6	56.9	12.6	1.49
BWW08	48	11/04/92	2305	269	9.2	6.63	198	8.3	8.3	4.2	2	77.2	13.4	1.62
BWW08	72	11/05/92	1625	279	11	NA	228	7.75	3.5	11.66	9.7	80.5	16.4	1.93
BWW09	P	11/02/92	1640	33.6	7	6.48	72	9.4	ND	ND	ND	55.2	7.34	0.86
BWW09	0	11/02/92	2315	33.6	6.5	6.69	65	10.2	NA	ND	ND	26	6.29	0.77
BWW09	3	11/03/92	0230	33.8	7.2	6.7	65	8.7	1	2.4	ND	21.4	6.17	0.73
BWW09	6	11/03/92	0505	44.4	7.5	6.85	70	10.9	1.9	2.6	1.2	30.2	6.2	0.74
BWW09	9	11/03/92	0845	60.8	8	6.54	60	11.2	ND	2	1.4	26	5.92	0.7
BWW09	12	11/03/92	1205	78.7	8.2	6.59	65	10.5	2.7	2.2	1.4	27	5.71	0.7
BWW09	16	11/03/92	1530	86.1	8.3	6.45	71	10.2	3.8	1.4	1	28.7	5.46	0.64
BWW09	20	11/03/92	1900	104	8.2	6.54	70	9.6	NA	2.8	2.8	26.5	5.1	0.63
BWW09	24	11/03/92	2300	96.5	8.5	6.74	70	10.4	2	1	ND	22.8	4.2	0.63
BWW09	28	11/04/92	0325	104	9	6.61	62	8	NA	2.6	1.8	26.3	4.4	0.58
BWW09	32	11/04/92	0715	104	9	6.75	62	10.1	1.5	1.7	1.3	22.3	4.65	0.58
BWW09	36	11/04/92	1040	104	9	6.62	60	9.6	NA	1.8	ND	24.1	4.2	0.54
BWW09	40	11/04/92	1405	104	10.5	6.61	60	8.7	ND	1.6	1.2	23.7	4.5	0.52
BWW09	44	11/04/92	1917	100	8.7	6.33	60	9.3	NA	1.2	1	23	4.39	0.51
BWW09	48	11/04/92	2250	92.9	9.1	6.7	73	9	ND	ND	ND	22.7	4.08	0.53
BWW09	72	11/05/92	1600	73.8	9.4	NA	68	8.35	ND	ND	ND	20.2	4.05	0.48
BWW10	P	11/02/92	1655	12.6	6.6	6.55	127	9.1	NA	ND	ND	63.6	6.25	1.03
BWW10	0	11/02/92	2325	13.0	6.5	6.37	115	12.2	NA	ND	ND	66.5	7.36	1.21
BWW10	3	11/03/92	0235	13.2	7	6.74	112	8.3	NA	1.6	1.8	59.9	7.41	1.21
BWW10	6	11/03/92	0515	14.4	6.8	6.61	116	9.1	NA	ND	ND	70.4	7.34	1.19

Table A.2 Water Quality Data for Storm 2 (Continued)

Station	Run	Date	Time	Flow cfs	Temp deg C	pH	Cond umhos/cm	DO mg/L	BOD mg/L	TSS mg/L	VSS mg/L	Cl mg/L	Ca mg/L	Mg mg/L
BWW10	9	11/03/92	0900	17.9	7	6.73	110	8.8	NA	1.6	ND	64.5	7.1	1.12
BWW10	12	11/03/92	1215	19.4	7.8	6.74	110	10.8	NA	1.2	ND	58.8	8.55	1.1
BWW10	16	11/03/92	1545	21.0	7.8	6.76	120	11.2	NA	ND	ND	67.4	8.64	1.08
BWW10	20	11/03/92	1915	20.0	7.5	6.56	130	9.6	NA	3	1.8	58.8	6.7	1.11
BWW10	24	11/03/92	2315	20.8	7.5	6.74	130	9.8	NA	ND	ND	58.4	5.9	1.09
BWW10	28	11/04/92	0330	22.0	8.2	6.65	115	8.8	NA	1.2	1	67.8	6.3	1.12
BWW10	32	11/04/92	0730	22.7	9	6.73	122	8.1	NA	ND	ND	57.2	6.63	1.1
BWW10	36	11/04/92	1055	23.4	9	6.64	125	6.1	NA	1.2	ND	61.7	NA	1.04
BWW10	40	11/04/92	1410	25.2	9.6	6.7	125	8.3	NA	ND	ND	62.3	6.4	1.09
BWW10	44	11/04/92	1927	26.6	8.1	6.59	127	9.1	NA	1.8	1.2	62.7	6.56	1.08
BWW10	48	11/04/92	2255	27.2	6.3	6.72	133	6.4	NA	ND	ND	65.1	6.07	1.03
BWW10	72	11/05/92	1610	28.8	9.7	NA	138	8.3	NA	2.67	2.3	57.1	6.33	1.04
BWW11	P	11/02/92	1630	252	6.6	6.39	191	8.9	2.3	4.2	2.6	64.3	14.5	2.07
BWW11	0	11/02/92	2305	207	7	6.57	168	12.2	NA	4.2	2.6	42.3	14.0	2
BWW11	3	11/03/92	0210	152	7.5	6.61	160	7.8	1.7	2.4	1.8	55.8	13.0	1.94
BWW11	6	11/03/92	0450	198	7.5	6.59	152	10.6	2.3	3.5	2.5	71.4	12.9	1.91
BWW11	9	11/03/92	0830	250	8	6.69	152	7.6	2.7	3.6	3	84.2	12.6	1.84
BWW11	12	11/03/92	1155	307	8.2	6.82	155	13.6	3.5	6.6	2.6	66.8	12.4	1.64
BWW11	16	11/03/92	1520	376	8.6	6.65	162	9.7	8.3	16	6.3	62	11.4	1.73
BWW11	20	11/03/92	1845	517	9.1	6.58	195	8	NA	23	6	69.2	12.1	1.72
BWW11	24	11/03/92	2240	553	8.2	6.66	210	9	8	39	11.5	63.9	10.3	1.47
BWW11	28	11/04/92	0315	412	9	6.57	205	9.1	NA	14	9	61.7	13.8	1.78
BWW11	32	11/04/92	0710	409	9.5	6.62	185	8.3	6.2	1.4	0.5	64.7	12.9	1.83
BWW11	36	11/04/92	1035	413	9.8	6.58	165	10.2	NA	8.2	3	61.3	11.1	1.67
BWW11	40	11/04/92	1400	412	10.5	6.61	158	8.2	5	8.4	2.8	58.1	10.8	1.54
BWW11	44	11/04/92	1905	414	9.1	6.72	140	8.4	NA	6	3.8	55.8	9.4	1.33
BWW11	48	11/04/92	2240	389	9.3	6.66	147	6.7	4	1.2	0.5	54.3	9.2	1.48
BWW11	72	11/05/92	1540	382	10.2	NA	155	6.25	NA	2.6	1.6	48.2	10.4	1.55
BWW13	P	11/02/92	1610	321	6.5	6.89	140	9.9	ND	3.4	2	53.1	10.9	1.52
BWW13	0	11/02/92	2240	274	6.8	6.75	138	11.6	NA	2.4	1.4	57.3	11.2	1.56
BWW13	3	11/03/92	0150	222	7	6.63	140	8	1.1	2.4	2	55.1	11.2	1.57
BWW13	6	11/03/92	0430	273	7.5	6.59	135	9.7	2.1	4.7	2.7	59.8	10.9	1.5
BWW13	9	11/03/92	0800	353	7.5	6.62	125	8.6	1.4	2.8	1.8	55.1	9.98	1.48
BWW13	12	11/03/92	1135	408	8.2	6.58	120	10.6	2.9	2.2	1	53.3	9.45	1.35
BWW13	16	11/03/92	1500	483	9	6.67	149	10.7	3.5	2.6	1.6	61.5	10.4	1.51
BWW13	20	11/03/92	1830	635	6.7	6.72	160	9	NA	4	3.2	56.2	11.1	1.51
BWW13	24	11/03/92	2220	676	8	6.76	150	7.8	2.5	1.6	0.5	55.8	7.3	1.47
BWW13	28	11/04/92	0300	542	9	6.59	145	8.15	NA	8	2.8	57.7	9.2	1.43
BWW13	32	11/04/92	0650	540	9.5	6.76	155	9.4	3.3	1.6	0.5	54	10.3	1.44
BWW13	36	11/04/92	1015	545	9.8	6.69	162	9.9	NA	7	2.8	58.2	8.3	1.42
BWW13	40	11/04/92	1340	545	10.5	6.63	165	8.8	2.9	5.8	2.4	63.7	11.3	1.5
BWW13	44	11/04/92	1850	547	9.2	6.72	151	10.6	NA	6.8	3.5	62.9	10.8	1.52
BWW13	48	11/04/92	2230	520	10	6.76	145	8.3	3	2	1.6	60.3	9.28	1.15
BWW13	72	11/05/92	1525	497	10	NA	133	8.1	2.1	3.7	3	43.2	7.6	1.21
BWW14	P	11/02/92	1600	67.6	7.2	6.86	61	8.6	ND	1.4	ND	20.4	4.35	0.49
BWW14	0	11/03/92	0030	66.2	8	6.64	60	12.6	NA	ND	ND	24.7	4.13	0.49
BWW14	3	11/03/92	0330	68.4	7.5	6.76	60	8.8	1.4	1.6	1.4	22.2	4.12	0.49
BWW14	6	11/03/92	0630	74.2	8	6.8	60	7.9	2.1	2.8	1	28.4	4.07	0.45
BWW14	9	11/03/92	1000	101	8.2	6.73	60	10.6	1.4	2.4	1.6	26.9	4.07	0.47
BWW14	12	11/03/92	1325	99.4	8.5	6.72	60	9.8	1.6	1.6	1	26.8	3.95	0.46
BWW14	16	11/03/92	1700	105	9	6.64	69	11.3	3	2.67	NA	27.9	4.02	0.47
BWW14	20	11/03/92	2220	116	9.3	6.74	70	10.4	NA	2.6	2.2	24.8	3.7	0.44
BWW14	24	11/04/92	0015	121	9.1	6.52	68	9.4	2	ND	ND	23.1	3.2	0.46
BWW14	28	11/04/92	0430	127	9	6.74	62	10	NA	1.6	1.2	27.1	3.4	0.46
BWW14	32	11/04/92	0830	129	9	6.74	65	9.7	1.5	4.67	4	23.7	3.69	0.45
BWW14	36	11/04/92	1145	129	9.5	6.63	65	9.5	NA	1.8	1.4	25.4	3.2	0.44
BWW14	40	11/04/92	1505	130	10.5	6.81	70	8.2	1.6	1.2	1	27	3.8	0.43
BWW14	44	11/04/92	2030	130	10.6	6.44	71	NA	NA	1.2	1	26.2	3.62	0.43
BWW14	48	11/04/92	2340	128	9.5	6.67	85	6.7	ND	1	ND	27.2	3.65	0.43
BWW14	72	11/05/92	1730	113	10	NA	82	9	ND	1.6	1.6	24.5	3.69	0.43
BWW15	P	11/02/92	1600	9.6	6.5	6.26	125	5.6	NA	2.2	ND	47	8.53	1.07
BWW15	0	11/02/92	2225	9.4	5	6.62	127	8.5	NA	3	1.6	54.1	8.03	1.04
BWW15	3	11/03/92	0145	9.6	7	6.72	122	7	NA	2.4	NA	44.3	8.54	1.08
BWW15	6	11/03/92	0435	11.5	8.7	6.55	121	7.2	NA	ND	ND	46.8	8.37	1.07
BWW15	9	11/03/92	0800	19.7	9	6.71	120	7.3	NA	4	3	51.3	8.2	1.06
BWW15	12	11/03/92	1135	21.6	9.5	6.65	128	7.2	NA	3.6	1.6	53.9	8.15	1.07
BWW15	16	11/03/92	1500	20.1	10	6.7	130	6.9	NA	5.4	2.6	58.7	6.09	1
BWW15	20	11/03/92	1855	18.1	11.2	6.65	122	6	NA	4.4	3	52.4	6.1	1.03
BWW15	24	11/03/92	2210	18.0	11.1	6.44	125	6.7	NA	2.4	1.6	50.7	7.1	1.01
BWW15	28	11/04/92	0250	21.8	7.5	6.65	120	7.8	NA	4	1.8	55.9	7.6	1.03
BWW15	32	11/04/92	0640	24.0	9	6.52	121	8.65	NA	3.4	1.6	48.9	8.15	0.99
BWW15	36	11/04/92	1018	24.0	9.5	6.53	120	7.7	NA	2.6	1.2	52.4	7.6	1.09
BWW15	40	11/04/92	1445	23.2	10.5	6.59	126	7.1	NA	2.4	1.4	56.2	7.9	1.06
BWW15	44	11/04/92	1845	30.7	10.6	6.65	132	6.6	NA	2.6	1.2	54.7	8.16	1.07

Table A.2 Water Quality Data for Storm 2 (Continued)

Station	Run	Date	Time	Flow cfs	Temp deg C	pH	Cond umhos/cm	DO mg/L	BOD mg/L	TSS mg/L	VSS mg/L	Cl mg/L	Ca mg/L	Mg mg/L
BWW15	48	11/04/92	2215	20.8	11	6.65	127	8.6	NA	2.8	1.4	80	8.13	1.09
BWW15	72	11/05/92	1450	18.0	9.5	NA	148	8.7	NA	2	1.4	52.9	8.22	1.11
BWW16	P	11/02/92	1540	6.2	6.5	6.34	135	6.25	3.1	2	1.6	38.8	10.25	1.21
BWW16	0	11/02/92	2235	5.9	6.3	6.64	115	6.8	NA	90.4	31.2	44.8	9.52	1.05
BWW16	3	11/03/92	0130	5.6	6	6.74	112	6.8	3.3	2	1	42.2	9.91	1.2
BWW16	6	11/03/92	0420	8.3	5.9	6.52	110	6.5	4.8	45.2	15.6	45.6	9.86	1.14
BWW16	9	11/03/92	0740	29.9	6	6.81	60	7.25	6	ND	ND	28.9	7.03	0.7
BWW16	12	11/03/92	1120	27.5	7	6.65	118	6.1	3.7	3	2	43.1	9.2	1.08
BWW16	16	11/03/92	1445	27.5	6	6.74	102	6.2	7.6	3.6	3	38.3	7.78	0.61
BWW16	20	11/03/92	1840	19.8	11	6.88	91	6.5	NA	6.6	4.8	32.5	7.3	0.66
BWW16	24	11/03/92	2200	21.3	11.3	6.44	100	6.9	6	1.4	ND	33.8	7.1	0.98
BWW16	28	11/04/92	0240	17.9	8	6.65	90	7.4	NA	2.5	1.7	38.5	8.1	1.01
BWW16	32	11/04/92	0630	17.9	7.6	6.42	96	6.1	3	2	1.5	33.7	8.83	1.05
BWW16	36	11/04/92	1010	18.4	8.2	6.59	108	7.6	NA	2.4	2	37.1	8.3	1.1
BWW16	40	11/04/92	1430	18.4	10	6.55	112	6.2	3.1	2	1.4	40.4	8.5	1.02
BWW16	44	11/04/92	1830	13.7	9.2	6.98	120	6.7	NA	7.2	4.8	32.7	8.5	1.03
BWW16	48	11/04/92	2200	11.5	10	6.53	115	7	2.4	ND	ND	43.2	7.72	0.85
BWW16	72	11/05/92	1425	10.9	9.8	NA	NA	7	2.3	2.2	1.6	38.4	8	0.98
BWW17	P	11/02/92	1545	259	7.3	6.25	184	11.4	ND	2	1.4	50.2	12.0	2.13
BWW17	0	11/02/92	2230	286	NA	6.6	140	12	NA	1.6	1.2	54.1	11.5	2.12
BWW17	3	11/03/92	0135	282	7.2	6.7	140	11.4	1.7	1.4	1.2	58.9	11.1	1.88
BWW17	6	11/03/92	0415	286	7.5	6.63	135	11.8	2.5	3.8	2.2	63.9	11.2	1.99
BWW17	9	11/03/92	0730	310	8	6.85	125	8.6	3.2	3.6	1.6	56.3	10.3	1.82
BWW17	12	11/03/92	1105	326	6.2	6.65	135	10.5	2.3	2	1.2	59.7	11.0	1.9
BWW17	16	11/03/92	1440	385	8.2	6.68	150	10.8	4	2.8	1.4	65.5	11.0	1.89
BWW17	20	11/03/92	1810	445	6.3	6.49	152	10.8	NA	1.6	0.5	54.9	10.7	1.91
BWW17	24	11/03/92	2200	529	8	6.63	145	10	2.5	5.3	2.2	50.1	8.9	1.8
BWW17	28	11/04/92	0245	675	9	6.68	150	8.75	NA	8.75	4	63.6	10.6	1.93
BWW17	32	11/04/92	0625	693	9	6.8	145	8.3	2.2	4.2	1.5	52.3	10.5	1.77
BWW17	36	11/04/92	1000	683	9.5	6.61	150	9.7	NA	5	2	57.3	10.0	1.64
BWW17	40	11/04/92	1320	640	10.2	6.7	180	8.2	2.5	4.4	2	63.4	11.0	1.75
BWW17	44	11/04/92	1835	660	10	6.91	175	10.4	NA	4.8	2.2	67.1	11.8	1.94
BWW17	48	11/04/92	2215	606	10.2	6.7	175	9.2	NA	1.4	0.5	74.4	11.7	1.9
BWW17	72	11/05/92	1500	569	10	NA	150	8	1.9	6.7	1.33	48.9	6.85	1.47
BWW18	P	11/02/92	1630	295	6	6.05	170	8.1	2.1	3	2.6	56.8	12.4	1.5
BWW18	0	11/02/92	2315	272	8.5	6.69	171	7.2	NA	1.8	1.4	57	12.2	1.57
BWW18	3	11/03/92	0205	265	6.5	6.76	190	6.9	2.2	3.8	2.2	71.8	12.4	1.97
BWW18	6	11/03/92	0500	272	6.2	6.53	178	7.4	3.2	3.2	2.2	77.2	12.3	1.5
BWW18	9	11/03/92	0830	451	6.2	6.45	180	6.45	3.3	2.2	1.6	71.8	11.6	1.6
BWW18	12	11/03/92	1200	395	6.5	6.72	175	6.6	2.6	1.6	1	73.5	11.3	1.89
BWW18	16	11/03/92	1510	500	8.7	6.59	172	6.7	4.1	3	1	75.2	11.4	1.69
BWW18	20	11/03/92	1915	451	9	6.61	179	9.7	NA	5.6	3.4	67.1	10.8	1.79
BWW18	24	11/03/92	2220	526	9	6.37	181	6.1	5.3	6.6	4.8	69.1	9.7	1.84
BWW18	28	11/04/92	0305	587	8	6.57	163	7.55	NA	10.6	6.6	71.4	10	1.71
BWW18	32	11/04/92	0655	767	8	6.5	152	6.25	3	3.4	1	56.6	10.2	1.64
BWW18	36	11/04/92	1030	712	8.5	6.48	180	7.2	NA	6	2.8	62.2	10.4	2.1
BWW18	40	11/04/92	1500	712	9.8	6.63	182	8.4	3.1	7.4	3.6	68.5	10.4	1.81
BWW18	44	11/04/92	1800	730	10.2	6.91	184	8.4	NA	11.8	6	39.5	10.6	1.7
BWW18	48	11/04/92	2230	628	9.7	6.78	191	8.6	3.5	22.5	15.5	80	11.3	1.56
BWW18	72	11/05/92	1500	568	10	NA	200	8.2	2.9	1.6	0.5	62.4	9.46	1.6
BWW20	P	11/02/92	1655	328	8.5	6.34	185	8.5	1.8	2.8	2	61.5	12.9	1.4
BWW20	0	11/02/92	2335	302	8	6.58	180	7.2	NA	2.4	1.8	80	12.7	1.35
BWW20	3	11/03/92	0230	294	8	6.7	180	6.65	2.5	2	1.4	75.8	13.1	1.41
BWW20	6	11/03/92	0530	302	6	6.61	173	7.7	3	4.2	2.2	81	13.0	1.36
BWW20	9	11/03/92	0900	500	6.7	6.58	167	6.9	2.4	4	2.2	73.5	12.5	1.49
BWW20	12	11/03/92	1230	439	9	6.36	178	6.9	3.7	4.67	3.3	70.5	13.0	1.68
BWW20	16	11/03/92	1530	554	9	6.48	178	6.9	4.7	2.6	2.8	73.5	12.3	1.48
BWW20	20	11/03/92	1940	500	9.9	6.48	180	7.3	NA	4.2	2.4	69.5	12.5	1.48
BWW20	24	NS	NS	584	NS	NS	NS	NS	NS	6.9	3.4	72	11.5	1.31
BWW20	28	11/04/92	0330	683	6.1	6.63	172	7.9	NA	9.8	4.4	74.8	10.5	1.35
BWW20	32	11/04/92	0710	852	8.2	6.48	170	7.6	5	12.6	7.6	62	10.3	1.36
BWW20	36	11/04/92	1055	790	9	6.64	180	7	NA	13.6	6.6	69.1	10.1	1.33
BWW20	40	11/04/92	1510	790	10.5	6.57	182	6.6	4.8	8.6	4.6	70.8	10.3	1.24
BWW20	44	11/04/92	1925	810	9.1	6.94	180	7.4	NA	8.2	4.2	69	10.4	1.37
BWW20	48	11/04/92	2300	697	9.8	6.61	170	7.8	3	3.6	2.2	74.1	10.7	1.27
BWW20	72	11/05/92	1755	630	10.5	NA	210	8	4.1	7	6	71.5	11.9	1.34
BWW21	P	11/02/92	1715	294	8	6.3	175	8.8	ND	1.4	1	67.7	12.7	1.82
BWW21	0	11/02/92	2355	311	6	6.62	192	7.6	NA	2.4	2	63.6	13.1	2.1
BWW21	3	11/03/92	0245	302	6.3	6.68	191	7.3	1.6	3	2.2	79.3	12.9	1.85
BWW21	6	11/03/92	0545	208	6	6.57	171	6	2.7	3.6	2.2	80.1	13.0	1.8
BWW21	9	11/03/92	0925	410	8.5	6.75	172	7.15	3.3	5.3	4.3	69.9	12.5	1.92
BWW21	12	11/03/92	1250	458	9.2	6.61	185	7.2	2.4	3.4	1.2	74.7	12.7	1.86
BWW21	16	11/03/92	1545	458	9	6.58	190	7.3	4.3	2	1.2	68.4	12.9	2.09

Table A.2 Water Quality Data for Storm 2 (Continued)

Station	Run	Date	Time	Flow cfs	Temp deg C	pH	Cond umhos/cm	DO mg/L	BOD mg/L	TSS mg/L	VSS mg/L	Cl mg/L	Ca mg/L	Mg mg/L
BWW21	20	11/03/92	2000	446	9.2	6.59	162	6.8	NA	1.8	1	70.3	13.0	1.77
BWW21	24	NS	NS	584	NS	NS	NS	NS	NS	1.9	1	71.3	12.5	1.86
BWW21	28	11/04/92	0345	684	8.7	6.52	170	8.25	NA	2	1	72.5	11.7	1.94
BWW21	32	11/04/92	0730	890	8.5	6.44	180	8	4.9	2.2	1	84.5	11.7	1.88
BWW21	36	11/04/92	1115	820	9.5	6.53	174	7.2	NA	12.2	5.2	68	10.2	1.76
BWW21	40	11/04/92	1535	820	10.8	6.55	185	8.85	5.1	10.3	4.8	75.4	10.3	1.7
BWW21	44	11/04/92	2000	799	9.2	6.96	180	9.2	NA	9.6	5	71	10.5	1.78
BWW21	48	11/04/92	2315	956	10.2	6.85	177	8.7	3.9	2.4	0.5	76.7	10.2	1.75
BWW21	72	11/05/92	1820	702	13	NA	205	8.55	4.4	4	1.6	72	11.4	1.8
BWW22	P	11/3/92	0735		NA	NA	NA	NA	68.2	18	11.2	76	4.08	3.11
BWW22	0	11/3/92	0930		NA	NA	NA	NA	76.3	33.6	22.8	40.6	7.68	0.58
BWW22	3	11/3/92							43.9	20	16	26.2	18.9	0.23
BWW23	P	11/2/92	1455		NA	6.8	384	NA	9.5	12.5	8	95.5	21.2	1.96
BWW23	0	11/2/92	2255		NA	6.61	470	NA	NA	3.8	2	143	19.7	1.72
BWW23	3	11/3/92	0155		NA	6.7	520	NA	16.9	7.4	6	120	20.0	2.05
BWW23	6	11/3/92	0435		NA	6.7	520	NA	23	16.6	13.6	132	19.3	2.06
BWW23	9	11/3/92	0727		NA	6.58	435	NA	22	8.8	5.8	121	19.1	1.83
BWW23	12	11/3/92	1030		NA	6.74	480	NA	21.5	12	4.8	79.9	14.6	1.59
BWW23	16	11/3/92	1457		NA	6.44	280	NA	27.5	12.4	11.2	73.8	11.8	1.55
BWW23	20	11/3/92	1843		NA	6.64	295	NA	NA	5.2	4.8	72.5	12.2	1.27
BWW23	24	11/3/92	2230		NA	6.63	292	NA	20.1	3.8	ND	77.3	12.1	1.49
BWW23	28	11/4/92	0230		NA	6.65	321	NA	NA	4.7	NA	67.8	14.1	1.62
BWW23	32	11/4/92	0635		NA	6.58	338	NA	19	10	6.5	64.3	15.5	1.54
BWW23	36	11/4/92	1034		NA	6.6	360	NA	NA	9	7	96.3	16.6	1.55
BWW23	40	11/4/92	1433		NA	6.68	NA	NA	20	6.6	5.4	115	17.8	1.88
BWW23	44	11/4/92	1830		NA	8.83	NA	NA	NA	8	7	120	18.2	1.9
BWW23	48	11/4/92	2240		NA	NA	NA	NA	12.8	11.4	8.9	137	18.6	1.58
BWW23	72	11/5/92			17	NA	NA	5.4	NA	3	NA	123	22.1	1.94
BWW24	P	11/2/92	2100		NA	6.5	1300	NA	33.9	202	151	379	9.78	0.97
BWW24	0	11/2/92	2340		NA	6.64	1390	NA	NA	78	78	371	9.94	1.55
BWW24	3	11/3/92	0300		NA	6.68	1320	NA	11.2	23	21	421	11.4	1.77
BWW24	6	11/3/92	0600		NA	6.74	1200	NA	12	23	21	489	12.1	1.58
BWW24	9	11/3/92	0915		NA	6.5	1350	NA	64.9	297	239	449	9.66	1.07
BWW24	12	11/3/92			NA	6.45	1290	NA	82.5	281	227	477	9.2	0.76
BWW24	16	11/3/92			NA	6.38	1300	NA	51.4	194	150	486	8.47	0.83
BWW24	20	11/3/92	1850		NA	6.44	1395	NA	NA	113	90	485	9.5	0.94
BWW24	24	11/3/92	0145		NA	6.44	1380	NA	NA	160	100	454	8.8	1.58
BWW24	28	11/4/92	0545		NA	6.65	1410	NA	NA	15	12	475	10.6	1.58
BWW24	32	11/4/92	0905		NA	6.7	1480	NA	69	350	290	456	9.1	0.91
BWW24	36	11/4/92	1200		NA	6.54	1450	NA	NA	338	143	508	9.3	0.87
BWW24	40	11/4/92	1540		NA	6.55	NA	NA	71	208	171	748	9.8	0.58
BWW24	44	11/4/92			NA	6.72	NA	NA	NA	16.4	13.4	659	8.26	0.5
BWW24	48	11/4/92	0000		NA	6.61	NA	NA	39	227	165	587	6.41	0.71
BWW24	72	11/5/92	1400		21	NA	1200	6	NA	235	194	603	NA	NA
BWW25	P	11/02/92	1735		15	6.66	490	2.8	8.9	14.4	12.6	165	14.5	1.5
BWW25	0	11/03/92	0010		15.5	6.75	610	5	NA	17	17	183	19.9	1.7
BWW25	3	11/03/92	0310		16.2	6.7	720	3.8	15.9	15.6	13.8	190	21.9	1.71
BWW25	6	11/03/92	0600		15.8	6.78	750	2	34.8	36.4	32	167	20.8	1.79
BWW25	9	11/03/92	0945		14	6.68	580	3.05	66.4	146	117	164	15.5	1.79
BWW25	12	11/03/92	1330		13.2	6.57	412	2.7	15	15.6	14.6	128	15.4	1.23
BWW25	16	11/03/92	1600		12.8	6.64	380	2.65	78	112	50	118	13.9	0.93
BWW25	20	11/03/92	2015		14	6.52	410	3.5	NA	28.3	23	88.9	20.8	1.03
BWW25	24	NS	NS		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
BWW25	28	11/04/92	0410		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
BWW25	32	11/04/92	0740		12.9	6.42	462	2.6	9.6	3.4	ND	113	20.4	1.19
BWW25	36	11/04/92	1125		15.2	6.4	450	2.55	NA	21.4	18.8	136	20.1	1.55
BWW25	40	11/04/92	1550		16.5	6.57	550	2.35	10.9	17.2	14.8	148	19.5	1.86
BWW25	44	11/04/92	2050		18.5	6.78	600	2.8	NA	15.5	13.5	153	19.6	1.9
BWW25	48	11/04/92	2340		17.1	6.91	600	1.9	9.1	20	15.6	167	18.0	1.58
BWW25	72	11/05/92	1900		15	NA	820	2	NA	3.3	2.7	157	NA	1.94
BWW26	8	11/03/92	0800		10	6.25	205	7.2	89.5	158	96	68.2	8.1	0.2
BWW26	9	11/03/92	0845		10.5	7.1	130	7	53.1	285	150	31.3	10.2	0.13

ND = Not Detected
 NS = No Sample
 NM = Not Measured
 NA = Not Analyzed

Table A.2 Water Quality Data for Storm 2 (Continued)

Station	Run	Na mg/L	Zn ug/L	NH3 mg/L	NO3 mg/L	PO4 mg/L	Cd ug/L	Cr ug/L	Cu ug/L	Ni ug/L	Pb ug/L	F.C. md/100mL	E.C. md/100mL
BWW00	P	28	9	0.03	0.14	0.02	0.08	0.57	3	1.8	2.3	1700	78
BWW00	0	29	15	0.04	0.14	0.02	0.13	2.87	3.7	1.2	3.8	NA	NA
BWW00	3	27	10	0.03	0.16	0.01	0.03	0.87	3.8	1.9	6.1	1800	320
BWW00	6	27	20	0.05	0.20	0.01	0.03	0.91	7	1.4	6.3	8900	620
BWW00	9	17	68	0.16	0.36	0.06	0.12	4.49	22.7	4.5	41.1	9300	4200
BWW00	12	10	45	0.20	0.02	0.16	0.07	2.4	14.2	3.4	21.8	8300	9100
BWW00	16	19	38	0.09	0.12	0.09	0.05	1.43	8.4	2.1	11.5	4300	6300
BWW00	20	22	28	0.05	0.08	0.05	0.08	1.05	8.5	1.8	8.3	NA	NA
BWW00	24	24	20	0.01	0.04	0.01	0.03	0.74	4.6	1.4	5	190	360
BWW00	28	24	20	0.06	0.07	0.01	0.03	0.7	4.6	2.1	4.5	NA	NA
BWW00	32	25	23	0.06	0.07	0.01	0.03	0.94	3.9	1.7	5.3	3000	480
BWW00	36	25	15	0.05	0.02	0.01	0.03	1.03	3.8	2.1	4.3	NA	NA
BWW00	40	27	10	0.05	0.08	0.01	0.03	0.11	2.8	1.5	5.1	1100	220
BWW00	44	24	21	0.04	0.09	0.01	0.03	0.75	5.2	1.9	6.4	NA	NA
BWW00	48	26	15	0.01	0.12	0.01	0.03	0.69	4	2	5.7	2500	290
BWW00	72	27	16	0.07	0.09	0.00	0.03	0.64	3.7	1.9	4.1	1400	170
BWW01	P	62	52	0.18	0.41	0.01	0.03	3.81	8.1	4	4.5	1700	500
BWW01	0	47	32	0.32	0.33	0.01	0.08	2.77	7.9	4.4	11.1	NA	NA
BWW01	3	43	34	0.16	0.32	0.01	0.20	6.34	9.2	4.1	4.6	3500	400
BWW01	6	32	88	0.35	0.23	0.02	0.18	6.58	22.9	5.8	21.7	7100	4600
BWW01	9	28	75	0.17	0.41	0.04	0.14	4.84	19.9	4.7	26.2	8000	5200
BWW01	12	19	1.6	0.13	0.16	0.10	0.18	3.41	18.5	5	26.7	13000	8900
BWW01	16	24	60	0.07	0.24	0.08	0.09	2.9	12.6	9.5	15	7900	6500
BWW01	20	28	49	0.21	0.22	0.03	0.08	2.27	10	6.1	9.1	NA	NA
BWW01	24	29	39	0.11	0.18	0.01	0.08	2.35	7.5	3.4	7.4	2100	1100
BWW01	28	29	36	0.09	0.16	0.01	0.03	1.37	5.9	3	8.2	NA	NA
BWW01	32	30	36	0.10	0.11	0.03	0.03	1.24	4.4	2	3.8	2900	770
BWW01	36	31	33	0.13	0.17	0.01	0.03	3.91	4.8	2.1	5.7	NA	NA
BWW01	40	35	37	0.22	0.18	0.01	0.03	1.75	4.5	3	3.2	2900	600
BWW01	44	35	30	0.18	0.23	0.01	0.07	1.81	3.1	4.6	2	NA	NA
BWW01	48	33	34	0.22	0.30	0.01	0.09	1.93	2.8	3.4	2.4	2500	280
BWW01	72	36	39	0.23	0.31	0.01	0.14	4.42	4.4	4.2	3.5	400	270
BWW02	P	70	48	5.32	0.80	0.83	1.63	7.66	15.2	15.6	4.7	15000	2800
BWW02	0	64	31	7.09	0.42	0.85	1.38	6.03	10.9	15.2	2.9	NA	NA
BWW02	3	59	36	6.94	0.30	0.61	1.35	5.36	11.2	13.9	3.2	10000	15000
BWW02	6	58	78	3.70	0.21	0.71	2.04	11.8	24.2	16.1	16.1	35000	5000
BWW02	9	38	88	3.78	0.19	0.46	1.73	10.9	27	12.6	28.8	22000	8000
BWW02	12	25	70	2.80	0.29	0.35	1.32	5.45	21.3	9.2	19.7	600	12000
BWW02	16	25	54	2.55	0.32	0.48	1.04	6.58	19	10.8	16	43000	22000
BWW02	20	30	42	3.00	0.38	0.43	1.04	7.66	16.1	13.4	10.3	NA	NA
BWW02	24	34	33	3.56	0.32	0.40	0.71	8.1	12.3	12.2	5.9	17000	8700
BWW02	28	36	27	1.73	0.32	0.27	0.55	4.66	10.4	10.1	5	NA	NA
BWW02	32	36	21	2.66	0.17	0.21	0.46	3.61	7.6	8.2	4.1	28000	4300
BWW02	36	42	23	3.67	0.17	0.30	0.84	4.67	10.5	13.8	5.2	NA	NA
BWW02	40	42	16	4.42	0.17	0.27	0.54	3.76	7.1	10.3	2.7	18000	2200
BWW02	44	41	23	4.08	0.39	0.02	0.62	5.65	8.9	12.3	4	NA	NA
BWW02	48	46	16	5.52	0.17	0.30	0.50	6.65	7.5	12.2	2.7	31000	1900
BWW02	72	45	16	5.51	0.22	0.05	0.63	5.48	8.4	13.1	3.5	11000	470
BWW04	P	51	29	3.46	1.21	0.90	1.55	3.97	10.9	11.8	1.9	9800	670
BWW04	0	48	42	5.00	1.21	0.66	1.60	5.02	13.7	12.9	5.8	NA	NA
BWW04	3	44	36	8.65	0.45	0.79	1.56	4.94	11.6	14.2	3.2	13000	1800
BWW04	6	50	47	2.80	0.07	0.67	1.62	5.62	13.9	14.9	7.2	8300	1300
BWW04	9	40	115	4.24	0.45	0.58	5.18	27.5	60.6	27.7	39.1	25000	3900
BWW04	12	23	136	2.27	0.25	0.42	4.14	23.8	58.5	20.8	51.3	31000	7100
BWW04	16	18	57	5.42	0.37	0.42	1.76	5.9	20.9	10.3	18.2	38000	10000
BWW04	20	18	51	2.25	0.37	0.58	0.98	5.65	18	9.3	13.4	NA	NA
BWW04	24	20	43	2.74	0.50	0.49	1.08	5.57	14.7	11.3	8.5	61000	12000
BWW04	28	19	28	1.84	0.62	0.42	0.76	5.04	12.4	11.8	5.8	NA	NA
BWW04	32	20	32	2.15	0.32	0.34	0.66	3.81	9.3	9.7	4.2	22000	4400
BWW04	36	23	26	1.40	0.31	0.27	0.55	2.88	8.4	8.2	7.5	NA	NA
BWW04	40	28	22	2.85	0.37	0.34	0.72	3.22	9.4	11.2	3.9	18000	1400
BWW04	44	20	18	1.34	0.31	0.23	0.43	2.41	5.7	10	1.5	NA	NA
BWW04	48	25	25	4.32	0.42	0.27	0.58	2.85	8.5	10.6	3.8	17000	1400
BWW04	72	26	18	2.77	0.49	0.16	0.60	3.29	7.2	11.2	3.5	6300	1900
BWW05	P	28	9	NA	0.11	ND	ND	0.27	1.5	ND	ND	NA	NA
BWW05	0	29	10	ND	0.12	ND	ND	0.29	2.2	0.9	1.9	NA	NA
BWW05	3	27	2	NA	0.12	ND	0.06	0.29	2.8	0.7	3.1	NA	NA
BWW05	6	27	6	NA	0.12	ND	ND	0.1	1	ND	2.1	NA	NA
BWW05	9	26	6	NA	0.11	ND	ND	0.1	1.4	ND	0.8	NA	NA
BWW05	12	27	3	NA	0.07	ND	0.20	0.48	4.1	ND	2.9	NA	NA
BWW05	16	27	7	NA	0.05	ND	ND	0.1	1.2	ND	2.1	NA	NA
BWW05	20	27	ND	NA	0.05	ND	ND	0.1	0.8	ND	1.5	NA	NA
BWW05	24	31	20	NA	0.02	ND	ND	0.56	1.6	1.5	ND	NA	NA
BWW05	28	29	ND	NA	0.02	ND	ND	0.54	1.4	2.2	NA	NA	NA
BWW05	32	28	ND	NA	0.02	ND	ND	0.49	1	1.1	2.8	NA	NA

Table A.2 Water Quality Data for Storm 2 (Continued)

Station	Run	Na mg/L	Zn ug/L	NH3 mg/L	NO3 mg/L	PO4 mg/L	Cd ug/L	Cr ug/L	Cu ug/L	Ni ug/L	Pb ug/L	F.C. md/100mL	E.C. md/100mL
BWW05	36	25	4	NA	0.02	ND	ND	0.39	1.4	0.7	4.7	NA	NA
BWW05	40	30	6	NA	ND	ND	ND	0.42	2	0.6	2.9	NA	NA
BWW05	44	27	ND	NA	0.02	ND	ND	0.64	1.8	3	7	NA	NA
BWW05	48	28	3	NA	0.02	ND	ND	0.55	1	2.1	0.9	NA	NA
BWW05	72	30	ND	NA		ND	ND	0.5	1	1.2	1	NA	NA
BWW06	P	40	27	4.25	1.75	0.71	1.40	2.48	13	12.3	2.8	1700	220
BWW06	0	42	43	4.77	1.86	0.77	1.57	3.27	14.5	11.4	5.5	NA	NA
BWW06	3	40	32	4.83	1.04	0.88	1.47	2.9	14.5	12	5.5	3700	280
BWW06	6	50	43	3.02	1.54	0.55	1.38	3.39	13.1	10.4	10.6	5100	100
BWW06	9	47	33	3.89	1.22	0.61	1.40	4.25	12.9	11.3	5.4	8500	2500
BWW06	12	41	102	6.17	0.29	0.48	3.64	20	50.8	19.7	37.7	38000	2400
BWW06	16	30	54	3.79	0.35	0.40	1.95	7.49	23.7	11.8	19.2	26000	7100
BWW06	20	21	48	2.90	0.75	0.40	1.38	4.29	16	8.2	14.8	NA	NA
BWW06	24	19	42	2.01	0.58	0.36	1.12	4.3	15.6	8.6	18.2	24000	11000
BWW06	28	22	39	1.71	0.40	0.33	1.05	5.11	13.8	6.2	15.1	NA	NA
BWW06	32	25	36	3.00	0.55	0.30	0.96	4.77	12.9	9	8.2	38000	6200
BWW06	36	26	38	1.83	0.44	0.30	0.81	4.02	11.2	8.4	19.4	NA	NA
BWW06	40	28	34	2.03	0.52	0.21	0.70	3.12	10.3	7.9	7.4	11000	810
BWW06	44	28	27	2.80	0.58	0.24	0.69	3.34	9.7	8.6	6.8	NA	NA
BWW06	48	31	28	2.52	0.41	0.24	0.71	3.23	10.5	6.2	6.1	8400	1000
BWW06	72	30	22	1.40	0.52	0.18	0.60	3.57	6.9	7	6.2	1400	390
BWW07	P	46	38	2.57	1.72	0.69	1.48	3.89	13.2	13.5	3.5	1200	78
BWW07	0	45	39	3.51	1.66	0.66	1.31	3.92	13.3	12.9	3.8	NA	NA
BWW07	3	41	45	2.92	1.72	0.69	1.41	3.89	13.3	13.2	4.7	2100	40
BWW07	6	37	37	2.67	1.77	0.66	1.31	3.52	12.7	12.6	5.2	2200	130
BWW07	9	43	31	2.85	1.43	0.66	1.31	3.48	13.3	12	4.8	3800	970
BWW07	12	38	33	4.40	1.57	0.62	1.31	3.64	14.2	12.8	5	1200	280
BWW07	16	49	43	3.10	1.10	0.52	1.42	4.96	15.8	10.2	6.5	5000	500
BWW07	20	45	24	3.73	0.63	0.39	0.49	1.23	15.4	6.2	8.75	NA	NA
BWW07	24	37	42	4.56	0.63	0.32	1.38	5.13	16.5	7.8	11.6	20000	2600
BWW07	28	33	47	1.55	0.84	0.29	1.28	4.35	16	8.6	10.2	NA	NA
BWW07	32	30	48	2.66	0.66	0.29	1.16	4.1	14.7	8.2	9.3	17000	2800
BWW07	36	28	48	2.26	0.83	0.25	1.72	4.35	15	9.9	8.8	NA	NA
BWW07	40	27	50	1.64	0.54	0.32	0.88	4.41	12	8.5	7.4	11000	6400
BWW07	44	29	45	1.26	0.54	0.32	1.00	4.94	13.3	8.8	7.2	NA	NA
BWW07	48	30	54	1.25	0.54	0.25	1.11	3.29	9.3	8.5	6.3	16000	2400
BWW07	72	33	53	1.16	0.54	0.25	1.10	4.19	12.6	8.9	8	4900	410
BWW08	P	50	38	1.65	2.00	0.63	1.55	4.83	14	14.3	4.1	1400	91
BWW08	0	47	47	2.47	1.95	0.58	1.56	4.88	14.9	13.9	5	NA	NA
BWW08	3	46	48	2.12	2.00	0.55	1.63	4.99	14.7	14	5.4	910	70
BWW08	6	47	47	2.17	1.63	0.61	1.61	4.74	14.9	13.5	5.9	780	40
BWW08	9	45	41	2.14	1.60	0.65	1.49	4.29	15.3	13.1	6.9	3000	55
BWW08	12	45	49	2.82	1.60	0.61	1.65	5.08	18.8	12.7	7.3	5000	220
BWW08	16	43	61	3.48	1.57	0.61	2.38	13.6	33	14.9	18.5	1800	390
BWW08	20	48	50	3.31	1.49	0.58	2.13	11.4	25.8	13.4	15.1	NA	NA
BWW08	24	48	45	2.95	0.86	0.43	2.09	9.44	22	12.9	12.7	3200	780
BWW08	28	41	46	1.97	0.69	0.36	1.83	7.44	20.8	12.3	13.6	NA	NA
BWW08	32	33	42	2.93	0.69	0.34	1.68	6.65	19.8	10.4	13.1	19000	3800
BWW08	36	30	39	2.69	0.58	0.34	1.35	4.15	15.5	9.4	9.4	NA	NA
BWW08	40	28	56	2.55	0.57	0.35	2.15	4.91	17.1	9	12.3	16000	2300
BWW08	44	28	45	2.11	0.52	0.35	1.41	6.44	16.7	9.8	14	NA	NA
BWW08	48	30	36	2.20	0.52	0.30	1.57	2.63	12.2	10.1	17.4	15000	3300
BWW08	72	34	28	1.05	0.52	0.30	0.81	3.52	10.1	6.6	5.6	4700	580
BWW09	P	5	3	0.01	0.12	ND	ND	0.42	2.3	ND	ND	3	3
BWW09	0	5	7	ND	0.13	0.01	ND	0.78	0.7	ND	0.9	NA	NA
BWW09	3	4	12	ND	0.17	0.01	ND	0.63	1.4	ND	0.7	70	30
BWW09	6	4	9	ND	0.15	0.00	ND	0.8	0.8	ND	1	60	11
BWW09	9	5	15	ND	0.16	0.01	ND	0.63	1	ND	2.1	200	98
BWW09	12	5	11	0.05	0.15	0.01	ND	0.97	1.1	ND	2.4	350	130
BWW09	16	ND	16	ND	0.14	0.01	ND	0.93	1.4	ND	1.2	170	250
BWW09	20	4	12	ND	0.12	0.00	ND	1.09	1	ND	0.8	NA	NA
BWW09	24	2	14	ND	0.09	0.00	ND	0.95	1.2	ND	1.6	280	200
BWW09	28	3	17	0.05	0.11	0.00	ND	0.83	1.2	ND	1.1	NA	NA
BWW09	32	2	15	ND	0.11	0.00	ND	0.92	1.2	ND	8.9	130	180
BWW09	36	ND	8	0.08	0.04	0.00	ND	0.6	1.1	ND	3.9	NA	NA
BWW09	40	ND	14	ND	0.06	0.00	ND	0.51	1.3	ND	1.2	90	83
BWW09	44	ND	13	0.02	0.07	0.00	ND	0.49	1.5	ND	1.4	NA	NA
BWW09	48	ND	16	ND	0.38	0.00	0.05	0.28	1.3	ND	0.8	140	83
BWW09	72	ND	12	0.01	NA	NA	0.09	0.24	0.9	ND	1.3	190	61
BWW10	P	10	4	NA	0.10	0.01	0.05	0.45	1	ND	0.8	NA	NA
BWW10	0	26	6	0.10	0.00	ND	ND	ND	1.1	ND	0.5	NA	NA
BWW10	3	26	7	NA	0.02	0.01	ND	ND	0.9	ND	1	NA	NA
BWW10	6	25	8	NA	0.22	ND	ND	ND	1.4	ND	1.7	NA	NA

Table A.2 Water Quality Data for Storm 2 (Continued)

Station	Run	Na mg/L	Zn ug/L	NH3 mg/L	NO3 mg/L	PO4 mg/L	Cd ug/L	Cr ug/L	Cu ug/L	Ni ug/L	Pb ug/L	F.C. md/100mL	E.C. md/100mL
BWW10	9	25	9	NA	0.39	ND	ND	ND	1	ND	1.5	NA	NA
BWW10	12	24	12	NA	0.02	ND	ND	ND	1	ND	1	NA	NA
BWW10	16	25	8	NA	0.02	ND	ND	ND	0.9	ND	0.7	NA	NA
BWW10	20	24	7	NA	0.02	ND	ND	ND	0.9	ND	1	NA	NA
BWW10	24	25	10	NA	0.00	ND	ND	ND	1.7	ND	1	NA	NA
BWW10	28	25	7	NA	0.03	ND	ND	ND	0.9	ND	2.1	NA	NA
BWW10	32	24	8	NA	0.02	ND	0.07	ND	1	ND	0.9	NA	NA
BWW10	36	24	5	NA	0.01	ND	ND	ND	0.8	ND	0.4	NA	NA
BWW10	40	24	7	NA	0.04	ND	ND	0.49	1.5	ND	0.8	NA	NA
BWW10	44	24	4	NA	0.03	ND	ND	0.41	1.1	ND	0.8	NA	NA
BWW10	48	22	9	NA	0.08	0.04	0.19	0.8	1.9	ND	0.9	NA	NA
BWW10	72	23	5	NA	NA	NA	0.10	0.42	1.4	ND	0.8	NA	NA
BWW11	P	37	28	0.61	2.08	0.31	0.73	3.73	12.5	7.4	3.5	120	5
BWW11	0	34	28	0.73	2.08	0.30	0.68	3.08	10.6	7	2.6	NA	NA
BWW11	3	33	27	0.63	2.05	0.25	0.57	2.66	9	5.7	2.1	250	30
BWW11	6	31	25	0.66	1.10	0.26	0.58	2.72	9.4	6.3	2.4	280	40
BWW11	9	30	24	0.68	2.22	0.25	0.84	2.9	10.2	6.4	3.6	310	80
BWW11	12	30	40	0.82	0.95	0.26	0.80	4.67	13.8	6.5	5.7	370	300
BWW11	16	30	47	1.15	1.03	0.30	1.30	8.58	22	8.1	10.9	880	160
BWW11	20	32	55	0.88	1.05	0.34	1.56	11.1	22.4	9.5	14.3	NA	NA
BWW11	24	34	71	1.41	1.40	0.39	2.38	19.3	41.3	12.5	28.5	1300	180
BWW11	28	36	43	1.15	1.13	0.30	2.22	6.31	19.6	9.2	12.2	NA	NA
BWW11	32	33	36	1.94	0.80	0.25	1.96	6.02	15.4	7.7	9.4	5100	730
BWW11	36	30	36	2.10	0.70	0.23	1.21	5.14	14.3	6.4	8.8	NA	NA
BWW11	40	26	31	1.60	0.70	0.23	1.08	4.25	13.4	7.2	8.4	6200	890
BWW11	44	22	42	1.07	0.67	0.21	0.56	6.74	16.1	6.5	11.6	NA	NA
BWW11	48	20	42	1.19	1.67	0.19	0.64	1.99	7.5	5.3	7.6	8800	460
BWW11	72	23	33	0.72	1.67	0.19	0.63	3.49	9.8	5.6	10.3	4700	410
BWW13	P	27	15	0.12	1.28	0.16	0.43	2.21	7.8	5.5	2.7	79	23
BWW13	0	26	22	0.22	0.62	0.17	0.52	2.18	8.5	5.4	3.1	NA	NA
BWW13	3	28	26	0.17	0.62	0.18	0.49	2.5	6.2	5.3	5.6	100	40
BWW13	6	26	20	0.20	0.81	0.17	0.39	2.11	6.7	5.1	2.4	50	5
BWW13	9	25	17	0.13	0.56	0.16	0.44	2.14	6.5	4.6	3.3	140	63
BWW13	12	22	29	0.30	0.47	0.14	0.48	2.09	6.3	4	3.9	240	96
BWW13	16	26	17	0.49	0.95	0.17	0.44	2.58	7.8	4.8	3.8	110	68
BWW13	20	27	19	0.36	1.46	0.18	0.46	3.75	8.6	5.6	3.9	NA	NA
BWW13	24	26	21	0.48	0.65	0.18	0.42	3.48	8.3	4.7	4	230	72
BWW13	28	26	24	0.47	1.43	0.18	0.56	4.65	11.9	5.5	7.5	NA	NA
BWW13	32	26	28	1.37	5.07	0.25	0.55	4.65	11.7	5.4	7	800	220
BWW13	36	28	21	1.18	1.41	0.25	0.70	5.23	13.3	5.9	14.4	NA	NA
BWW13	40	28	20	1.97	2.66	0.24	0.59	3.77	10	4.7	6.3	1500	170
BWW13	44	27	18	1.86	1.38	0.20	0.56	4.9	12.4	5.6	7.7	NA	NA
BWW13	48	23	25	1.53	1.29	0.14	0.49	1.57	6.5	3.5	9.2	1900	330
BWW13	72	18	27	0.56	1.29	0.14	0.52	5.06	12.1	4.1	10.2	2100	2100
BWW14	P	3	7	0.08	0.37	ND	ND	0.64	2.2	ND	1.3	320	120
BWW14	0	3	10	0.08	0.38	ND	ND	0.33	1.6	ND	1	NA	NA
BWW14	3	3	16	0.08	0.37	ND	ND	0.54	1.7	ND	1.4	400	70
BWW14	6	3	8	0.11	0.42	ND	0.06	1.65	2.3	ND	7.8	380	110
BWW14	9	2	9	0.07	0.31	ND	0.05	0.62	1.9	ND	1.8	440	140
BWW14	12	3	11	0.14	0.42	ND	0.06	0.47	1.9	ND	1.5	210	190
BWW14	16	4	2	0.10	0.33	ND	ND	0.21	1.7	ND	0.9	130	97
BWW14	20	4	4	0.08	0.32	ND	ND	NA	1.7	0.6	1.2	NA	NA
BWW14	24	3	5	0.08	0.33	ND	ND	0.45	1.5	0.6	1.2	80	53
BWW14	28	3	4	0.17	0.28	ND	ND	0.23	1.6	ND	1.2	NA	NA
BWW14	32	3	ND	0.03	0.38	ND	ND	0.36	1.9	1	2.2	170	2600
BWW14	36	3	ND	0.17	0.32	ND	0.05	0.73	1.8	ND	2	NA	NA
BWW14	40	2	ND	0.03	0.31	ND	0.05	0.47	2.1	0.7	1.5	170	160
BWW14	44	4	5	0.13	0.33	ND	ND	0.45	1.5	ND	1.2	NA	NA
BWW14	48	3	6	0.05	0.32	ND	ND	0.31	1.6	1	0.6	60	40
BWW14	72	9	5	0.15	NA	NA	0.06	0.27	2.3	1.1	1.7	380	850
BWW15	P	21	10	0.31	0.55	ND	ND	0.6	1.7	0.5	1	NA	NA
BWW15	0	20	9	0.33	0.55	ND	0.07	0.1	5.6	0.9	3.1	NA	NA
BWW15	3	20	14	0.35	0.54	ND	ND	0.7	1.1	1	1.6	NA	NA
BWW15	6	21	5	0.32	0.54	ND	ND	0.51	1	ND	1.2	NA	NA
BWW15	9	19	9	0.45	NA	0.00	0.09	0.46	1.5	ND	3.3	NA	NA
BWW15	12	19	10	0.36	0.67	0.02	ND	0.24	1.1	0.6	6.1	NA	NA
BWW15	16	20	11	0.36	0.46	0.06	0.05	0.36	1.2	0.7	2.8	NA	NA
BWW15	20	21	4	0.36	0.43	0.01	0.05	0.35	1.2	0.6	3.4	NA	NA
BWW15	24	20	6	0.26	0.43	0.00	ND	0.21	1.4	1	2	NA	NA
BWW15	28	20	7	0.37	0.47	ND	ND	0.28	1.5	0.7	1.4	NA	NA
BWW15	32	21	5	0.39	0.48	ND	ND	0.54	1.2	0.7	1.4	NA	NA
BWW15	36	20	8	0.39	0.49	0.01	ND	0.29	1.1	0.8	1.1	NA	NA
BWW15	40	17	4	0.34	0.49	0.01	ND	ND	0.8	1.2	0.9	NA	NA
BWW15	44	18	4	0.35	0.49	0.01	ND	ND	1.2	ND	1.4	NA	NA

Table A.2 Water Quality Data for Storm 2 (Continued)

Station	Run	Na mg/L	Zn ug/L	NH3 mg/L	NO3 mg/L	PO4 mg/L	Cd ug/L	Cr ug/L	Cu ug/L	Ni ug/L	Pb ug/L	F.C. md/100mL	E.C. md/100mL
BWW15	48	20	5	0.33	0.48	ND	0.14	ND	4.5	1.5	1.5	NA	NA
BWW15	72	18	4	0.26	NA	NA	0.25	ND	1.7	ND	1	NA	NA
BWW16	P	19	16	0.28	0.75	0.03	0.39	ND	3.9	0.9	1.9	46000	3000
BWW16	0	18	24	0.54	0.75	0.07	0.15	ND	3.5	0.6	8.6	NA	NA
BWW16	3	18	25	0.17	0.81	0.03	0.14	ND	2.4	ND	4.3	59000	6700
BWW16	6	18	23	0.19	0.82	0.04	0.17	ND	3.1	ND	5.9	45000	1700
BWW16	9	12	67	0.18	0.54	0.09	0.37	ND	7.3	1.6	5.35	62000	12000
BWW16	12	16	15	0.19	0.75	0.04	0.10	ND	2	0.6	2.9	44000	3800
BWW16	16	14	24	0.01	0.63	0.04	0.11	ND	5.7	0.6	8.7	79000	4800
BWW16	20	13	21	0.14	0.48	0.01	0.07	4.93	3.8	9	3.8	NA	NA
BWW16	24	12	18	ND	0.52	0.01	0.12	ND	3.7	0.5	8.3	42000	2800
BWW16	28	13	8	0.13	0.45	0.01	0.10	ND	3.1	0.5	6	NA	NA
BWW16	32	12	4	ND	0.42	0.01	ND	ND	1.6	ND	4.1	26000	1500
BWW16	36	15	8	0.51	0.40	0.03	0.07	ND	1.6	1	1.5	NA	NA
BWW16	40	14	5	0.05	0.47	0.01	ND	ND	1.8	0.9	2.3	26000	1600
BWW16	44	15	3	0.21	0.45	0.01	0.07	0.14	1.7	1.1	2.6	NA	NA
BWW16	48	14	82	0.03	0.74	0.01	0.24	1.07	2.1	ND	2.9	14000	2200
BWW16	72	15	5	0.34	0.74	0.01	ND	0.46	1.7	ND	1.8	28000	3400
BWW17	P	28	17	0.12	2.13	0.19	0.52	2.05	8	4.9	2.4	110	43
BWW17	0	27	33	0.10	1.58	0.18	0.41	1.81	8.9	4.7	2.7	NA	NA
BWW17	3	26	27	0.10	1.44	0.16	0.35	1.92	6.8	4.7	2.6	120	40
BWW17	6	26	18	0.08	1.51	0.18	0.41	2.12	6.7	4.7	3.5	640	310
BWW17	9	24	27	0.01	1.37	0.16	0.34	2.3	9.2	4	5.1	1200	1100
BWW17	12	28	24	0.11	1.41	0.17	0.34	1.97	7	4.7	5.3	990	390
BWW17	16	26	18	0.18	1.44	0.18	0.38	1.99	7.6	5	3.4	200	780
BWW17	20	25	13	0.17	1.31	0.16	0.38	2.09	7.4	5.9	3.3	NA	NA
BWW17	24	24	12	0.21	1.17	0.16	0.38	1.75	7	4.2	12.4	750	170
BWW17	28	27	12	0.48	1.86	0.19	0.51	2.52	9.9	6	3.4	NA	NA
BWW17	32	28	19	0.37	1.27	0.16	0.52	2.87	8.2	5.4	5.8	340	160
BWW17	36	27	15	0.88	1.31	0.19	0.64	3.24	9.4	5.6	6.1	NA	NA
BWW17	40	27	24	0.18	1.51	0.24	0.68	3.31	10.5	6.3	5.7	870	330
BWW17	44	28	19	1.20	1.34	0.25	0.70	3.09	10.8	6.6	5.5	NA	NA
BWW17	48	26	17	0.95	2.60	0.21	0.54	1.68	6.8	5.7	1.5	1200	350
BWW17	72	20	27	0.74	2.60	0.21	1.04	3.07	9.5	5	9.3	2000	620
BWW18	P	32	20	0.80	2.74	0.16	0.42	1.68	8.5	5	2.6	120	12
BWW18	0	33	33	0.42	1.72	0.30	0.36	1.46	7.4	4.3	2.5	NA	NA
BWW18	3	34	22	1.87	1.62	0.31	0.39	1.6	6.9	5.1	3	630	46
BWW18	6	35	20	1.36	1.72	0.31	0.41	1.94	9.2	4.6	4.1	980	77
BWW18	9	35	36	0.68	1.55	0.36	0.71	2.72	10.2	4.6	8.3	930	130
BWW18	12	32	29	1.08	1.51	0.31	0.41	1.71	6.5	4.3	3	280	24
BWW18	16	32	17	1.52	1.48	0.26	0.37	1.53	8.6	4	2.7	310	80
BWW18	20	34	20	1.62	1.23	0.26	0.37	1.94	9	4.4	3.9	NA	NA
BWW18	24	35	22	1.19	1.35	0.31	0.50	2.26	10.6	4.1	6	1300	570
BWW18	28	32	20	0.75	1.51	0.28	0.57	1.92	12	4.9	4.3	NA	NA
BWW18	32	29	21	1.24	1.40	0.25	0.51	3.36	10	4.5	5.07	1000	58
BWW18	36	29	17	0.62	1.31	0.23	0.52	2.67	9	5.2	4.5	NA	NA
BWW18	40	30	18	1.30	1.12	0.25	0.59	3.04	11.3	4.9	4.7	560	130
BWW18	44	33	23	0.74	1.15	0.31	0.64	3	11.6	5.6	4.8	NA	NA
BWW18	48	31	19	1.52	1.47	0.33	0.46	1.31	7.7	5.3	1.3	980	170
BWW18	72	28	16	2.06	1.47	0.33	0.62	2.53	11.1	3.8	5.2	2100	630
BWW20	P	32	17	0.54	1.80	0.23	0.35	1.36	6.9	3.7	2.2	140	3
BWW20	0	33	32	0.56	1.71	0.19	0.35	1.39	7.1	4.3	2.7	NA	NA
BWW20	3	33	15	0.70	1.40	0.20	0.35	1.42	7.2	3.9	2.7	290	11
BWW20	6	34	20	0.79	1.40	0.23	0.23	0.93	6.9	4.7	3.3	120	9
BWW20	9	32	23	0.47	1.40	0.23	0.28	0.88	6.7	5.6	2.7	380	45
BWW20	12	30	28	0.72	1.77	0.23	0.43	1.26	7.5	4.2	4.2	120	73
BWW20	16	30	23	0.80	1.77	0.22	0.44	1.07	9.8	7.7	3.6	90	34
BWW20	20	31	13	1.15	1.70	0.27	0.41	1.05	8.9	4.8	2.9	NA	NA
BWW20	24	31	21	0.80	1.60	0.29	0.47	1.66	8.3	5.9	4.4	NS	NS
BWW20	28	31	29	0.32	1.50	0.32	0.55	2.37	9.7	7	6	NA	NA
BWW20	32	32	26	1.10	1.46	0.28	0.64	3.12	11.4	6.1	7.9	590	290
BWW20	36	31	32	0.69	0.82	0.25	0.71	2.6	10.2	7	6.2	NA	NA
BWW20	40	30	24	0.56	1.33	0.29	0.46	2.42	11.4	6.8	5.7	760	120
BWW20	44	28	26	0.68	1.36	0.27	0.52	1.62	8.9	6	5.4	NA	NA
BWW20	48	28	26	0.93	1.33	0.23	0.37	0.95	5.6	6.1	1.6	150	3
BWW20	72	31	26	1.48	1.33	0.23	0.62	2.47	8.9	7.9	5.4	840	86
BWW21	P	29	19	0.73	1.91	0.32	0.31	0.72	5.1	3.2	3.7	96	17
BWW21	0	28	36	0.33	1.82	0.25	0.39	0.64	5.9	4.5	6	NA	NA
BWW21	3	29	18	1.07	1.52	0.22	0.30	0.75	5	4.8	9	200	20
BWW21	6	30	19	0.89	1.61	0.22	0.28	0.42	5.7	6	10.1	60	40
BWW21	9	26	26	0.56	1.56	0.20	0.40	2.26	8.2	5.4	2.7	15000	4300
BWW21	12	28	25	0.94	1.78	0.16	0.29	1.69	7.4	4.6	3.9	5100	540
BWW21	16	28	19	0.94	1.63	0.20	0.35	1.06	7.6	5	2.9	1700	550

Table A.2 Water Quality Data for Storm 2 (Continued)

Station	Run	Na mg/L	Zn ug/L	NH3 mg/L	NO3 mg/L	PO4 mg/L	Cd ug/L	Cr ug/L	Cu ug/L	Ni ug/L	Pb ug/L	F.C. md/100mL	E.C. md/100mL
BWW21	20	27	20	1.18	1.83	0.17	0.44	0.82	6.7	4.5	3	NA	NA
BWW21	24	27	20	0.85	1.77	0.17	0.44	0.78	6.7	5	4	NS	NS
BWW21	28	26	21	0.50	1.73	0.17	0.43	0.74	6.7	5.5	4.9	NA	NA
BWW21	32	27	27	0.89	1.88	0.26	0.63	1.67	8	4.2	5	340	88
BWW21	36	27	23	0.62	1.45	0.25	0.65	2.62	9.5	5.3	7.3	NA	NA
BWW21	40	27	34	0.62	1.56	0.25	0.72	2.82	10.9	5.8	10.9	800	140
BWW21	44	27	35	0.78	1.62	0.24	0.63	2.25	10.7	4.3	7.2	NA	NA
BWW21	48	27	30	0.67	1.75	0.25	0.68	2.11	8.8	5.6	5.9	630	73
BWW21	72	28	31	1.33	1.75	0.25	0.73	1.92	9.2	5	6.8	980	410
BWW22	P	20	82	3.20	1.56	0.09	0.40	4.2	15	8.8	28	400000	24000
BWW22	0	16	103	1.28	1.43	0.23	0.25	4.9	13	6	35	190000	84000
BWW22	3	12	98	0.35	1.24	0.31	0.20	3.8	22	4.3	22		
BWW23	P	59	24	13.1	1.70	1.15	2.68	2.44	17.9	17.9	1.6	28000	4900
BWW23	0	74	38	17.7	0.88	1.53	2.66	8.6	15.4	26.3	1.9	NA	NA
BWW23	3	75	40	20.8	0.34	1.30	2.82	7.67	15.5	30.1	1.9	12000	8500
BWW23	6	74	39	12.7	0.18	1.45	2.75	5.63	15.5	27.7	4.3	120000	13000
BWW23	9	63	35	7.38	0.63	1.45	2.38	4.2	13	22	2.4	100000	11000
BWW23	12	38	29	12.6	0.38	1.30	1.77	3.42	14.9	17.1	3.1	120000	18000
BWW23	18	32	35	12.7	0.43	1.45	1.63	11.3	19.1	15.5	4.7	120000	13000
BWW23	20	39	40	12.0	0.18	1.61	1.63	13.6	20.5	21.8	4.3	NA	NA
BWW23	24	42	36	12.5	0.08	1.45	1.49	12.8	21.7	23	2.7	39000	13000
BWW23	28	NS	38	12.8	0.05	1.45	1.56	10.9	22	25.9	3.2	NA	NA
BWW23	32	48	33	12.5	0.03	1.22	1.59	10.1	18.2	28.8	3.6	100000	14000
BWW23	36	48	38	8.1	0.05	0.84	2.02	8.43	16.7	28.9	4.5	NA	NA
BWW23	40	54	39	12.7	0.08	0.99	2.45	12.4	15.6	23	4.1	90000	12000
BWW23	44	55	32	13.3	0.01	1.22	2.52	13.9	17.9	28	1.8	NA	NA
BWW23	48	62	28	17.6	0.01	1.30	2.35	20.2	16.3	31.7	2.5	110000	18000
BWW23	72	62	27	12.5	0.61	0.24	2.66	31.5	14	45.5	3.2	21000	5600
BWW24	P	236	232	29.0	0.21	4.70	0.80	2.55	40.8	4.4	19.1	70	10
BWW24	0	226	121	22.3	0.03	4.18	0.48	1.49	24.8	3.6	8.5	NA	NA
BWW24	3	223	63	32.7	0.05	3.58	0.25	1.5	7.4	4.8	3.2	<1.0E+00	<1.0E+00
BWW24	6	238	55	18.4	0.04	2.91	0.23	6.74	8.5	3.2	3.3	2	1
BWW24	9	240	275	19.2	0.08	3.13	1.50	3.87	46.3	5	19.5	48000	3000
BWW24	12	242	311	20.5	0.84	3.43	1.30	3.66	55.7	5.4	17.4	69000	14000
BWW24	18	262	248	24.0	0.07	4.18	1.14	3.03	53	4.4	14.5	3	70
BWW24	20	255	238	25.2	0.04	4.77	0.70	2.91	41.8	4.1	15	NA	NA
BWW24	24	254	47	33.6	0.03	4.77	0.16	0.62	7.3	3.6	2.8	610	3
BWW24	28	267	45	28.0	0.03	3.43	0.11	0.33	4.6	4.1	2.5	NA	NA
BWW24	32	267	367	24.8	0.31	3.21	0.63	2.69	61.9	5.6	22.7	79000	15000
BWW24	36	280	328	28.9	0.21	4.85	1.30	5.3	53.7	4.4	21	NA	NA
BWW24	40	296	255	26.7	0.02	7.16	1.01	5.11	43	4.2	17.9	230	13
BWW24	44	297	180	25.8	0.01	6.19	0.69	3.98	26.5	5	11.4	NA	NA
BWW24	48	289	169	28.4	0.01	5.96	0.65	3.87	28.1	4.8	10.5	1	1
BWW24	72	NA	NA	29.8	NA	NA	NA	NA	NA	NA	NA	10	15
BWW25	P	82	63	14.1	3.69	*.76	0.25	4.98	20.5	111	10.8	110	<1.0E+00
BWW25	0	108	72	17.9	1.36	4.76	0.36	4.02	21.7	112	11.3	NA	NA
BWW25	3	111	95	25.9	1.36	4.76	0.34	4.01	25.9	106	7.9	200	<1.0E+00
BWW25	6	122	104	15.6	1.40	5.23	0.42	6.78	34.6	101	7.4	1800	46
BWW25	9	98	200	10.3	1.20	4.56	0.43	17.3	67.2	88.5	24.9	3000	210
BWW25	12	75	59	9.8	1.48	3.10	0.21	4.24	16.9	55.2	5	140	3
BWW25	16	60	189	9.9	1.88	2.03	0.34	17.1	86.8	72.8	24	1400	110
BWW25	20	60	107	19.6	1.48	2.43	0.32	6.16	24.2	53.7	9.1	NA	NA
BWW25	24	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
BWW25	28	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
BWW25	32	81	86	10.3	0.28	3.10	0.26	40.12	30.5	53.5	7.7	11	25
BWW25	36	83	90	6.5	0.22	2.36	0.20	6	35.2	73.4	7.7	NA	NA
BWW25	40	88	82	10.3	0.32	3.10	0.29	5.44	37	73.6	12.9	320	9
BWW25	44	98	107	15.8	NA	3.63	0.23	4.15	32.3	65.9	4.3	NA	NA
BWW25	48	95	372	16.7	NA	4.16	0.22	11.77	53.4	35	72.3	240	2
BWW25	72	NA	NA	19.3	NA	NA	NA	NA	NA	NA	NA	1600	14
BWW26	6	NA	474	3.70	0.40	1.00	1.20	6.1	54.2	120	40.2	1500000	280000
BWW26	9	NA	313	3.45	0.44	1.41	0.66	5.66	54.8	112	39.9	210000	1200

ND = Not Detected
 NS= No Sample
 NM= Not Measured
 NA = Not Analyzed

Table A.3 Water Quality Data for Storm 3

Station	Run	Date	Time	Flow cfs	Temp deg C	pH	Cond umhos/cm	DO mg/L	BOD mg/L	TSS mg/L	VSS mg/L	Cl mg/L	Ca mg/L	Mg mg/L
BWW00	P	10/12/93	0730	38.3	9.5	6.69	178	9	4.6	2.6	0.5	54.7	16	3.47
BWW00	0	10/12/93	1230	38.3	9.5	6.82	169	10.4	2.3	1.2	1	61.8	16	2.96
BWW00	9	10/12/93	2025	530	9	6.26	72	10.6	12.3	73	21.6	16.9	6	1.06
BWW00	12	10/13/93	0030	407	10.4	6.26	71	10.4	4	24.2	8.6	14.6	8	1.53
BWW00	16	10/13/93	0420	140	9	6.53	147	11	1.35	12	3.8	38.5	11	2.26
BWW00	20	10/13/93	0840	128	7	6.63	160	10	2.1	4	2	50.5	11	2.61
BWW00	24	10/13/93	1219	122	9	6.79	160	11.2	2.1	1.8	1	98.1	13.1	2.33
BWW00	28	10/13/93	1626	109	9.5	6.88	190	11.3	4.6	4.8	2.2	53.2	13	2.76
BWW00	32	10/13/93	2018	48.4	10	6.81	130	11.8	1.3	3.4	1.8	54.3	13	2.59
BWW00	36	10/14/93	0035	100	9	6.71	135	10.2	3.3	2	1	54.1	13	2.62
BWW00	44	10/14/93	0830	76	8	6.75	140	11.2	1.6	1.8	1.6	55.2	13	3
BWW00	52	10/14/93	1609	76	9.2	6.83	NA	10.9	1.6	2.2	1.6	48.1	13	3.15
BWW01	P	10/12/93	0740	41.2	10	6.67	258	9	5.2	0.8	0.5	81.6	23	4.42
BWW01	0	10/12/93	1240	41.2	9.8	6.73	230	10	3.1	0.5	0.5	89.9	21	3.75
BWW01	9	10/12/93	2050	570	9	6.46	110	10.6	13.7	53.4	15.8	28.8	8	1.68
BWW01	12	10/13/93	0040	438	11	6.34	92	11	4.15	43.4	10	21.8	10	2.2
BWW01	16	10/13/93	0430	150	9	6.53	142	11	2	14.4	4.4	38.7	12	4.2
BWW01	20	10/13/93	0854	138	7.2	6.64	162	11	2.3	5.4	2.6	55	11	2.75
BWW01	24	10/13/93	1229	131	9	6.86	182	11	4.8	13	5.4	54.5	14	2.55
BWW01	28	10/13/93	1634	117	10	6.92	209	10.8	5.2	3.6	4.4	57.8	14	2.81
BWW01	32	10/13/93	2026	52	10	6.73	155	11.4	2.2	2.2	1.4	66.4	14	2.72
BWW01	36	10/14/93	0045	108	9	6.53	150	9	2.4	3	1.4	63	14	2.94
BWW01	44	10/14/93	0840	81.7	7	5.96	180	10.6	1.95	4.8	2.4	65.9	14	3.36
BWW01	52	10/14/93	1618	81.7	9.5	6.72	186	10.4	NA	1.8	1.8	63.4	14	3.59
BWW02	P	10/12/93	0750	60.4	13	6.38	322	7.9	6.8	6.4	1.8	98.8	20	4.28
BWW02	0	10/12/93	1255	73.3	13.8	6.49	285	8.6	4.8	1.2	0.5	103	16	3.46
BWW02	9	10/12/93	2120	829	10.5	6.47	155	10.1	13.5	39	12.6	59.9	10	2.59
BWW02	12	10/13/93	0050	637	12.5	6.34	120	12.5	5	37.4	12.6	37.6	9	2.32
BWW02	16	10/13/93	0445	165	10	6.42	178	10.5	2.8	17	6.4	45.1	9	2.26
BWW02	20	10/13/93	0905	153	9.8	6.2	182	10	4.5	7.2	3.6	52.4	9	2
BWW02	24	10/13/93	1245	148	11	6.45	172	9.4	3.8	3.6	2.6	58.1	11	1.67
BWW02	28	10/13/93	1644	130	11.5	6.71	235	10.1	6.8	13.8	11.4	60.9	13	2.81
BWW02	32	10/13/93	2040	130	12	6.49	168	9.8	4.1	2.2	0.5	70.9	12	2.04
BWW02	36	10/14/93	0055	107	11	6.34	200	9	4.2	2.8	1.6	72.6	12	2.21
BWW02	44	10/14/93	0852	103	10.5	6.71	205	9.6	1.3	2.4	2.6	77.2	11	2.59
BWW02	52	10/14/93	1628	105	13	6.55	250	9.1	1.3	1.4	1.4	76.8	13	3.74
BWW04	P	10/12/93	0810	109	11	6.65	249	9.2	7	3	1.4	80.6	16	3.18
BWW04	0	10/12/93	1315	109	11.2	6.68	240	10.5	3.1	0.5	0.5	89.2	15	3.1
BWW04	9	10/12/93	2155	746	11.1	6.51	240	10.5	13.5	129	38.2	63.4	3	ND
BWW04	12	10/13/93	0120	541	12.5	6.53	155	12.5	5	74	23.4	52.1	5	2.04
BWW04	16	10/13/93	0505	378	10	6.63	179	11.5	2.8	26.6	26	46.8	6	2.11
BWW04	20	10/13/93	0921	246	8.5	6.57	160	11.2	4.5	8.2	3.4	50.1	7	1.75
BWW04	24	10/13/93	1300	271	10	6.67	180	10.8	3.8	4.4	3.6	53.2	11	2.03
BWW04	28	10/13/93	1700	277	12	6.9	212	10.9	6.8	6.2	2.4	58.5	12	2.8
BWW04	32	10/13/93	2100	230	10	6.75	160	10.9	4.1	6	2.6	60.9	12	2.5
BWW04	36	10/14/93	0105	215	10	6.63	210	9.4	4.2	4.2	1.4	64.9	11	2.62
BWW04	44	10/14/93	0908	173	9	7	165	10.6	1.3	2.6	2.2	71.2	12	3.08
BWW04	52	10/14/93	1645	187	11.8	6.82	220	10.2	NS	2	2	73.8	13	3
BWW05	P	10/12/93	0835	8.3	10	NA	200	8.2	NA	ND	ND	57.5	16	4.02
BWW05	0	10/12/93	1348	8.8	10.5	6.73	218	9.85	NA	0.8	ND	78.6	17	3.9
BWW05	9	10/12/93	1235	20.2	10.1	6.59	225	10.4	NA	0.6	ND	70.1	12	2.67
BWW05	12	10/13/93	0200	20.8	12.5	6.67	232	12.5	NA	1.4	1.2	73.3	13	3.1
BWW05	16	10/13/93	0540	25.8	10	6.59	230	10	NA	2.4	1.4	78.1	14	3.99
BWW05	20	10/13/93	0952	26.9	8.2	6.69	196	10.1	NA	ND	ND	74.2	12	3.49
BWW05	24	10/13/93	1325	29.9	10	6.71	181	10.4	NA	1.2	ND	73.2	14	3.29
BWW05	28	10/13/93	1723	28.8	11	6.75	248	10.5	NA	4	1.4	75.6	12	2.79
BWW05	32	10/13/93	2128	26.5	10	6.77	192	10.8	NA	2.2	ND	76.8	14	3.3
BWW05	36	10/14/93	0145	24.7	9	6.67	203	10	NA	ND	ND	75.3	14	3.33
BWW05	44	10/14/93	0920	22.7	9	6.42	205	10	NA	2.4	2	78.8	11	2.91
BWW05	52	10/14/93	1713	21.9	10.2	6.65	190	10.2	NA	ND	ND	83.6	12	3.13
BWW06	P	10/12/93	0825	97.9	10.8	6.71	240	8.2	5.2	0.6	0.5	76.8	16	3.56
BWW06	0	10/12/93	1332	97.9	10.3	6.65	220	10.4	3	2	1	86.7	14	3.35
BWW06	9	10/12/93	1215	229	10.8	6.75	269	9.1	3.6	7.4	1	73.5	11	2.74
BWW06	12	10/13/93	0140	456	14	6.69	271	14	4.6	99.2	28.8	75.2	9	2.5
BWW06	16	10/13/93	0525	456	10	6.57	200	11.5	4	28.4	11.2	52.6	7	2.47
BWW06	20	10/13/93	—	216	7	6.65	155	10.3	6.7	15.2	5.8	53.9	8	2.37
BWW06	24	10/13/93	1313	244	10	6.63	183	10.8	5.3	6.4	4.2	51.9	11	2.21
BWW06	28	10/13/93	1712	229	11.5	6.61	200	10.8	5.2	12.4	8.4	53.8	10	2.63
BWW06	32	10/13/93	2113	229	10	6.79	150	10.8	3.3	12.2	10.2	58.2	12	2.62
BWW06	36	10/14/93	0130	260	9	6.75	180	9.4	3.8	5.8	3.2	60.3	13	3.09
BWW06	44	10/14/93	0932	224	9	6.68	201	9.8	1.15	5.4	3.4	70.3	12	3.52
BWW06	52	10/14/93	1701	110	10.4	6.65	210	10.6	NS	2.6	2.6	73.6	12	2.93
BWW07	P	10/12/93	1015	144	10	6.79	300	8.8	6.5	4.8	1.2	75.2	15	3.49

Table A.3 Water Quality Data for Storm 3 (Continued)

Station	Run	Date	Time	Flow cfs	Temp deg C	pH	Cond umhos/cm	DO mg/L	BOD mg/L	TSS mg/L	VSS mg/L	Cl mg/L	Ca mg/L	Mg mg/L
BWW07	0	10/12/93	1440	144	10	6.71	300	8.8	2.1	8.8	4.2	87.1	14	3.27
BWW07	9	10/12/93	2325	201	10	6.77	280	9.5	2.2	8.2	6	76.5	11	2.81
BWW07	12	10/13/93	0315	421	10.5	6.89	275	9.8	2.95	6.6	4	83.2	12	3.37
BWW07	18	10/13/93	0845	570	9.5	6.72	270	10.6	4.3	18.6	5.8	75.2	11	3.35
BWW07	20	10/13/93	1250	300	11	6.79	180	9.6	7.4	14.8	19.2	58.5	9	2.47
BWW07	24	10/13/93	1600	278	10	6.68	221	14.4	6.3	11	5.4	57.8	11	2.37
BWW07	28	10/13/93	1815	287	10	6.65	230	12.3	6.5	8.4	3	56.9	12	2.51
BWW07	32	10/13/93	2230	265	10	6.63	142	12.4	4.2	11	4.8	56.8	11	2.39
BWW07	36	10/14/93	0245	249	9	6.61	170	13	2.9	8	3.6	55.8	10	2.46
BWW07	44	10/14/93	1300	238	10.5	6.71	208	10	1.95	4.2	2.8	63.8	12	3.3
BWW07	52	10/14/93	1805	144	11	6.72	220	10.8	NA	8.4	3.6	71.8	12	3.3
BWW07	72	10/15/93	1135	144	11	NA	240	10	NA	7.2	3.8	75.7	12	3
BWW08	P	10/12/93	0955	152	10	6.68	300	9	4.1	8.2	2.2	76.5	16	3.51
BWW08	0	10/12/93	1425	229	10	6.89	300	9.2	2.6	7.8	3.8	87.4	14	3.39
BWW08	9	10/12/93	2315	127	10	6.65	262	8.4	2.1	9.6	3	74.4	11	2.8
BWW08	12	10/13/93	0255	184	10.5	6.69	260	9.4	2.3	9.6	4.4	77.7	13	3.24
BWW08	16	10/13/93	0630	364	10	6.71	275	10	2.8	62.6	12.8	81.1	8	2.52
BWW08	20	10/13/93	1210	414	11	6.74	210	9.6	6.7	25.6	8	65.4	9	2.69
BWW08	24	10/13/93	1545	352	10	6.59	240	12.4	7.2	14.2	2.4	60.7	11	2.42
BWW08	28	10/13/93	1810	332	10	6.63	229	11.8	4.1	13.6	8.4	59.2	12	2.73
BWW08	32	10/13/93	2215	294	10	6.59	152	13	4.5	12.2	3.6	60.2	8	2.59
BWW08	36	10/14/93	0220	301	8.5	6.67	190	12.4	4.3	9.6	4.2	57.7	10	2.37
BWW08	44	10/14/93	1250	283	10	6.92	180	11.1	1.1	9	3	60.8	11	3.08
BWW08	52	10/14/93	1755	283	10	6.63	205	10.6	NA	8.2	3.2	68.7	10	3.18
BWW08	72	10/15/93	1120	266	10.5	NA	230	10.2	NA	5.6	3	72.1	12	2.88
BWW09	P	10/12/93	0945	16.6	10	7	150	9.8	1.7	1.6	ND	19.3	7	2.31
BWW09	0	10/12/93	1400	23.1	10	6.63	120	9.4	1.2	2.2	0.6	23.3	6	2.28
BWW09	9	10/12/93	2250	38.8	10	6.4	90	9.4	ND	2	ND	20.1	7	1.88
BWW09	12	10/13/93	0225	41.2	10	6.82	90	10.4	1.6	3	1.2	17.3	5	2.2
BWW09	16	10/13/93	0605	37.1	10	6.9	100	10	1.25	3	2	19.3	6	2.41
BWW09	20	10/13/93	1140	17.8	10	6.88	75	9.8	1.7	1.6	1.2	21	6	2.03
BWW09	24	10/13/93	1530	29.5	10	6.64	111	14	1.1	4	7	22.2	8	1.85
BWW09	28	10/13/93	1745	29.5	10	6.16	105	12.2	1.7	3	3	22.5	7	2.08
BWW09	32	10/13/93	2200	25.8	10.5	6.55	162	13.2	1	11.2	10.2	21.5	6	1.99
BWW09	36	10/14/93	0200	25.8	9	6.71	80	13.2	1.8	1.2	ND	21.2	6	2
BWW09	44	10/14/93	1230	27.3	11	6.81	215	11	ND	1.4	1.4	23.5	5	2.42
BWW09	52	10/14/93	1735	25.1	10	6.75	80	10.8	NA	1	1	24.7	5	2.36
BWW09	72	10/15/93	1105	26.6	10.5	NA	85	10.3	NA	3.8	1.2	22.7	5	2.14
BWW10	P	10/12/93	0945	9.1	8.5	6.57	250	8.2	NA	1	ND	62.9	10	2.77
BWW10	0	10/12/93	1405	9.2	9	6.43	200	8.3	NA	1	ND	69.3	10	2.83
BWW10	9	10/12/93	2300	11.9	10	6.06	180	8.2	NA	5.2	2	59.5	9	2.35
BWW10	12	10/13/93	0235	12.8	10	6.32	200	8.8	NA	2.8	2.6	61	8	2.52
BWW10	16	10/13/93	0610	12.6	9.5	6.4	185	9	NA	4	1.6	59.9	10	2.74
BWW10	20	10/13/93	1150	12.1	10	6.45	170	8.8	NA	1.2	ND	64.3	8	2.34
BWW10	24	10/13/93	1540	12.6	10	6.59	212	11.3	NA	2.4	12	63.1	10	2.19
BWW10	28	10/13/93	1745	11.7	10	6.03	209	11	NA	1.6	1.6	64.2	8	2.43
BWW10	32	10/13/93	2200	11.7	9	6.32	165	13	NA	2.6	2.4	64.8	9	2.44
BWW10	36	10/14/93	0200	12.1	8	6.12	175	11.8	NA	1.6	1	61.5	6	2.32
BWW10	44	10/14/93	1230	12.3	9	6.67	165	9.6	NA	2.8	2.2	65.6	9	2.9
BWW10	52	10/14/93	1735	13.0	10	6.45	175	10	NA	1	ND	70.9	7	2.71
BWW10	72	10/15/93	1105	13.9	10.5	NA	185	10.6	NA	0.6	ND	62.7	7	2.4
BWW11	P	10/12/93	0910	202	10	6.65	350	6.5	5.2	5.8	2	73.7	15	2.65
BWW11	0	10/12/93	1330	149	10	6.82	300	9.1	2.1	2.8	1.8	80.3	14	3.37
BWW11	9	10/12/93	2230	372	10	6.61	255	9	1.35	6	3.2	70.3	10	2.8
BWW11	12	10/13/93	0215	143	10	6.59	240	10.8	2.3	5.2	2.8	69	12	3.04
BWW11	16	10/13/93	0550	188	10	6.63	240	9.4	1.5	8.4	3.8	73.3	13	3.4
BWW11	20	10/13/93	1115	341	10	6.59	250	9.8	3.2	42.4	10.8	78.9	10	3.03
BWW11	24	10/13/93	1510	494	10.5	6.61	285	11.7	3.2	35.4	25.8	70.1	13	2.76
BWW11	28	10/13/93	1725	460	10	6.63	252	13.5	5.2	6	6	65.5	11	2.83
BWW11	32	10/13/93	2135	346	10	6.65	180	12.4	4.5	14.2	5.2	65.3	11	2.6
BWW11	36	10/14/93	0145	288	9	6.65	200	11.8	4.5	12.6	4.6	60.6	11	2.57
BWW11	44	10/14/93	1215	267	10	6.71	185	10.1	4	10	3.8	58.4	10	3
BWW11	52	10/14/93	1720	235	10.5	6.6	180	10.3	NA	5.2	2.8	65	10	2.85
BWW11	72	10/15/93	1100	228	10.5	NA	200	10	NA	2.2	1.2	65.3	9	2.84
BWW13	P	10/12/93	0905	228	8.8	6.9	250	10.5	2.4	4.6	1.6	68.6	15	3.46
BWW13	0	10/12/93	1305	177	10.5	6.88	300	9.6	2.1	2.4	1.6	76.7	13	3.61
BWW13	9	10/12/93	2205	423	10	6.69	220	9.4	1.15	3.6	3.2	63.9	9	2.26
BWW13	12	10/13/93	0148	186	11	6.69	240	10.2	2.65	3.6	3	69.3	11	3.07
BWW13	16	10/13/93	0530	223	10	6.71	250	10.2	1.9	5.2	2.6	72	12	3.36
BWW13	20	10/13/93	1057	378	10	6.66	205	10.2	1.5	4.4	2	67.3	10	2.79
BWW13	24	10/13/93	1455	580	10	6.94	270	12.9	1.6	4.4	3.2	66.5	13	2.84
BWW13	28	10/13/93	1710	530	10	6.77	250	12.4	2.4	3.8	3.8	64.7	12	3.01
BWW13	32	10/13/93	2120	495	10	6.69	170	13.5	2	13.4	8.6	68.3	11	2.64

Table A.3 Water Quality Data for Storm 3 (Continued)

Station	Run	Date	Time	Flow cfs	Temp deg C	pH	Cond umhos/cm	DO mg/L	BOD mg/L	TSS mg/L	VSS mg/L	Cl mg/L	Ca mg/L	Mg mg/L
BWW13	36	10/14/93	0135	379	9	6.69	220	12.8	2.1	4.4	2.6	66.6	11	2.82
BWW13	44	10/14/93	1200	320	10	6.9	215	11.6	3.3	12	6.2	65.4	12	3.2
BWW13	52	10/14/93	1710	299	10	6.85	180	10.5	NA	6.2	4.2	66.3	10	2.9
BWW13	72	10/15/93	1045	259	10.5	NA	175	10.7	NA	3.4	3	55	8	2.42
BWW14	P	10/12/93	1035	40.6	11.5	6.9	150	9.1	2.2	2.6	1	23.5	5	1.67
BWW14	0	10/12/93	1520	43.2	11.5	6.47	150	9.4	1.7	1	ND	28.3	4	1.68
BWW14	9	10/12/93	2350	62.1	10	6.4	100	9.4	1.3	2.8	1.6	25	6	1.41
BWW14	12	10/13/93	0345	58.2	12	6.87	110	9.8	2	2.8	2.4	27.1	5	1.69
BWW14	16	10/13/93	0705	54.4	11.5	6.72	105	10.5	1.2	5.8	4.8	22	5	1.63
BWW14	20	10/13/93	-	48.4	12	6.7	90	9.75	1.2	2	1	24.7	6	1.44
BWW14	24	10/13/93	1815	45	10	6.61	111	12.4	1.2	2	1.8	25	6	1.34
BWW14	28	10/13/93	1830	44.5	10	6.82	115	12.8	2.2	20.2	13.6	25.8	5	1.49
BWW14	32	10/13/93	2245	45	11	6.67	165	13.4	1.5	2	1.2	24.7	4	1.46
BWW14	36	10/14/93	0300	45	10	6.71	85	12.6	1.3	1	1	25.8	4	1.46
BWW14	44	10/14/93	1320	45	12	6.92	82	10.5	ND	4.4	1.8	26.3	6	1.78
BWW14	52	10/14/93	1820	44.5	12	6.85	340	10.3	NA	1.8	1.4	27.8	4	1.61
BWW15	P	10/12/93	0840		9.75	5.6	138	5.3	NA	6	3.2	32.2	13	2.74
BWW15	0	10/12/93	1315		11.5	5.91	138	8.3	NA	4.2	2.4	39.8	10	2.75
BWW15	9	10/12/93	2145		11	6.2	125	7.8	NA	43.2	15.8	30.4	8	2.1
BWW15	12	10/13/93	0130		11	6.03	131	7.4	NA	3.8	3	29.9	9	2.52
BWW15	16	10/13/93	0515		10	6.1	135	4.7	NA	6.4	2	31.1	7	2.44
BWW15	20	10/13/93	1105		11	5.9	180	8.4	NA	10.4	2.8	32.2	8	2.24
BWW15	24	10/13/93	1410		13.5	6.25	138	7.8	NA	7.4	4.6	33.6	8	2.05
BWW15	28	10/13/93	1905		10.8	6.28	148	8.1	NA	6.2	4	34.9	9	2.39
BWW15	32	10/13/93	2210		9.9	6.08	135	7	NA	28	26.4	34.5	9	2.46
BWW15	36	10/14/93	0220		8.5	6.22	130	5.2	NA	2.2	1.8	33	8	2.37
BWW15	44	10/14/93	1105		9.9	5.38	130	6	NA	9.2	3	36.2	7	2.6
BWW15	52	10/14/93	1705		12	5.9	150	8	NA	7.4	3.4	38.9	7	2.59
BWW15	72	10/15/93	1030		11	NA	160	4.7	NA	6.6	3.4	36	8	2.47
BWW16	P	10/12/93	0855	1.6	8.8	6.1	152	6.3	6.6	3.4	1.8	39.9	10	3.24
BWW16	0	10/12/93	1305	1.5	9.3	6.12	155	7.1	3.5	3	1.8	45.2	11	3.26
BWW16	9	10/12/93	2125	6.5	10	8.3	100	8.4	6.35	44	16	34.4	8	2.5
BWW16	12	10/13/93	0120	4.4	9.5	8.34	130	6.8	4	3.4	2.6	33.9	8	2.75
BWW16	16	10/13/93	0520	3.6	8	6.12	142	7	4	16.8	6.2	37	11	3.35
BWW16	20	10/13/93	1045	3.6	9	6.16	190	6.1	4.4	9	6.6	39.7	8	2.73
BWW16	24	10/13/93	1425	3.6	10.4	6.2	135	7.45	5.9	3.2	2.6	33.3	9	2.34
BWW16	28	10/13/93	1655	3.2	9.5	6.34	120	7.3	6.8	53.4	16.2	31.7	8	2.42
BWW16	32	10/13/93	2105	3.1	8.5	6.36	105	8.4	6.1	56	54.8	29.4	8	2.27
BWW16	36	10/14/93	0115	3.2	7.3	6.44	115	7.75	5.7	13	7.6	25.8	7	2.41
BWW16	44	10/14/93	1140	3.1	6.2	6.48	120	6.6	4.45	2	1.6	32.3	8	3.05
BWW16	52	10/14/93	1635	5.1	10	6.38	360	7.8	NA	3.6	2	36.8	10	3.4
BWW16	72	10/15/93	1000	6.5	11	NA	155	8.5	NA	2.4	2.2	42.6	7	2.88
BWW17	P	10/12/93	0840	165	11	6.66	300	10.6	2.3	4.2	2.4	63.9	13	3.28
BWW17	0	10/12/93	1300	172	11.5	6.61	300	9.8	2.7	1.6	1	75.6	13	3.23
BWW17	9	10/12/93	2130	204	10	6.67	180	9.2	2.2	30.8	4	47	9	2.13
BWW17	12	10/13/93	0120	248	11	6.75	250	10.4	2.4	3.6	2.8	69.6	13	3.17
BWW17	16	10/13/93	0520	207	10	6.77	245	10	1.8	11.6	2.4	73	13	3.7
BWW17	20	10/13/93	1045	223	11	6.73	220	11.2	2.9	6.2	2.6	73.3	10	2.85
BWW17	24	10/13/93	1425	420	10	6.75	263	13.4	1.8	5.4	4.2	65.2	11	2.7
BWW17	28	10/13/93	1655	797	10	6.75	256	13	2.3	5.8	6.4	67.6	12	3.1
BWW17	32	10/13/93	2105	551	10	6.89	172	13.2	2	11.2	4.4	70.9	12	2.88
BWW17	36	10/14/93	0115	416	9	6.89	225	13.8	2.2	10.2	3.6	68.4	11	2.78
BWW17	44	10/14/93	1140	416	10	6.81	210	10.6	1.4	4.9	4.4	68.6	11	3.3
BWW17	52	10/14/93	1635	406	10	6.81	230	11.8	NA	5.8	1.4	78.4	9	3.32
BWW17	72	10/15/93	1000	280	10.5	NA	220	10.6	NA	5.6	1.3	60.9	10	2.52
BWW18	P	10/12/93	0915	240	13	6.57	270	9.1	2.3	4.8	2.8	74	13	3.16
BWW18	0	10/12/93	1410	280	13	6.5	282	10.3	1.9	4	1.6	79.3	12	3.22
BWW18	9	10/12/93	2215	218	12	6.53	222	9.7	0.5	3.6	1.4	68.5	9	2.68
BWW18	12	10/13/93	0140	280	12	6.71	285	9	2.25	11.6	3.4	74.5	11	3.2
BWW18	16	10/13/93	0530	236	11.6	6.55	255	9.5	1.25	6.2	2.6	76.8	12	3.41
BWW18	20	10/13/93	1120	302	12.7	6.57	291	10	1.9	5.4	3.2	80.9	10	2.69
BWW18	24	10/13/93	1505	403	12.5	6.5	245	9.4	3.5	5.6	3.6	70.4	10	2.58
BWW18	28	10/13/93	1935	682	11.5	6.79	225	10	2.3	11.2	7.4	78.4	12	3.03
BWW18	32	10/13/93	2305	429	10.5	6.67	265	11.2	2.3	10.2	6.6	81.8	11	2.88
BWW18	36	10/14/93	0240	420	10.5	6.77	240	10.3	1.8	4.9	3.2	73.5	11	2.72
BWW18	44	10/14/93	0830	338	9.3	6.94	240	9.6	0.5	5.8	3.2	75.9	11	3.08
BWW18	52	10/14/93	1845	395	11	6.82	340	10.2	NA	5.6	2.6	67.3	11	3.22
BWW20	P	10/12/93	0940	255	12	6.61	272	9.2	3.1	3.8	1.8	79.3	13	3.12
BWW20	0	10/12/93	1435	300	13	6.66	252	11.1	1.4	2	1	67.1	12	3.22
BWW20	9	10/12/93	2245	231	12	6.69	265	10.9	0.5	11.6	4	72.1	9	2.51
BWW20	12	10/13/93	0205	300	12.3	6.69	250	9.4	1.95	5	2.6	72	11	3.02
BWW20	16	10/13/93	0555	250	11.8	6.68	250	9.45	0.5	5.6	2.4	71.7	12	3.49

Table A.3 Water Quality Data for Storm 3 (Continued)

Station	Run	Date	Time	Flow cfs	Temp deg C	pH	Cond umhos/cm	DO mg/L	BOD mg/L	TSS mg/L	VSS mg/L	Cl mg/L	Ca mg/L	Mg mg/L
BWW20	20	10/13/93	1145	323	12.6	6.71	280	13.2	2	9	2.6	73.9	10	2.69
BWW20	24	10/13/93	1610	437	12.6	6.69	240	10.7	1.6	6	4.2	70.3	10	2.68
BWW20	28	10/13/93	2005	746	11	6.69	235	8.2	3.1	26.4	6.4	66.6	12	3.12
BWW20	32	10/13/93	2335	484	11	6.69	205	12	2.1	12	4.4	77.8	11	3.04
BWW20	36	10/14/93	0310	455	11.3	6.67	255	10.5	1.9	8	3.6	78.3	11	2.83
BWW20	44	10/14/93	0915	363	10	6.74	225	10.3	1.4	9.4	4.4	78.9	11	3.49
BWW20	52	10/14/93	1900	427	11.5	6.68	260	10.6	NA	6.8	1.4	85.2	11	3.24
BWW21	P	10/12/93	1000	254	12.6	6.53	260	9.7	2.3	5	2	74.6	12	3.02
BWW21	0	10/12/93	1500	264	13	6.79	295	11.1	2	3	1.6	89.6	11	3.2
BWW21	9	10/12/93	2315	385	12.6	6.67	260	11.6	1	6	3.4	75.3	9	2.52
BWW21	12	10/13/93	0230	314	12	6.62	243	9.8	2.25	31.4	21.6	78.7	10	3.01
BWW21	16	10/13/93	0615	290	12	6.61	255	10	1	1.8	1	73	12	3.3
BWW21	20	10/13/93	1205	314	12.6	6.69	269	13.6	1.6	6.2	2.2	74.6	9	2.66
BWW21	24	10/13/93	1645	302	12.6	6.65	239	10.2	1.6	3.2	2.6	66.2	10	2.67
BWW21	28	10/13/93	2045	485	11.6	6.62	220	10.2	2.3	9.8	5.6	61.6	13	2.91
BWW21	32	10/13/93	0010	668	11.9	6.61	250	12.1	2.1	6.2	1.4	73.3	112	2.95
BWW21	36	10/14/93	0315	558	11.3	6.77	231	11.1	1.6	11	7.2	66.6	11	2.89
BWW21	44	10/14/93	0935	429	10.5	6.66	248	10.4	1.45	9	4.6	73.2	11	3.56
BWW21	52	10/14/93	1920	402	12	6.82	265	10.6	NA	7.4	3.2	88.4	10	3.5
BWW22	0	10/12/93	2111		11	6.1	120	NA	51.7	67.3	24	30.5	4	0.83
BWW22	3	10/12/93	2132		10	6.26	80	NA	41.7	96	38.3	44.4	ND	0.25
BWW22	6	10/12/93	2152		9.5	6.16	60	NA	24.7	83.2	33.6	11.3	1	0.39
BWW22	9	10/12/93	2212		6	6.22	50	NA	7.75	73.4	22.4	17.3	1	0.37
BWW22	12	10/12/93	2312		6.5	6.3	60	NA	16.7	47.4	13.6	NA	2	0.41
BWW22	16	10/12/93	0012		6	6.14	85	NA	6.6	52	26.2	NA	2	0.36
BWW23	P	10/12/93	0715		NA	6.18	290	NA	10.3	2.6	ND	93.3	14	3.33
BWW23	0	10/12/93	1210		19	6.14	300	NA	7.2	1.6	1.4	105	13	3.35
BWW23	9	10/12/93	2130	33	14	6.14	335	NA	13	8.2	6.6	101	10	3.02
BWW23	12	10/13/93	0000	69	NA	6.32	385	NA	29.5	6.4	5.4	109	10	2.85
BWW23	16	10/13/93	0405	75	NA	6.12	312	NA	17	3.6	3	78.1	6	2.52
BWW23	20	10/13/93	0815	30	16	6.1	310	NA	6.9	5.6	3.6	63.5	8	1.85
BWW23	24	10/13/93	1200	42	15	6.01	255	NA	7.9	1.4	ND	63.9	10	2.24
BWW23	28	10/13/93	1613	36	16.5	6.2	302	NA	10.3	5.2	4.6	66.7	10	2.51
BWW23	32	10/13/93	2005	31	NA	6.16	290	NA	6	1.6	ND	80.5	6	2.16
BWW23	36	10/14/93	0020	33	17.5	6.2	280	NA	6.6	7.8	6.6	84.4	10	2.8
BWW23	44	10/14/93	0600		17	6.36	300	NA	4.5	3.6	3.4	91.1	11	3.25
BWW23	52	10/14/93	1557		16	6.14	315	NA	NA	2.6	2	112	11	3.27
BWW24	P	10/12/93			NA	3.45	690	NA	29	29.2	22	224	7	3.65
BWW24	0	10/12/93			NA	4.2	720	NA	21.7	34.4	23.2	308	5	2.84
BWW24	9	10/12/93			NA	5.09	720	NA	11.5	30.6	11.4	261	5	2.85
BWW24	12	10/13/93			NA	5.23	800	NA	13	25.2	23.6	314	4	2.51
BWW24	16	10/13/93			NA	5.05	1100	NA	9	26.4	16.8	369	4	2.55
BWW24	20	10/13/93			NA	5.58	1080	NA	15.4	41.3	27.3	366	4	1.93
BWW24	24	10/13/93			NA	5.66	1150	NA	20.6	30.6	27.6	359	5	1.65
BWW24	28	10/13/93			NA	5.66	1400	NA	29	33.7	22.5	364	3	2.09
BWW24	32	10/13/93			NA	5.69	1200	NA	13.2	25.6	20.6	373	2	2
BWW24	36	10/14/93			NA	5.69	880	NA	12.1	30.4	23.2	374	2	1.97
BWW24	44	10/14/93			NA	5.6	800	NA	6	13.3	2.4	393	2	2.5
BWW25	P	10/12/93	1020	23	18	6.55	550	5.2	15	10	6	87.1	21	2.99
BWW25	0	10/12/93	1515	23.6	17	6.61	520	5	26.2	9	3.6	95	17	3.01
BWW25	9	10/12/93	2323		19	6.94	600	2.4	6	35.6	33.2	116	7	2.49
BWW25	12	10/13/93	0240	16	16	6.61	565	4.55	14.5	20.4	16.8	112	5	2.49
BWW25	16	10/13/93	0620	12.3	17.6	6.44	500	4.5	9	10	7.2	106	12	3.04
BWW25	20	10/13/93	1220	23.6	17.3	6.62	550	3.55	7.9	6.4	6.2	65.6	10	1.9
BWW25	24	10/13/93	1700	20.5	16.5	6.73	435	3.1	10.6	43.2	19.2	80.8	12	1.67
BWW25	28	10/13/93	2115	22.2	17.5	6.79	420	3	15	12.9	10.7	93.4	16	2.22
BWW25	32	10/13/93	0035	16.2	16.5	6.79	500	3.6	6.7	31.2	28	119	15	2.2
BWW25	36	10/14/93	0335	13.6	17.3	6.9	658	2.9	6.9	6.8	4.2	119	16	2.24
BWW25	44	10/14/93	0950	23.3	15.5	6.76	500	2.7	6	12.9	12.4	122	17	2.6
BWW25	52	10/14/93	1930	22.7	16	6.6	720	2.25	NA	11	10	149	15	2.68

ND = Not Detected

NS= No Sample

NM= Not Measured

NA = Not Analyzed

Table A.3 Water Quality Data for Storm 3 (Continued)

Station	Run	Na mg/L	Zn ug/L	NH3 mg/L	NO3 mg/L	PO4 mg/L	Cd ug/L	Cr ug/L	Cu ug/L	Ni ug/L	Pb ug/L	F.C. md/100mL	E.C. md/100mL
BWW00	P	33	5	0.04	0.25	0.01	0.36	0.35	0.9	1.4	7.7	1100	290
BWW00	0	33	11	0.08	0.25	0.01	0.35	0.5	3.7	1.5	3	930	520
BWW00	9	9	90	0.07	0.3	0.01	0.56	14.4	44	7.3	89.2	52000	13000
BWW00	12	12	10	0.07	0.21	0.01	0.6	12	21	5	56.2	14000	16000
BWW00	18	22	25	0.07	0.16	0.01	0.12	1.08	4.9	2.9	8.1	4700	4900
BWW00	20	28	15	0.01	0.16	0.01	0.08	0.78	3.2	1.5	5.8	2300	1800
BWW00	24	28	19	0.02	0.21	0.01	0.33	1.03	3.4	1.8	4.9	8200	1800
BWW00	28	27	16	0.01	0.16	0.01	0.07	0.91	2.8	1.1	3.9	2700	750
BWW00	32	28	5	0.02	0.16	0.01	0.02	0.4	5.2	0.3	3.7	NS	NS
BWW00	36	28	15	0.01	0.16	0.01	0.02	0.64	2.9	1.6	5.3	2100	590
BWW00	44	27	5	0.02	0.16	0.01	0.09	0.78	2.7	ND	2.6	NS	NS
BWW00	52	28	12	0.01	0.16	0.01	0.07	0.51	2.9	0.3	2.5	NS	NS
BWW01	P	48	29	0.30	0.5	0.01	0.27	0.7	3.5	2.7	2.6	1500	390
BWW01	0	51	23	0.20	0.5	0.01	0.37	0.7	1.2	2.3	3.2	2100	600
BWW01	9	20	71	0.05	0.37	0.01	0.43	6.9	30.4	6.4	53.4	16000	7100
BWW01	12	22	123	0.05	0.29	0.01	0.62	14	26	7.5	48	12000	9000
BWW01	16	30	42	0.04	0.33	0.01	0.63	3.09	14.1	7.7	19	5300	5800
BWW01	20	28	37	0.06	0.33	0.01	0.17	1.3	5.8	2.6	9.7	2600	2500
BWW01	24	29	413	0.05	0.37	0.01	0.73	3.89	21.4	5.6	67.2	8700	2500
BWW01	28	31	111	0.09	0.41	0.01	0.07	1.44	3.1	1.7	1.8	3100	580
BWW01	32	34	5	0.05	0.25	0.01	0.02	1.09	2.8	0.3	3.9	NS	NS
BWW01	36	31	12	0.05	0.37	0.01	0.02	1.64	3.3	2.6	5.6	1600	580
BWW01	44	35	20	0.05	0.29	0.01	0.02	1.32	17.9	4.5	2.8	NS	NS
BWW01	52	36	5	0.15	0.09	0.01	0.24	1.9	3.1	2.3	3	NS	NS
BWW02	P	63	17	0.40	3.56	0.74	0.37	1.47	11.6	11.5	3	1200	130
BWW02	0	67	20	0.17	3.89	0.62	0.5	1.25	13.3	13.4	1.2	400	240
BWW02	9	36	98	0.35	0.89	0.2	1.16	12.8	40.8	12.3	68	13000	130
BWW02	12	26	43	0.71	0.89	0.26	1.05	10	42	13	24.7	350	170
BWW02	16	29	43	0.24	1.28	0.26	0.67	3.71	15.7	11.5	15	8000	8200
BWW02	20	34	37	0.11	1.45	0.26	0.33	2.36	13.9	8.7	6.4	2100	1600
BWW02	24	35	21	0.14	1.63	0.23	0.52	2.3	13.2	9.5	6.7	2800	1300
BWW02	28	35	15	0.09	1.75	0.23	0.33	3.13	14.1	8.8	21.1	2800	340
BWW02	32	46	28	0.09	2.14	0.33	0.3	2.71	13.4	9.6	3.3	NS	NS
BWW02	36	47	26	0.11	2.01	0.33	0.17	3.32	13.4	11.4	2.7	900	510
BWW02	44	48	12	0.06	1.73	0.33	0.21	2.26	12.2	10.6	2.7	NS	NS
BWW02	52	45	25	0.35	1.44	0.26	0.4	2.32	13.9	11.3	1.9	NS	NS
BWW04	P	50	17	0.16	2.8	0.48	0.41	1.82	11.6	8.1	3	210	160
BWW04	0	52	20	0.13	2.07	0.41	0.45	0.85	6.5	7.6	1.3	1000	110
BWW04	9	ND	5	0.24	1.75	0.22	0.45	0.85	6.5	8	1.3	16000	5900
BWW04	12	28	12	0.65	0.77	0.19	1.1	18	38	8.5	24	20	30
BWW04	16	30	56	0.48	0.86	0.28	0.59	4.16	22	9.5	20.9	3200	1700
BWW04	20	30	48	0.24	0.94	0.25	0.51	3.24	13.9	9.7	12.6	4100	1600
BWW04	24	33	5	0.09	1.22	0.22	0.18	0.47	5.8	5.9	0.3	2000	830
BWW04	28	35	5	0.12	1.18	0.25	0.27	1.71	11.5	7.7	4.9	700	310
BWW04	32	36	61	0.21	1.3	0.25	0.38	1.79	12.5	6.2	9.3	NS	NS
BWW04	36	39	36	0.14	1.59	0.29	0.17	2.6	11.3	8.5	4.6	1100	420
BWW04	44	43	19	0.16	1.34	0.25	0.31	1.92	9.8	7.9	3	NS	NS
BWW04	52	37	17	0.14	1.71	0.39	0.34	2.32	11.8	12.7	31.2	NS	NS
BWW05	P	40	ND	0.05	0.64	ND	0.22	0.25	ND	0.8	1.6	NS	NS
BWW05	0	40	ND	0.01	0.04	ND	0.16	ND	ND	1.6	ND	NS	NS
BWW05	9	39	ND	0.01	0.03	ND	0.23	ND	1.4	1.5	1.6	NS	NS
BWW05	12	38	ND	0.01	0.03	ND	0.1	0.32	1	1.2	2	NS	NS
BWW05	16	40	ND	0.02	0.03	ND	0.29	0.7	0.8	1.1	NS	NS	NS
BWW05	20	38	ND	0.01	0.03	ND	ND	0.45	ND	1.1	3	NS	NS
BWW05	24	38	ND	0.04	0.03	ND	ND	0.37	0.5	1	0.7	NS	NS
BWW05	28	41	ND	ND	0.03	ND	ND	0.21	ND	ND	ND	NS	NS
BWW05	32	40	ND	0.06	0.03	ND	ND	0.33	ND	ND	1.4	NS	NS
BWW05	36	37	ND	0.05	0.03	ND	ND	0.62	0.8	0.8	2.1	NS	NS
BWW05	44	43	ND	0.03	0.03	ND	0.08	0.22	0.7	ND	1.5	NS	NS
BWW05	52	42	NS	0.06	0.03	ND	ND	0.51	0.8	0.7	0.6	NS	NS
BWW06	P	48	12	0.16	2.3	0.54	0.38	0.36	7.2	7.7	5	420	56
BWW06	0	51	18	0.10	2.54	0.54	0.38	0.45	6	7.6	2.5	140	90
BWW06	9	50	15	0.09	2.02	0.5	0.48	3	17	9.5	11.7	710	3500
BWW06	12	36	22	0.16	2.59	0.54	0.64	6.25	28	10	23	4100	2900
BWW06	16	33	79	0.32	1.06	0.29	0.75	8.14	35.8	12.2	37.9	6100	1600
BWW06	20	32	53	0.35	1.06	0.32	0.52	3.77	19	9.5	14.6	3300	830
BWW06	24	32	32	0.35	1.67	0.32	0.85	2.88	15.7	9.9	11.7	2800	1000
BWW06	28	31	26	0.08	1.12	0.25	0.41	1.74	12.3	6.3	6.3	2100	370
BWW06	32	34	22	0.09	1.23	0.24	0.36	1.76	11.8	6.4	1.5	NS	NS
BWW06	36	39	57	0.06	1.34	0.24	0.32	2.85	15.2	7.8	24.9	1900	290
BWW06	44	43	23	0.10	1.4	0.24	0.39	2.13	10.8	7.5	4.5	NS	NS
BWW06	52	62	5	0.07	1.45	0.24	0.26	2.03	6.7	7.7	3.6	NS	NS
BWW07	P	50	22	0.05	2.28	0.39	0.43	2.41	14.2	9.5	4.9	260	75

Table A.3 Water Quality Data for Storm 3 (Continued)

Station	Run	Na mg/L	Zn ug/L	NH3 mg/L	NO3 mg/L	PO4 mg/L	Cd ug/L	Cr ug/L	Cu ug/L	Ni ug/L	Pb ug/L	F.C. md/100mL	E.C. md/100mL
BWW07	0	50	24	0.05	2.28	0.43	0.47	0.64	10.5	8.5	4.7	290	70
BWW07	9	50	14	0.11	2.32	0.43	0.38	2.2	17.2	9.5	5.4	1100	86
BWW07	12	46	10	0.12	2.44	0.43	0.35	3.64	24	10.5	7.1	510	310
BWW07	18	45	49	0.17	2.6	0.39	0.67	8.11	30.2	12.9	19.2	5200	420
BWW07	20	33	57	0.26	1.18	0.25	0.44	4	19	9.2	23.1	3400	480
BWW07	24	35	45	0.40	1.26	0.25	0.49	3.77	18.1	9	12.1	2000	200
BWW07	28	34	37	0.30	1.22	0.29	0.42	3.72	17.9	9	12	1800	380
BWW07	32	34	27	0.28	1.18	0.29	0.33	3.78	18.8	10.2	11.5	NS	NS
BWW07	36	31	30	0.11	1.14	0.25	0.45	3.56	17.9	9	9.2	2300	400
BWW07	44	37	23	0.07	1.3	0.22	0.4	1.92	10.2	8.4	7.4	NS	NS
BWW07	52	39	24	0.08	0.41	0.11	0.5	3.15	12.1	8.7	8.8	NS	NS
BWW07	72	38	34	NA	1.26	0.11	0.36	3.45	14.7	29.1	7.8	NS	NS
BWW08	P	51	21	0.11	2.45	0.36	0.45	0.37	7	7.7	5.1	130	37
BWW08	0	50	34	0.05	2.54	0.39	0.67	3.73	17.9	10.2	8.1	190	140
BWW08	9	49	30	0.18	2.35	0.36	0.47	2.4	6.4	8.7	7.5	270	87
BWW08	12	45	24	0.10	2.45	0.39	0.43	8.83	7.4	8.5	10.1	310	170
BWW08	16	45	148	0.10	2.54	0.43	0.85	47.6	97	22.5	68	1900	250
BWW08	20	41	71	0.29	1.87	0.36	0.66	7.82	31	11.5	22	4800	730
BWW08	24	36	52	0.31	1.68	0.34	0.6	5.79	22.7	10.8	17.1	3400	380
BWW08	28	36	45	0.31	1.49	0.32	0.46	4.75	20.4	10.2	14.1	2900	1200
BWW08	32	35	40	0.16	1.4	0.32	0.46	4.78	19.7	10.1	14.8	NS	NS
BWW08	36	33	47	0.19	1.25	0.29	0.52	4.58	17.8	9.9	12.8	2000	620
BWW08	44	34	26	0.11	1.05	0.2	0.49	1.88	11.3	6.8	6.8	NS	NS
BWW08	52	39	26	0.02	0.83	0.11	0.49	3.15	12.2	9	22.9	NS	NS
BWW08	72	38	26	NA	0.25	0.11	0.26	2.84	14.2	15.1	8.9	NS	NS
BWW09	P	13	ND	ND	0.13	0.26	0.21	0.18	ND	0.7	0.8	34	53
BWW09	0	14	ND	0.03	0.13	0.23	0.05	0.37	ND	ND	1.1	41	58
BWW09	9	13	ND	ND	0.13	0.33	0.05	ND	ND	0.8	2.1	82	54
BWW09	12	12	ND	ND	0.13	0.26	ND	0.26	ND	ND	1.3	200	160
BWW09	16	13	ND	ND	0.13	0.26	0.2	2.15	0.5	0.7	1.4	430	120
BWW09	20	12	ND	ND	0.13	0.26	ND	0.53	ND	0.9	0.7	290	170
BWW09	24	13	ND	ND	0.08	0.24	ND	0.48	1.6	ND	1.6	270	80
BWW09	28	12	ND	ND	0.08	0.24	0.06	0.78	1	0.6	1.6	140	49
BWW09	32	13	ND	ND	0.08	0.24	0.05	0.83	ND	1.3	0.9	NS	NS
BWW09	36	12	ND	ND	0.08	0.24	ND	0.65	1.7	ND	1.9	82	61
BWW09	44	14	ND	ND	0.08	0.24	0.06	0.49	1.7	ND	2.2	NS	NS
BWW09	52	13	ND	ND	0.08	0.24	0.05	0.95	1.2	ND	0.9	NS	NS
BWW09	72	12	ND	ND	NA	NA	ND	0.62	1.9	2.7	1.4	NS	NS
BWW10	P	36	ND	0.01	ND	ND	0.19	ND	0.7	1.4	2.6	NS	NS
BWW10	0	39	ND	0.02	ND	ND	0.06	ND	ND	1.2	0.9	NS	NS
BWW10	9	36	ND	0.05	ND	ND	0.06	ND	ND	ND	2.9	NS	NS
BWW10	12	35	ND	0.04	ND	ND	ND	0.26	1.4	ND	2.2	NS	NS
BWW10	16	36	ND	0.02	ND	ND	0.1	1.1	1.5	ND	2.9	NS	NS
BWW10	20	34	12	0.02	ND	ND	ND	0.2	0.6	ND	0.5	NS	NS
BWW10	24	35	ND	0.04	ND	ND	0.06	ND	1	ND	2.6	NS	NS
BWW10	28	35	ND	0.00	ND	ND	ND	ND	ND	ND	0.7	NS	NS
BWW10	32	36	ND	0.02	ND	ND	ND	0.32	ND	0.8	1.2	NS	NS
BWW10	36	34	ND	0.06	ND	ND	ND	0.64	ND	ND	3	NS	NS
BWW10	44	39	ND	0.02	ND	ND	ND	ND	0.5	ND	0.9	NS	NS
BWW10	52	35	ND	0.01	ND	ND	ND	0.34	0.9	0.8	2.3	NS	NS
BWW10	72	36	ND	NA	ND	ND	ND	0.34	1.7	1.7	3.2	NS	NS
BWW11	P	50	15	0.01	2.11	0.33	0.51	0.44	6.9	8.5	5.8	110	38
BWW11	0	51	20	0.01	2.49	0.3	0.51	1.47	6.4	8.9	4.2	99	47
BWW11	9	43	25	0.04	2.24	0.3	0.41	3.6	14	10	10.9	230	75
BWW11	12	41	27	0.01	0.34	0.3	0.37	3.44	9.6	6.3	25.2	330	390
BWW11	16	43	24	0.03	0.34	0.23	0.39	4.04	13.5	7.3	8.8	200	170
BWW11	20	46	74	0.06	0.34	0.23	1.04	16.43	41.2	13.1	25.8	400	310
BWW11	24	43	45	0.10	0.34	0.23	0.74	8.64	29.2	11.7	15.2	1200	340
BWW11	28	39	42	0.18	0.34	0.23	0.53	6.65	21.9	10.6	12.7	1900	270
BWW11	32	36	44	0.23	0.34	0.26	0.43	5.9	25.1	9.7	15.2	NS	NS
BWW11	36	35	57	0.12	0.34	0.26	0.23	5.45	21.6	9.9	57.4	1100	350
BWW11	44	34	37	0.21	0.43	0.26	0.56	2.75	12.2	7.4	8.9	NS	NS
BWW11	52	35	27	0.11	0.08	0.29	1.06	3.58	12.1	8	15.8	NS	NS
BWW11	72	36	72	NA	0.08	0.22	0.4	4.42	13.7	8.5	7.9	NS	NS
BWW13	P	46	12	0.06	2.25	0.36	0.32	0.3	6.1	7.4	5.1	67	41
BWW13	0	49	14	0.05	2.29	0.36	0.82	1.17	9.5	9.8	1.3	130	32
BWW13	9	43	5	0.04	1.85	0.3	0.4	1.4	3.3	7.1	4	360	300
BWW13	12	42	11	0.07	1.85	0.3	0.26	1.82	7.4	7.2	4	380	120
BWW13	16	42	18	0.04	1.77	0.24	0.3	2.63	9.2	8.3	4.8	90	75
BWW13	20	40	15	0.01	1.81	0.27	0.21	2.4	9.5	7.7	4	290	83
BWW13	24	43	20	0.05	1.85	0.3	0.55	3.76	13.4	6.9	11.8	130	71
BWW13	28	40	23	0.04	1.77	0.3	0.27	3.99	14.7	8.9	6.2	130	90
BWW13	32	40	5	0.03	1.77	0.3	0.14	3.5	13	8.7	0.3	NS	NS

Table A.3 Water Quality Data for Storm 3 (Continued)

Station	Run	Na mg/L	Zn ug/L	NH3 mg/L	NO3 mg/L	PO4 mg/L	Cd ug/L	Cr ug/L	Cu ug/L	Ni ug/L	Pb ug/L	F.C. md/100mL	E.C. md/100mL
BWW13	38	39	28	0.08	1.85	0.3	0.13	2.87	12.2	7.8	6.6	230	190
BWW13	44	38	37	0.18	1.85	0.3	0.58	3.95	14.1	7.9	10.7	NS	NS
BWW13	52	35	18	0.19	1.85	0.3	0.86	3.73	12.6	7.6	13.3	NS	NS
BWW13	72	37	5	NA	1.13	0.3	0.02	0.74	4.1	9.1	4	NS	NS
BWW14	P	17	ND	0.01	0.06	ND	0.21	ND	ND	0.8	1.1	1800	210
BWW14	0	16	ND	0.05	0.06	ND	0.06	ND	ND	0.9	0.9	1300	1000
BWW14	9	14	ND	0.08	0.08	ND	0.19	0.8	ND	0.6	2.6	1100	740
BWW14	12	17	ND	0.07	0.06	ND	ND	0.3	1	0.9	0.2	480	280
BWW14	16	16	ND	0.05	0.35	ND	0.09	1.29	1.3	0.1	2.8	5800	1300
BWW14	20	14	ND	0.07	0.35	ND	ND	0.71	1	ND	2.3	1200	240
BWW14	24	14	ND	0.02	0.35	ND	ND	0.85	1	ND	1.2	480	79
BWW14	28	13	ND	0.03	0.35	ND	ND	0.95	1.3	0.8	1.1	370	190
BWW14	32	14	ND	0.07	0.35	ND	ND	0.91	0.7	1	1.7	NS	NS
BWW14	38	16	ND	0.10	0.35	ND	ND	0.68	1.1	ND	1.4	230	120
BWW14	44	16	ND	0.06	0.35	ND	ND	0.58	1.4	ND	1.1	NS	NS
BWW14	52	16	ND	0.06	0.48	ND	ND	0.87	1.5	ND	1.1	NS	NS
BWW15	P	20	ND	0.67	1.3	ND	0.18	ND	1.6	0.5	0.9	NS	NS
BWW15	0	22	16	0.85	1.32	ND	ND	ND	1.2	1	1	NS	NS
BWW15	9	19	ND	1.09	1.14	ND	0.05	ND	ND	0.5	2.7	NS	NS
BWW15	12	19	ND	0.63	1.32	ND	0.05	0.37	1.5	0.6	2	NS	NS
BWW15	16	19	ND	0.98	1.3	ND	0.05	1.84	0.5	0.5	4.1	NS	NS
BWW15	20	18	ND	1.12	1.35	ND	0.05	0.37	2.6	ND	5.1	NS	NS
BWW15	24	20	ND	NA	1.38	ND	0.07	ND	0.7	ND	1.3	NS	NS
BWW15	28	18	ND	1.03	1.65	ND	ND	0.68	ND	0.6	0.8	NS	NS
BWW15	32	19	ND	0.82	1.89	ND	ND	0.3	0.5	1.5	2.2	NS	NS
BWW15	38	20	ND	0.98	1.52	ND	ND	0.27	ND	ND	1.4	NS	NS
BWW15	44	20	ND	0.98	1.36	ND	ND	0.35	1	1.2	0.8	NS	NS
BWW15	52	19	ND	0.97	1.56	ND	ND	0.33	0.9	ND	3.8	NS	NS
BWW15	72	19	ND	NA	1.81	ND	ND	0.47	1.3	3.5	1.6	NS	NS
BWW16	P	24	ND	0.03	0.59	ND	0.23	ND	2.2	0.5	1.3	63	800
BWW16	0	26	ND	0.02	0.59	ND	ND	ND	0.5	1.4	3.8	84	570
BWW16	9	22	15	ND	0.51	ND	0.11	ND	3.2	1.5	7.5	1000	3600
BWW16	12	22	18	0.03	0.51	ND	0.08	0.32	2.4	1.7	3.3	1200	7300
BWW16	16	24	ND	0.01	0.51	ND	0.26	0.65	1.5	0.1	7.3	480	1000
BWW16	20	21	13	0.05	0.59	ND	0.12	0.33	1.9	0.8	4.4	94000	800
BWW16	24	22	ND	0.04	0.48	ND	0.08	0.2	2.6	1	4.6	71000	1000
BWW16	28	20	18	0.05	0.59	ND	0.08	0.94	3.8	1.4	5.6	80000	1100
BWW16	32	17	ND	0.01	0.51	ND	0.05	0.51	2	2.2	2.7	NS	NS
BWW16	38	17	21	0.08	0.42	ND	ND	1.17	3	1.1	6.6	13000	3600
BWW16	44	20	ND	0.05	0.42	ND	ND	0.47	1.7	1.1	2	NS	NS
BWW16	52	21	ND	0.05	0.42	ND	ND	0.81	1.9	0.9	4.8	NS	NS
BWW16	72	18	ND	NA	0.36	ND	ND	ND	1.3	3.1	2.6	NS	NS
BWW17	P	44	14	0.02	2.09	0.06	0.36	2	9.9	6.9	3.7	1900	64
BWW17	0	43	11	0.03	2.09	0.06	0.22	0.1	4.7	7.4	4.4	550	48
BWW17	9	27	57	0.03	1.41	0.04	0.29	3.3	14	5.6	44.8	12000	8100
BWW17	12	43	22	0.03	2.17	0.06	0.26	2.69	10.5	8	17.5	1600	840
BWW17	16	45	10	0.03	2.25	0.06	0.3	2.86	10.1	6.4	5.2	880	540
BWW17	20	42	18	0.06	2.13	0.06	0.32	1.95	9.2	7	4.5	760	360
BWW17	24	43	10	0.08	1.93	0.06	0.24	1.72	9.6	8	4.3	430	150
BWW17	28	43	21	0.01	1.85	0.06	0.22	2.41	10.6	6.6	5.2	490	220
BWW17	32	40	5	0.09	1.85	0.06	0.19	2.32	9.5	8.2	5.9	NS	NS
BWW17	38	40	24	0.02	1.77	0.09	0.09	2.41	10.2	7.5	5.5	150	374
BWW17	44	41	20	0.01	1.77	0.09	0.36	2.4	10.5	7.1	5.6	NS	NS
BWW17	52	40	12	0.01	1.85	0.04	0.32	3.08	13.4	8.4	9.6	NS	NS
BWW17	72	38	12	0.01	1.48	0.06	0.21	2.35	11.6	8.1	7.8	NS	NS
BWW18	P	49	14	0.01	2.58	0.46	0.5	1.4	12.2	6.8	3.7	220	28
BWW18	0	50	23	0.03	2.62	0.46	0.31	1.2	6.3	5.2	4.4	360	30
BWW18	9	43	15	0.02	2.46	0.36	0.29	1	4.4	5.9	4.5	4800	160
BWW18	12	48	20	0.04	2.79	0.41	0.3	1.75	13.6	6.9	4.5	1800	130
BWW18	16	48	26	0.02	2.91	0.52	0.34	2.17	11	6.7	6.9	1500	77
BWW18	20	49	21	0.50	2.87	0.46	0.31	2.16	11.8	6.4	6	1400	250
BWW18	24	43	27	0.49	2.56	0.41	0.3	2.14	13.7	7.6	7.6	10000	950
BWW18	28	53	22	0.19	2.58	0.46	0.23	2.47	12.4	6.1	6.5	1400	390
BWW18	32	49	5	0.17	2.25	0.35	0.24	2.06	10.7	7.7	5.6	NS	NS
BWW18	38	46	22	0.24	2	0.3	0.09	2.03	10	7.7	4.9	260	79
BWW18	44	49	15	0.28	2	0.27	0.22	0.46	8.5	7.1	5.7	NS	NS
BWW18	52	49	5	0.27	2	0.25	0.06	2.09	11.2	7.5	6.5	NS	NS
BWW20	P	53	5	0.17	2.01	0.44	0.3	0.91	9.8	5.2	4.1	120	52
BWW20	0	52	10	0.19	1.96	0.4	0.2	0.1	4.5	4.9	3.3	120	21
BWW20	9	48	18	0.27	2.09	0.4	0.27	2.3	10	5.8	8	480	340
BWW20	12	46	11	0.31	2.01	0.37	0.22	1.67	10.7	5.3	4	770	700
BWW20	16	44	16	0.27	1.96	0.33	0.2	1.38	11.7	6	4.4	190	120

Table A.3 Water Quality Data for Storm 3 (Continued)

Station	Run	Na mg/L	Zn ug/L	NH3 mg/L	NO3 mg/L	PO4 mg/L	Cd ug/L	Cr ug/L	Cu ug/L	Ni ug/L	Pb ug/L	F.C. md/100mL	E.C. md/100mL
BWW20	20	44	22	0.57	2.22	0.4	0.21	1.55	10.5	5.7	5.5	440	120
BWW20	24	45	5	0.21	2.33	0.44	0.2	1.41	10.6	6.3	4.1	630	90
BWW20	28	44	23	0.25	2.47	0.41	0.31	2.05	15.4	8	9.4	890	400
BWW20	32	46	16	0.08	2.85	0.78	0.25	1.9	13.1	7.6	7.5	NS	NS
BWW20	36	49	28	0.19	2.82	0.89	0.1	2.41	13	6.7	6.7	1900	540
BWW20	44	49	23	0.35	2.41	0.89	0.18	1.83	10.9	6.6	6.2	NS	NS
BWW20	52	49	11	0.32	1.87	0.84	0.07	2.33	14.9	7.9	9.6	NS	NS
BWW21	P	54	5	0.01	1.98	0.39	0.34	0.92	8.4	5	3.6	19	15
BWW21	0	52	12	0.36	2.07	0.41	0.29	1.2	9	4.6	5.9	13	31
BWW21	9	49	20	0.20	2.03	0.41	0.23	1.46	9.4	4.1	6.6	2500	6100
BWW21	12	47	24	0.05	2.07	0.37	0.21	1.54	9.6	5.5	5.4	6900	1900
BWW21	16	47	16	0.10	2.17	0.42	0.19	1.38	7.3	4.5	3.8	1100	390
BWW21	20	43	15	0.07	2.21	0.42	0.19	1.55	9.6	4.3	6.9	1200	260
BWW21	24	46	5	0.05	2.13	0.36	0.18	1.41	7.9	5.1	4.9	650	71
BWW21	28	43	5	0.05	2.25	0.36	0.17	2.05	9.9	6	4.5	610	90
BWW21	32	46	5	0.13	2.61	0.42	0.16	1.9	10.1	5	5.6	NS	NS
BWW21	36	42	29	0.11	2.65	0.42	0.31	2.41	11.3	6.1	6.8	650	390
BWW21	44	46	22	0.12	2.61	0.46	0.28	1.83	9.6	6	5.8	NS	NS
BWW21	52	48	20	0.04	1.57	0.36	0.41	2.33	12.5	6.6	6.9	NS	NS
BWW22	0	16	100	1.50	0.21	0.34	0.62	0.77	10.6	9.9	2.9	13000	7800
BWW22	3	15	127	0.67	0.17	0.34	0.88	7.89	67.1	11	57.6	90	46
BWW22	6	12	77	0.22	0.17	0.29	0.25	0.93	38.4	3.5	2	40	110
BWW22	9	8	60	0.36	0.17	0.23	0.2	0.35	13.8	2.9	2.9	52000	18000
BWW22	12	14	68	0.07	0.17	0.29	0.1	ND	9.7	ND	ND	ND	ND
BWW22	16	12	52	0.64	0.17	0.23	0.12	ND	ND	ND	ND	ND	ND
BWW23	P	65	16	1.74	7.32	1.65	0.23	3.88	30	24.9	0.8	30	4
BWW23	0	69	16	0.07	4.16	1.6	0.18	1.3	22.4	19.5	1.5	55	1
BWW23	9	23	28	1.84	4.5	1.93	0.91	6.07	32.2	26.1	2.2	90	33
BWW23	12	26	26	0.80	4.73	1.98	1.2	4.5	26	25	2	35	250
BWW23	16	55	35	2.08	4.5	1.34	0.7	4.39	24.4	23.6	3.4	21	16
BWW23	20	43	21	0.15	6.65	0.99	0.61	3.39	24	21.9	1.1	120	13
BWW23	24	42	15	0.63	NA	NA	0.42	2.74	25.3	21	1.3	37	ND
BWW23	28	53	23	0.85	9.02	0.99	0.41	3.6	29.1	20.3	1.3	26	4
BWW23	32	63	15	0.17	5.07	1.1	0.4	6.17	30.4	24.8	1.05	NS	NS
BWW23	36	69	36	0.16	4.62	1.16	0.67	6.77	33.4	31	3.4	190	2
BWW23	44	70	20	0.06	4.62	1.1	0.56	4.09	25.7	24.9	3	NS	NS
BWW23	52	73	15	0.90	4.62	1.04	0.66	4.15	71.1	26.1	1.8	NS	NS
BWW24	P	217	324	NA	9.27	6.86	1.84	5.28	97.1	10.6	31.4	ND	18
BWW24	0	158	191	0.50	8.88	6.14	2.73	4.31	72.5	7.3	30	ND	ND
BWW24	9	236	134	0.53	14.65	5.11	1.76	5.37	72.2	6.9	27	4	2
BWW24	12	229	106	0.53	14.65	5.11	1.64	7.2	84	7.1	24.5	6	ND
BWW24	16	282	124	0.37	13.74	5.01	1.66	6.58	75.8	7.3	21.4	36	52
BWW24	20	299	134	0.26	13.74	5.01	1.66	7.28	84.7	5.8	26.7	30	46
BWW24	24	300	112	0.43	13.52	5.22	1.42	7.49	84.3	6.7	22.8	8	50
BWW24	28	272	108	0.42	13.52	4.81	1.4	7.98	82.5	8	20.6	31	40
BWW24	32	309	77	0.24	13.52	4.39	1.08	7.64	72.4	6.8	22.8	NS	NS
BWW24	36	303	105	0.36	13.52	4.81	1.62	7.69	74.3	6	21.2	ND	ND
BWW24	44	297	109	0.20	13.5	4.81	1.76	8.38	71.1	6.4	20.5	NS	NS
BWW25	P	77	16	23.20	0.88	1.83	0.21	1.21	9.9	27.1	2.7	1	1
BWW25	0	77	25	20.60	0.78	1.95	0.08	1.17	4.5	19.8	3.2	90	9
BWW25	9	98	50	25.10	ND	5.84	0.35	3.04	12.8	31.6	9.2	900	93
BWW25	12	94	21	12.50	ND	5.64	0.06	4.36	16	30	4	180	51
BWW25	16	65	24	8.94	ND	3.25	ND	3.24	9.9	24.7	3.5	82	3
BWW25	20	73	25	10.50	0.14	1.22	0.05	2.61	8.2	23.5	3.4	110	8
BWW25	24	75	18	12.20	0.14	0.67	0.08	2.47	13.2	24.4	3.2	32	1
BWW25	28	88	23	12.50	ND	0.85	ND	2.79	15.3	24.4	2.7	110	17
BWW25	32	99	12	12.20	ND	0.91	ND	3.16	12.5	33.7	3.2	NS	NS
BWW25	36	102	37	16.80	ND	0.97	0.06	3.68	12.6	34.4	2.9	40	3
BWW25	44	103	46	NA	0.34	0.91	0.05	3.42	12.4	30.5	2.5	NS	NS
BWW25	52	117	37	18.00	0.34	0.97	0.22	8.14	14	30.9	7.3	NS	NS

ND = Not Detected

NS = No Sample

NM = Not Measured

NA = Not Analyzed

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