What Happens When It Rains?

A Study of Water Quality in Abrams Creek and Town Run, Winchester and Frederick County, Virginia

A Research Report by
Elizabeth A. Johnston and Woodward S. Bousquet

October 2003

SHENANDOAH UNIVERSITY

Environmental Studies Program
Shenandoah University, Winchester, Virginia

Scientists have long known that rain washes pollutants into streams, but in Abrams Creek and Town Run do pollution levels during storms increase to a point that should be a cause for concern?

Cover Photographs

From left to right: Town Run adjacent to Shawnee Springs Preserve; the confluence of Upper Abrams Creek and Town Run at Jim Barnett Park; Lower Abrams Creek in Jim Barnett Park. Photographs taken by Elizabeth Johnston.

Disclaimer

The information presented herein is intended for use in this research project, for reference purposes in decision-making, and as comparative data for future studies. The interpretations of the data, the conclusions reached, and the recommendations offered by the researchers do not represent the only interpretations, conclusions, and recommendations possible from this investigation.

Furthermore, any opinions stated herein are not necessarily those of Shenandoah University, its administrators, or its Board of Trustees.

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Unless indicated otherwise, the senior author took all photographs presented in this report.

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During Baseline (fair-weather) Conditions (see Section 5):

- Nitrates exceed the natural levels expected in ecologically healthy streams.
- Phosphate levels are generally acceptable.
- Turbidity levels are generally acceptable.

During Rainstorm Conditions (see Section 6):

- Both streams handle the storm-borne pollutants they receive poorly.
- Nitrates increase slowly to readings far above their already-high baseline levels.
- Phosphates increase quickly to levels above EPA and DEQ water quality standards.
- Turbidity levels increase quickly and dramatically.
- Town Run is more impaired than Abrams Creek in its ability to absorb and break down pollutants transported by rainstorms.

Recommended Goals (see Section 7):

- Prevent further deterioration of water quality in Town Run and Abrams Creek.
- Improve water quality enough to meet applicable water quality protection standards.
- Increase the public's knowledge of, understanding of and participation in appreciating, protecting and restoring the watershed.

Section 1.
INTRODUCTION

Overview

This report presents a study of water quality in Abrams Creek and its principal tributary Town Run. Located in Winchester and Frederick County, Virginia, both streams have been the subjects of ongoing research by Shenandoah University's Environmental Studies (ES) Program, by the Virginia Department of Environmental Quality (DEQ), and by two local citizens groups: The Opequon Watershed, Inc., (TOW) and the Friends of the Shenandoah River (FSR).

Elizabeth Johnston, a Shenandoah University undergraduate student, initiated the present project. During the 2002 calendar year, she carried out her research in collaboration with TOW and with assistance from several fellow students. Woodward Bousquet, Environmental Studies Program Coordinator at Shenandoah University, who is also the co-author of this report, supervised their work.

Plate 1. Aerial Photograph of the Study Site. This image shows the study site and surrounding areas as they are seen from above. Abrams Creek and Town Run form a thin black "T" through the center of the image as they converge and flow east (right). Figure 2 (in Section 4), created from the image seen here, identifies the study site boundaries and five sample site locations of this project.

Image courtesy of Frederick County Planning and Development, 1999.

The two streams have had a long history of flooding associated with even moderate rain showers. Pollution problems have placed Abrams Creek on Virginia's Impaired Waters List because of high bacteria counts and the low numbers and low diversity of aquatic life. The Virginia Department of Environmental Quality (DEQ) and the Virginia Department of Conservation and Recreation (DCR) are coordinating efforts to understand and improve the water quality of Abrams Creek. Their goal is to work with local governments and citizens to develop plans for cleaning up Abrams Creek enough to have it removed from the state's Impaired Waters List. The results and recommendations reported here are intended to support these efforts.

This investigation had three purposes: 1.) to measure the baseline water quality (that is, the water quality under normal or fair-weather conditions) in Abrams Creek and Town Run over the course of a year, 2.) to document how rainstorms affect the water quality of the two streams, and 3.) to use the findings to recommend ways to improve the streams' water quality. For reasons that are explained below, this research focused on three water quality characteristics: nitrate concentrations, phosphate concentrations, and levels of turbidity (i.e., cloudiness).

From January through December 2002, the researcher and her assistants collected and analyzed water samples from five sites located near the confluence of Town Run and Abrams Creek. (See Plate 1 above, and Figure 1 in Section 3.) These sampling sites are situated in the City of Winchester's Jim Barnett Park and on the adjoining main campus of Shenandoah University. To measure normal baseline water conditions, monthly samples were taken near mid-month after at least 48 hours had passed without precipitation. To document changes in water quality caused by rainstorms, several samples were taken at intervals of two hours or more during and after selected storms. Time limitations restricted the collection of storm-influenced water samples to five rainstorms that occurred over the year-long research period.

Laboratory analyses revealed that normal baseline water quality conditions in both Abrams Creek and Town Run were generally at acceptable levels for phosphates and turbidity. However, baseline conditions for nitrates exceeded the background level expected in undisturbed streams, and – more importantly – these nitrate levels exceeded the EPA's proposed standard for ecologically healthy streams.

Conditions worsened considerably during rainstorms. Phosphate levels rose well above the maximum recommended by the Environmental Protection Agency (EPA) and the Virginia Department of Environmental Quality (DEQ). Turbidity followed a similar pattern, since, like phosphates, turbidity is associated with soil erosion and other sediment inputs. Nitrate levels increased more slowly in the days following a storm, indicating that most nitrates entered Abrams Creek and Town Run via the slower groundwater pathway. Nitrate concentrations after rainstorms – already of concern during normal baseline conditions – peaked at levels far above the natural background level and above the ecological standard proposed by the EPA.

Various forms of human development have altered both streams and their watersheds. These include residential neighborhoods, commercial and industrial zones, farms, orchards, and other urban, suburban and rural land uses. Town Run – passing through (and beneath) downtown Winchester, with its banks and bed encased in concrete for most of its length – has been disturbed to a far greater extent. Water quality trends described in this report reflect these differences in development. Town Run exhibits little ability to handle pollutants washed in by storm runoff. Abrams Creek handles such pollutants to a better, yet still inadequate, degree.

The concluding section of this report proposes goals for addressing water quality concerns in Abrams Creek and Town Run. In addition, it offers recommendations to help achieve these goals. Stream restoration, improved riparian areas, alternate methods of storm water management, and public education are among the approaches discussed. Section 7 also provides suggestions for future research and monitoring efforts.

Objectives of the Study

The general purpose of this research project was to characterize the water quality of Abrams Creek and Town Run during baseline (i.e., normal or fair-weather) conditions and during storm conditions. This study had three specific objectives:

1. To describe the baseline levels of nitrates, phosphates and turbidity for Abrams Creek and Town Run using the cadmium reduction method, ascorbic acid method and turbidimeter, respectively.

2. To describe the effects of rainstorms on nitrate, phosphate and turbidity levels in Abrams Creek and Town Run.

3. To use the data to make general recommendations for restoring the water quality of Abrams Creek and Town Run to standards set under the Clean Water Act of 1972 and the Water Quality Act of 1987.

Need for the Study

At first glance, our local streams and rivers look clean and attractive. Visual appearance alone, however, does not define water quality. Much like an unseen virus can go undetected until it endangers a person's health, unseen and undetected pollutants can endanger the health of a stream. Polluted waters affect more than fish, frogs and other aquatic life. Many pollutants pose a threat to human health. And, as Sections 2 and 7 of this report explain, polluted rivers and streams may restrict a region's future growth and development options.

Local newspaper accounts (e.g., Van Meter 2002, Kennedy 2002, Eller 2003) show that concern about water quality is increasing in Winchester and Frederick County. The Virginia Department of Environmental Quality (DEQ) reported that 44% of the waterways tested in this state, including Abrams Creek, are too polluted for their designated uses (Virginia DEQ 2002b). As a result, the DEQ placed Abrams Creek on its Impaired Waters List (IWL). This list documents impaired stream segments and identifies the kinds of impairments found. Other area streams on the IWL include Opequon Creek (into which Abrams Creek flows), Hogue Creek, Spout Run, and the Shenandoah River. The number of impaired waters continues to rise as more streams and rivers are investigated, as water quality standards become stricter, and as some pollution problems worsen.

To address these situations, the DEQ and the Virginia Department of Conservation and Recreation (DCR) are working with government agencies, landowners, corporations and individuals in areas with streams on the Impaired Waters List. The process, described in more detail in Section 2, involves determining a "pollution budget" or Total Maximum Daily Load (TMDL) for each pollutant in each impaired river or stream. If voluntary efforts to improve water quality prove to be insufficient, mandatory regulations may be imposed (Virginia DEQ et al., 2003). Such requirements are likely to raise taxes and limit new construction, industrial recruitment, and other economic opportunities.

This study will help identify water pollution problems in Abrams Creek and Town Run and describe their sources and extent. The differences in land use and stream bank management make

Abrams Creek and Town Run interesting subjects for an investigation of this type. Comparing the effects of rainstorms on these two streams should help pinpoint where and how they receive the nutrients and sediment that contribute to the impairment of Abrams Creek. The findings can assist public officials and citizens in reducing water quality impairments before they lead to more severe ecological consequences or drain tax dollars and restrict regional economic development.

Previous and Ongoing Research

This project builds on several previous and ongoing studies. The State Water Control Board (one of four predecessors to the Virginia Department of Environmental Quality) began water quality monitoring programs on a trial basis in the late 1950s. These programs evolved into today's monitoring practices after Congress passed the Clean Water Act of 1972, which required monitoring for sewage and industrial discharges in urban areas (Hayden 2003).

Two local citizens groups – The Opequon Watershed, Inc., (TOW) and the Friends of the Shenandoah River (FSR) – have measured the water quality of this region's streams for several years. In 1992, TOW volunteers began monitoring local streams, including Abrams Creek, within the Opequon Creek watershed's four counties. TOW samples are analyzed for seven water quality parameters including nitrate, phosphate and turbidity levels, which are the parameters used in the present study. Their sister group, Friends of the Shenandoah River, organizes volunteer water quality monitoring for 160 miles of the Shenandoah River and its tributaries. The FSR analyzes its volunteers' water samples in its lab facility located at Shenandoah University. The Friends assist other organizations, such as TOW, by running lab tests on their samples as well.

Previous investigations by Shenandoah University's Environmental Studies Program have also shaped the present study. From June through October 1998, a student team examined the water quality of Abrams Creek as it flows along the Winchester-Frederick County border for a mile through the Abrams Creek Wetlands east of Route 37 (Barnes et al., 1999). The students discovered that nitrate levels were highest at Abrams Creek's major spring source* and tended to fall as distance from that spring increased. This finding led the group to infer the primary source of nitrates was likely to be groundwater contamination. They also speculated (p. 93) that rainstorms would produce even higher nitrate readings because of runoff from surrounding agricultural and urban developments.

The unusually dry 1998 season during which the study was conducted may have contributed to the low phosphate and turbidity levels the Shenandoah University students observed. Both factors varied widely from site to site and from day to day. The group predicted that rainfall would increase these levels considerably. These researchers also measured other water quality factors: temperature, pH, dissolved oxygen, ammonia and bacteria levels. While their findings revealed important aspects of the stream's ecology and water quality, the student team recommended that the influence of rainfall on three factors – nitrates, phosphates and turbidity – be investigated further.

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* The 1998 report *A Study of Abrams Creek-White's Pond Wetlands, Winchester and Frederick County, Virginia* labeled the primary spring source of Abrams Creek as Robinson Spring, which is one of several names by which this spring has been known. Since the reports' publication, however, Shenandoah University researchers have called this spring by its more commonly used name, Merrimans Spring.

A second Shenandoah University-sponsored study, this one conducted by James Wood High School senior Rachel Fitzgerald in the spring of 2000, followed the 1998 group's recommendation. Fitzgerald chose three sampling sites on Town Run and Abrams Creek that were located in Jim Barnett Park and on Shenandoah University's Main Campus. She measured temperature, pH, nitrates, phosphates and turbidity levels (Fitzgerald 2000). Her three-month set of baseline readings enabled Fitzgerald to describe the effects of a rainstorm on the parameters she monitored. Temperature and pH were unaffected by the storm. Nitrate, phosphate and turbidity levels, however, changed noticeably. Nitrate levels varied between 1.5 and 2.6 parts per million (ppm) under fair-weather conditions but rose to a high of 3.4 ppm during the storm. All nitrate levels – baseline and storm – were above the EPA's recommended maximum concentration of 1.0 ppm. Fitzgerald found that phosphate and turbidity levels varied little in her baseline samples. During the storm, both levels rose rapidly and then fell back quickly close to their pre-storm levels. These findings led Fitzgerald to conclude (pp. 24-26) that nitrates, phosphates and turbidity are strongly influenced by rainfall. The levels rose, she continued, probably because of erosion and surface runoff, which are often increased by human activity.

Another water quality investigation that contributed to this project took place at Winchester's Shawnee Springs Preserve during June 2002. Elizabeth Johnston examined eight water quality parameters at three sites. Sampling began at a spring upwelling and moved downstream past other springs through wetlands and wooded riparian areas to the spring run's convergence with Town Run. Her findings showed that nitrate concentrations were highest at the spring source (averaging 4.2 ppm) and fell as the spring run flowed through the protected riparian areas. These measurements led Johnston to conclude that nitrates were filtering through soil and bedrock into the groundwater but later absorbed from the surface stream by aquatic vegetation (Johnston 2002).

Limitations and Quality Assurance

Prior to water sampling and laboratory analysis, the researcher took steps to assure that accurate and reliable methods would be used to help assure the study's validity. Water quality assessment procedures came from established sources, including the EPA (1997), Hach Corporation (1992), American Public Health Associations (1998), and the Virginia DEQ (2002b). In addition, past research on Abrams Creek and Town Run guided the present study in the choice of sampling sites, water quality parameters and laboratory methods. Nonetheless, this study, like all scientific investigations, was limited by several factors.

First, the study was limited by time and labor. While sampling took place over the entire 2002 calendar year, the project was primarily the effort of one person. Baseline samples were obtained once a month. Storm samples were gathered when possible, but, given the researcher's other priorities, only five storms could be examined in detail. In this study, as in any research project, more tests performed over a longer time period will often produce a more complete and accurate set of results.

Second, water characteristics are affected by seasonal and annual variations in temperature, the uptake of nutrients by plants, and stream volume. The researcher and her assistants gathered monthly water samples in order to account for some of these variations by creating a year-long profile of conditions in Abrams Creek and Town Run. However, different rainfall patterns in another year could produce different water quality readings.

This project was intended to be a learning opportunity as well as a service to the community and region. Consequently, this study was both limited and shaped by the researcher's experience, which included several upper-level laboratory science courses and a concurrent water quality research project. She spent considerable time practicing the various field and lab procedures prior to any formal sampling. In May 2002, the researcher decided to improve her data collection forms to include additional information about factors such as weather conditions that could influence each sample. The revised form and an explanation of its development appear in Appendix A.

Finally, standard procedures were followed to help assure accuracy. Sample bottles and lab equipment were sterilized between sample runs. In an effort to obtain data compatible with previous Abrams Creek studies as well as minimize errors from improper procedures, the researcher consulted TOW, FSR, Shenandoah University faculty, and several published manuals (see above) about water quality assessment methodology. Recommended procedures sometimes varied from source to source. The methods finally employed, and why they were chosen, are described in Section 4 of this report.

Unforeseen and undetected errors can occur in any research investigation. This study is strengthened by its use of standard procedures, by the researcher's consultation with local citizens groups, and by Shenandoah University's growing experience with projects of this type. Despite some potential limitations to the project, the authors feel confident that the results of this study will be both reliable and useful to individuals, organizations and agencies interested in protecting the water quality of Town Run and Abrams Creek . . . and, by extension, Opequon Creek, the Potomac River, and the Chesapeake Bay.

Organization of the Report

Section 1 has given a brief overview of the study and explained its objectives, importance and limitations. Section 2 discusses water quality laws, water pollutants, and pollution standards. The next section, Section 3, describes Abrams Creek, Town Run and the five sampling sites used in this project. Research methods and analytical procedures are the subject of Section 4. Sections 5 and 6 present and interpret the study's findings, that is, the water quality measurements made during fair-weather and rainstorm conditions over the 2002 calendar year. Finally, Section 7 offers goals and recommendations for protecting and improving water quality in Abrams Creek and Town Run, and for future research and monitoring.

Section 2.
WATER QUALITY LAWS AND POLLUTANTS

Water Quality Laws

Federal Legislation and Programs

Water quality is not a new issue. By the close of the nineteenth century, the United States had become a booming industrial society. We were consuming some natural resources faster than they could be replenished, and we were polluting others faster than they could cleanse themselves. Gradually we recognized that environmental degradation threatened our own quality of life. We learned, for instance, that rapid timber cutting not only depleted forests. Over-harvesting trees and clearing forest land for agriculture could also cause soil erosion, damage wildlife habitat, create conditions for forest fires, and fill stream beds and river channels with sediment.

In the Hudson River, silt washing down the deforested slopes of New York's Adirondack and Catskill Mountains began to choke New York City's harbors. The U.S. Congress responded by passing the **Rivers and Harbors Act of 1899**. This law prohibited the release or discharge of refuse material – including sediment – into the nation's navigable waters and their tributaries. The Act granted the Army Corps of Engineers jurisdiction over these waterways and represents the federal government's first efforts to improve water quality (U.S. Fish and Wildlife Service, 2000).

A half-century later, Congress passed the **Federal Water Pollution Control Act of 1948** (FWPCA) to protect additional water bodies that had not been covered as navigable waterways under the Rivers and Harbors Act of 1899. The FWPCA also authorized the U.S. Surgeon General to develop programs at the federal, state and local levels to improve and conserve waters intended for "public water supplies, propagation of fish and aquatic life, recreational purposes, and agricultural and industrial uses". Pollution discharge standards were not developed, however, and this legislation was largely ignored for more than two decades.

Although Congress has amended the FWPCA several times since 1948, no changes are as significant as the sets of amendments passed in 1972 and 1987. These legislative actions are entitled the Clean Water Act and the Water Quality Act, respectively. The **Clean Water Act of 1972** (CWA) established water quality standards demanded by the American public and supported by Congress during a period that President Nixon termed "the environmental decade". The objectives of the CWA were to "restore and maintain the chemical, physical, and biological integrity of the Nation's waters". This law established water quality standards for sewage and other waste

Pollution Sources

Nonpoint Source: A source of pollution that cannot be easily identified, such as the source of nitrates in street runoff or groundwater.

Point Source: A discrete, easily identified source of pollution such as a discharge pipe from a factory. Point-source pollution is also called end-of-pipe pollution.

water, it set pretreatment standards for industrial wastes prior to their discharge into rivers and steams, and it created a system for identifying new point sources of pollution. (See box on types of pollution sources.) These measures were administered by the Environmental Protection Agency (EPA), which President Nixon had created in 1970. As new water treatment facilities were constructed, water pollution began to decline from industrial discharges, municipal sewage treatment plants and other point sources. Many states enacted their own water quality legislation and took over control of water pollution programs from the federal EPA.

Pollution from nonpoint sources, which is much harder than point-source pollution to identify and control, continued to rise. Through the **Water Quality Act of 1987** (WQA), Congress required individual states to identify major sources of nonpoint pollution and develop plans to rectify these problems (McKinney and Schoch, 1998). In addition, the WQA established funds to help states develop and implement programs to reduce water pollution in cases where wastewater discharge standards were not sufficient to meet state water quality standards. To support this effort, the WQA authorized the EPA to provide funds to states for nonpoint source management and control on a watershed-by-watershed basis (U.S. Fish and Wildlife Service 2003).

Virginia Legislation and Programs

The last decade of the twentieth century proved to be a time of change for the various agencies overseeing Virginia's water quality. In April 1993, four state agencies merged to form the **Virginia Department of Environmental Quality (DEQ)**. This state agency administers the Clean Water Act and enforces laws pertaining to improving water quality, air quality and waste management throughout the Commonwealth. The DEQ evaluates the water quality of a given river or stream based on that water body's designated uses such as sustaining aquatic life, protecting human health and/or supporting recreational uses (Virginia DEQ 2002c).

Waters that fail to meet standards for their designated uses – even after all planned point – source controls are in place – become part of the state's growing **Impaired Waters List (IWL)**. Improving the quality of these streams and rivers will require addressing nonpoint sources of water pollution. Currently, the IWL includes approximately 44% (4,318 miles) of Virginia's monitored rivers and streams (Virginia DEQ 2002a). The list, which has been updated every even year since its inception in 1992, identifies stream segments in violation of water quality standards, names the pollutants responsible for the violation, and identifies the sources of the pollutants. In accordance with both the Clean Water Act and the Water Quality Act, the DEQ is responsible for developing and implementing appropriate plans to restore the water quality of impaired rivers and streams.

Under its State Water Control Law, the Virginia General Assembly enacted a series of five pieces of legislation that are collectively called the **Water Quality Monitoring, Information, and Restoration Act of 1997 (WQMIRA)**. This act specifies the responsibilities for water quality assessment that are to be carried out by several Virginia agencies: the State Water Control Board; the DEQ; the Department of Conservation and Recreation (DCR); the Department of Mines, Minerals and Energy (DMME); and the Department of Health.

Many of WQMIRA's provisions describe monitoring and reporting regulations that are used to identify and improve impaired waters throughout the state. The Act also contains a citizens' right-to-know provision, and it grants permit options to enterprises that discharge to toxic-impaired waters.

Furthermore, key provisions of the WQMIRA require the DEQ to deal with nonpoint sources of water pollution in order to clean up rivers and streams on the Impaired Waters List. Virginia and other states throughout the U.S. are addressing these problems through a **Total Maximum Daily Load (TMDL) process** for each water body on the IWL. The TMDL approach identifies the source and extent of water quality impairments with the cooperation and input of local agencies, colleges and universities, private organizations, and the general public. The purpose of the TMDL process is not to implement a plan of action for the impaired stream. Instead, TMDL represents a process for gathering data, soliciting input, and developing recommendations in order to set the stage for subsequent implementation (Virginia DEQ et al., 2003).

Information gathered through the TMDL process helps the DEQ evaluate the significant pollution sources and describe the contribution of each pollutant to impaired water quality. These findings allow state-employed scientists to recommend the pollution reductions needed to reach the desired water quality levels that have been established through the federal and state laws described above. The numerical value for a TMDL is the "total pollutant a water body can assimilate and still meet standards" (Virginia DEQ, 2002a). This number is specific to each pollutant, and it incorporates both point and nonpoint sources. Waters that are impaired by more than one pollutant must have a TMDL recommendation for each pollutant (Virginia DEQ et al., 2003).

Water Pollutants and Water Quality Standards

Section 1 of this report summarized the water quality investigations that shaped the present research project. Based on those studies, the three water quality factors selected for this investigation were nitrates, phosphates and turbidity. In order to interpret this study's findings, it is necessary to understand how each of these factors influences aquatic life, water quality and human well-being.

Water quality standards are numeric values set by government agencies to prevent pollution (see box). Two water pollutants discussed below – nitrates and phosphates – represent only a small fraction of the 158 substances for which standards have been established at the federal and/or state levels (US EPA 2003a). Turbidity has not been utilized as a water quality standard at either the federal or state level. However, turbidity is closely associated with total suspended solids (TSS), for which a water quality standard has been established. These factors are discussed separately below.

> **Pollution:** Overloading a natural system; that is, introducing a harmful substance (or an excess of a particular substance) that creates an undesired environmental change.
>
> **Recommended Maximum Level:** The maximum level of a particular substance that should occur in a water body. Recommended levels are based on science, but not yet set by law.
>
> **Water Quality Standard:** The maximum level of a particular substance that is legally allowed in a water body. Standards are based on science but set by law through political decision-making.

Nitrates (NO_3^-)

All living organisms require nitrogen in order to construct the amino acids they use to produce proteins (Wolfe 1995). Nitrates are the natural byproduct of certain soil or water bacteria that convert various nitrogen-containing compounds – such as urea – into nitrates, which, in turn, are taken up by plant roots (Barbour et al., 1998). Animals obtain their nitrogen by eating plants. When animals urinate, defecate, or die and decompose, they return nitrogen to the soil.

Although animal wastes are a natural part of this nitrogen cycle, human activities can overload a water body with nitrates. Leaking sewers, failed septic systems, fertilizer runoff and poorly managed livestock waste all contribute to nitrate pollution (Mitchell and Stapp 1996). Large numbers of dogs, cats, wildlife and waterfowl also have the potential to raise a stream's nitrate concentrations to unhealthy levels. Since nitrates dissolve readily in water, they can enter rivers and streams by washing rapidly off the land or percolating more slowly through the soil into groundwater.

Increased nitrate levels produce several effects in streams and rivers. A slight rise in nitrate concentrations often increases the growth of plants and algae, which help the aquatic organisms that use stream vegetation for food, shelter and egg-laying sites. Excessively high nitrate concentrations, however, can harm animals, including humans, in two ways. First and foremost, elevated nitrate concentrations promote excessive plant and algal growth, leading to a condition known as **eutrophication** (see box below). Eutrophication depletes a water body's dissolved oxygen, often killing the majority of its fish, insects and other aquatic life. Second, animals that drink water with high nitrate concentrations can suffer from methemoglobinemia, a condition that interferes with the bloodstream's ability to carry oxygen. Infants are particularly vulnerable. Although nitrate levels must be much higher than those found in this study before humans begin to suffer such health problems, other organisms could possibly be affected by the lower levels found in Abrams Creek and Town Run.

How much nitrogen, then, is too much? According to the Environmental Protection Agency (EPA 1997), nitrate levels in undisturbed bodies of water generally stay below 1.0 parts per million (ppm). Concentrations above this natural "background" number usually indicate disturbance from one or more of the human activities listed above. Nitrate levels above 1.0 ppm could trigger eutrophication and, at higher levels, cause health problems related to decreased oxygen in the blood. (In humans, methemoglobinemia does not occur until nitrate levels reach at least 10 ppm; this is the nitrate standard for drinking water.)

Taking stream water samples during rainstorms can reveal important information about nitrate pollution. First, these samples show how nitrate levels change during a storm. Scientists have long known that rain washes pollutants into streams (see McKinney and Schoch 1998, Botkin and Keller 1998), but in Abrams Creek and Town Run do pollution levels increase to a point that should be a cause for concern? In addition, the pattern of change helps identify the pollution sources. The times when "spikes" or peaks (i.e., the highest levels) occur will indicate whether nitrates are entering a stream through surface runoff, through groundwater, or by both routes. For instance, increases in nitrate concentration that occur shortly after a storm begins can be attributed to surface runoff, because rainwater washes quickly across the land. Since nitrates entering streams through the groundwater must first percolate down through the soil and bedrock from the land's surface, nitrates following this route take much longer to enter a stream. Nitrate levels from groundwater sources will gradually increase over several hours or days from the time the storm begins.

EUTROPHICATION:
A Natural Process . . . Sometimes

Eutrophication is the accumulation of plant nutrients, such as phosphates and nitrates, in a body of water. Although it most commonly occurs in ponds, lakes and bays, eutrophication also takes place in slow-moving sections of streams and rivers.

This increase in nutrients produces thick growths of aquatic plants and dense mats of algae, which eventually prevent sunlight from reaching other aquatic vegetation. Animals that depend on these submerged plants for food or cover suffer. The dying vegetation begins to cover the bottom of the lake or river with organic debris faster than it can be decomposed or washed downstream. Bacteria break down the trapped, rotting material, lowering dissolved oxygen levels in the water. Fish and other aquatic animals suffocate and die. Their decomposition depletes oxygen supplies further and releases additional nutrients, thereby continuing the eutrophication process.

Plate 2. Merriman's Spring Run, Abrams Creek Wetlands, January 2002. Cultural eutrophication of this spring run two miles upstream from the study site is particularly evident during low-water conditions, which reveal the extensive plant growth.

There are two types of eutrophication. The natural deposition of nutrients by soil erosion, surface runoff and stream movement is termed **natural eutrophication**. Over time, this slow process can fill in a shallow pond, converting it into a marsh or dry land. The second type of eutrophication, called **cultural eutrophication**, results from human activities, such as improper sewage disposal and the deposition of agricultural runoff and certain industrial wastes into a body of water (Chiras 1994).

Although the processes are similar, cultural eutrophication progresses much faster because of the large quantities of nutrients that can rapidly enter the water from human developments. Cultural eutrophication often occurs in water bodies that would not, under natural conditions, accumulate enough plant nutrients to trigger natural eutrophication. Thus, cultural eutrophication reduces an aquatic habitat's ability to support life. Numerous studies (e.g., US EPA 2002) show that cultural eutrophication is widespread in the Chesapeake Bay. As a result, Virginia and other states in the Bay's watershed are implementing measures to reduce sediment and nutrients in the Bay and its tributaries – including Abrams Creek and Town Run (VA Secretary of Natural Resources 2003).

Phosphates (PO_4^{3-})

Phosphorous, like nitrogen, is a nutrient essential to all living organisms. Animals and plants utilize phosphorous in cell growth, cell membrane development, DNA formation and other biological processes (Barbour et al., 1998). Plants roots take up phosphorous from the soil in the form of water-soluble **orthophosphates**. In turn, animals eat plants to obtain the phosphorous they require.

Although phosphorous is one of the Earth's most abundant elements, it tends to bind firmly to soil particles. As a result, water held between soil particles and water flowing over streambeds usually contains only low levels of orthophosphates – between 0.005 and 0.05 parts per million (ppm). This situation makes phosphorous a **limiting factor** for plants. That is, even a slight increase in phosphorous can trigger a dramatic (and ecologically unhealthy) increase in plant growth. In ponds, lakes, estuaries (such as the Chesapeake Bay) and slow-moving streams and rivers, unnaturally high phosphorous levels can lead to cultural eutrophication (see box above).

As is the case with nitrates, large quantities of animal wastes from sewers, septic systems, poultry or livestock can raise phosphorous concentrations to harmful levels in aquatic ecosystems. Fertilizer runoff represents another potential source of elevated phosphorous concentrations. In addition, human activities such as construction, farming and forestry create land disturbances that can introduce soil-borne phosphates into water environments through erosion and surface runoff (Mitchell and Stapp 1996).

Maintaining the naturally low concentrations of available phosphorous (i.e., orthophosphates) is critical to the health of streams and rivers. Although elevated phosphate levels are likely to promote eutrophication, the EPA established the legal standard of 0.1 ppm for orthophosphate levels in streams and rivers for a different reason: its toxicity to marine and estuarine organisms. Phosphorus, like mercury, can accumulate to toxic levels in the tissues of living creatures at concentrations as low as 1.0 ppm. As a result, the standard was set at 10% of this lethal level (US EPA 1986).

Since phosphates bind readily to soil particles, they do not usually percolate into groundwater. Instead, phosphorous generally enters streams and rivers during rainstorms through surface runoff and the erosion of stream banks and channels. Analysis of water samples taken at intervals during a rainstorm – such as the studies performed in this investigation – should show an early phosphate peak if surface runoff is the primary source. Animal wastes and fertilizers will be carried away by stream waters and, once gone, will not contribute to observed levels of the nutrient. After an initial peak from surface runoff, any subsequent increases in orthophosphate concentration may be attributable to erosion of exposed soil or of stream banks and stream channels buffeted by the storm-swollen stream.

Turbidity

Turbidity is a measure of water clarity: the greater the turbidity, the murkier the water. It is the result of **suspended solids**, such as soil and other sediments, which are carried in a stream or river. Units of turbidity are reported as Nephelometric Turbidity Units (NTU). Readings with values of 0.0-2.0 NTU are considered clear; readings greater than 2.0 but less than 7.0 NTU are deemed cloudy; readings greater than 7.0 but less than 20.0 NTU are called muddy; and any reading higher than 20.0 NTU is termed opaque.

Stream-borne sediments can come from the stream channel itself or from land surrounding the stream. Churning and erosion of the stream's bed, banks and gravel bars contributes to the stream's **suspended load**, that is, the quantity of particles its current carries. This suspended material scours away even more sediment downstream. Any natural or human-caused land disturbances within the stream's watershed expose soil to erosion, particularly from rainwater. These water-borne particles eventually wash into streams and increase turbidity. Dust and dirt that accumulate in urban areas and flow into storm drains also contribute to a stream's load of suspended solids. In addition, leaves, twigs and other natural plant litter contribute to turbidity levels when storm runoff moves this debris into the nearest body of water. Turbidity is often aggravated by a lack of **riparian** (stream-bank) or aquatic vegetation, which not only holds soil in place but also protects banks and streambeds from rapid currents by blanketing these areas with their leaves (Armitage and Wood 1997). Eroded land and turbid water mean economic costs in lost agricultural productivity, stream bank erosion further downstream, and preventable repairs to roads, bridges and parking lots

Elevated turbidity can also harm aquatic life. Sediment buries the eggs and clogs the gills of fish, aquatic insects and other stream organisms. By blocking sunlight, these suspended solids can also limit the numbers and growth rates of underwater plants. These particles collect the sun's heat, raising water temperatures and, consequently, speeding up the process of eutrophication and killing off temperature-sensitive aquatic species (McKinney and Schoch 1998). In addition, sediment particles carried by storm runoff will transport nutrients to the stream environment. As Riley (1998) explains, more than 70% of the nitrogen and 85% of the phosphorus that enters streams via agricultural runoff is chemically bound to sediment.

In summary, high turbidity is often a consequence of urban development, suburban sprawl and land management practices that contribute to erosion and stream sedimentation. The consequences are economic as well as ecological. Despite this myriad of problems, the EPA and many state governments (including Virginia) have not yet established any recommendations or standards for turbidity levels. Nonetheless, measuring turbidity levels before, during and after rainstorms can illustrate the severity of erosion and stream sedimentation problems in a watershed.

Pollution is usually the result of ignorance, carelessness and lack of interest, for the needed technologies are usually available. A healthy river with wildlife is a place of aesthetic, educational and, with care, recreational values. Communities and land owners have the first responsibility to keep the water clean, to allow the river to be "wild".

-- Merritt Gibson, *The Old Place. A Natural History of a Country Garden*, 1997.

Section 3.
THE STUDY AREA

Abrams Creek and Town Run are located in northern Virginia's Shenandoah Valley. Land comprising both watersheds is contained entirely within Frederick County and Winchester, Virginia. In turn, Town Run and Abrams Creek make up the southwestern portion of the Opequon Creek watershed, which flows northward and enters the Potomac River north of Shepherdstown, West Virginia. See Figure 1.

The Abrams Creek watershed, which includes Town Run and its watershed, is made up of mixed rural and urban development. Approximately 50% of the 12,285 acres in the watershed are developed urban areas. The remaining portion of the watershed is divided between forested areas and agricultural land (Virginia DEQ et al., 2003).

The study area for the present investigation is bounded by Pleasant Valley Road, Christianson Family Playland in Jim Barnett Park, U.S. Route 50 (Millwood Avenue), and Shenandoah University's Main Campus. The total stream length within this area is approximately 2800 feet, that is, just over a half-mile. Plate 1 (in Section 1) and Figure 2 (in Section 4) depict the study area, the two streams and the locations of the five sample sites.

Physiography and Geology

The study area is situated in the Valley and Ridge Province of the Appalachian Highlands (Atwood 1940). These uplands run in a SW-NE direction. Erosion of the folded and faulted sedimentary bedrock created the long valleys and straight, parallel ridges that form the distinctive topography of Frederick County and land to the west. This province's broadest and easternmost valley is called the Great Valley. It runs for more than 1000 miles from central Alabama to the St. Lawrence River valley in Quebec. From Lexington, Virginia north through Frederick County to Harper's Ferry, West Virginia, the Great Valley is known by its local name, the Shenandoah Valley.

Limestone, deposited by the shallow tropical ocean that covered this area 500 million years ago, forms much of the Shenandoah Valley's floor and the two geologic formations that underlie the study area: the Elbrook Formation and the Conococheague Formation (Butts and Edmundson, 1966). Beds of shale in the Martinsburg Formation create low, rolling hills that lie primarily to the east of Winchester along Abrams and Opequon Creeks. Occasional weather-resistant beds of sandstone also occur in the Shenandoah Valley, although sandstone is much more characteristic of the Allegheny Mountain ridges in western Frederick County.

Rainwater readily dissolves limestone, forming the sinkholes, fissures and caves that occur frequently in some portions of the Shenandoah Valley. As water percolates downward through fissure-laden limestone bedrock, its path may be blocked by impermeable beds of sandstone or clayey layers of shale. This subsurface water – called **groundwater** – often accumulates in porous or perforated bedrock to form an **aquifer**, which can serve as a significant source of water for human use. Pulled by gravity, groundwater flows slowly through the bedrock, much like a stream

flows over land. When groundwater reaches an area of impermeable rock or clay, the water level rises until it finds an outlet, such as the springs that feed Abrams Creek and Town Run.

The streambeds of Abrams Creek and Town Run are generally covered by silt, gravel and larger limestone and shale rock fragments. Within the study area, Abrams Creek is floored with boulder- and cobble-sized blocks of limestone. These occur naturally in the streambed and, within Shenandoah University's Main Campus, they have been placed as riprap on the stream banks. Pebbles and small cobbles of shale also occur here. Approximately 800 feet downstream of the Route 50/Millwood Avenue bridge over Abrams Creek is a five-foot-high dam. This structure, built to capture and divert stream water into the Racey Ponds on campus, traps loose, finely textured sediment in the creek's channel upstream. After its convergence with Town Run downstream, Abrams Creek is heavily loaded with silt and gravel in many areas.

Pebbles, cobbles and boulders of both limestone and shale characterize the portion of Town Run included in this project. The stream segment just downstream of Pleasant Valley Road is noteworthy for its large, angular boulders of limestone and shale. (This particular stream segment, as discussed below, is situated below Town Run's artificially constructed channel.) Streambed rocks become more widely spaced and smaller in size just above the junction of Town Run and Abrams Creek.

Climate

Frederick County has a temperate climate with average temperatures ranging from 32.7°F in January to 75.0°F in July (Holmes et al., 1987). Air temperatures only occasionally fall below 10°F or rise above 100° F, although extremes of –12° F (20 January 1994) and 107° F (4 August 1930) have been recorded (Allen 2003).

Average annual precipitation for Frederick County is 38.4" of rain and 27.8" of snow. Most of the area's rain – 22", or 57% – falls between April and September, and most of that precipitation arrives in the form of summer storms (Winchester-Frederick County Economic Development Commission 1999).

For the year 2002, when this project took place, the records of the Virginia Tech Agricultural Research & Extension Center and WINC-FM radio show that Frederick County and Winchester received 40" of rain and 17" of snow. Rainfall was most abundant during the months of May, July and October. Further rainfall information appears in Appendix B.

Ecological Communities and Human Activities

Abrams Creek and Town Run change considerably as they emerge from their various spring sources and flow through the rural, residential and urban areas of Winchester and Frederick County. They traverse ecological communities such as forests, meadows and bedrock outcrops, they form riffle zones and small pools, and they flow beside wetlands. Abrams Creek and Town Run are also rejuvenated by springs fed from the local water table – an important consideration in light of sporadic drought conditions and the area's recent boom in population. In a collection of essays written just prior to the population spurt of the 1990s, Charles Boyd (1989) reported that local streams, particularly Abrams Creek and Town Run, contain less than half the flow they did in the late 1920s but carry twice the floodwater they did during that same time.

Town Run, the main tributary of Abrams Creek, begins its journey at the foot Little North Mountain just south of Albin in Frederick County (Figure 1, above). As it crosses beneath Route 37, Town Run enters Winchester. The stream flows through the Winchester Medical Center grounds, then into a small residential community before being fed by two springs at the Glen Burnie estate. These two springs – Old Town Spring and an unnamed spring (called simply "The Headwaters" by Glen Burnie staff) – follow two separate routes to Town Run.

Plate 3. Old Town Spring (left) and a Fountain It Feeds (right). Once suitable for drinking water, this spring now empties into a fish pond that requires daily cleaning.

Old Town Spring (Plate 3) holds a distinct place in American history. In 1808, Winchester became the first American city to pipe a municipal water supply to its residents. The water was gravity-fed from Old Town Spring through pipes made of cored logs. Creating this reliable, piped water supply kept citizens from throwing extra water they had drawn from springs onto the streets, a practice that often flooded city lanes (Lemmon 1955).

Old Town Spring no longer flows freely into Town Run. Several years ago the spring was diverted through pipes onto Glen Burnie's grounds for the estate's Chinese Garden. This water supplies three fountains, one of which runs into an algae-laden pool. The outflow then runs through sluggish channels before entering Town Run.

The Headwaters, the second spring that joins Town Run at Glen Burnie, emerges into a walled pool stocked with rainbow trout. It then runs through a short cement channel into Town Run. The stream channel remains in its natural state for approximately 200 feet. From this point, limestone walls line Town Run for a distance of approximately 150 feet. Although the limestone walls artificially cover Town Run's banks in this portion of the stream, the streambed itself remains in a natural state. Small pools and riffles created by limestone bedrock provide a substrate for the abundant aquatic mosses present. At the end of this limestone-walled section, Town Run is joined by the Chinese Garden's outlet and briefly resumes flowing through a natural channel before entering a small pond.

From the pond, Town Run again flows through cement and limestone channels as the stream is directed through historic downtown Winchester. It serves as the city's primary storm water drainage route here. With the exception of one and one-half blocks of the Loudoun Street Mall, the stream flows through an uncovered concrete channel until it reaches the southeast corner of Shawnee Springs Preserve at Hollingsworth Drive. From this point limestone walls channel Town Run into the study area. The limestone walls end at the Abrams Delight water sampling site (Site TR-ADEL), and the stream resumes a more natural path toward its convergence with Abrams Creek.

Abrams Creek also has its beginnings in western Frederick County. The stream originates on the eastern slope of Round Hill, near the northern end of Little North Mountain. As it meanders southeast, it passes through or adjacent to small agricultural areas, rural residences, the Winchester and Western railroad tracks, an auto junkyard, a golf course, and a campground. Once Abrams Creek crosses under Virginia Route 37, it is surrounded by residential developments – Merrimans Chase, Morlyn Hills, the Willows and Meadow Branch South – plus two livestock farms on the Frederick County-Winchester City boundary. Here, too, beside a 1.5-mile stretch of the creek from Route 37 to Harvest Drive, lies a series of small marshes and swamps collectively called the Abrams Creek Wetlands (Barnes et al., 1999).

Springs and seeps in the Abrams Creek Wetlands area provide most of Abrams Creek's water. The principal source is Merrimans Spring, also called Robinson Spring or Pennypacker Spring. Merrimans Spring emerges at the base of Spring Hill, just east of Merrimans Lane, and flows through a 300-foot run to White's Pond in Abrams Creek. White's Pond is a 3.85-acre excavated section of Abrams Creek. Prior to its construction, White's Pond was a marshy area fed by several cold springs. Upwellings from these springs are usually visible in the pond's clear, cold water.

From Harvest Drive, Abrams Creek continues to the southeast and east through industrial and commercial areas on either side of U.S. Route 11. After Abrams Creek passes north of the Apple Blossom Mall, it abruptly turns north-northeast, passes beneath U.S. Route 50 (Millwood Avenue) and enters the main campus of Shenandoah University – and the study area for this investigation. A small dam on campus diverts some of the stream's flow into the Racey Ponds. Beyond, Abrams Creek receives the water of Town Run where Jim Barnett Park, Duncan-Wilkins Lake Park and Shenandoah University's property come together. From this point, Abrams Creek makes a right-angle turn toward the east. It flows past the last sample site for this study and then runs beneath Interstate 81 at Winchester's eastern boundary. From here Abrams Creek heads northeast again to join Opequon Creek at the Frederick County-Clarke County line. See Figure 1 above.

In its winding 10.8-mile path from Round Hill to Opequon Creek, Abrams Creek presents many types of stream environments. Slow sections meander through farmland, while other stretches run next to railroad tracks or residential areas. There are also riffle-and-pool zones beneath high shaly banks, portions lined with riprap, straightened areas with grassy banks mowed to the water's edge, and landscaped sections adjacent to some of Winchester's busiest highway junctions.

Water is at once a liquid that seems to meld graciously with the shapes of all that it touches, yet it has the strongest of wills; given time, few substances can resist its sculpting, dissolving action. In water, nature has found its chameleon guise, an expression of its every mood.

-- Michael J. Caduto, *Pond and Brook. A Guide to Nature in Freshwater Environments*, 1985.

Section 4.
METHODOLOGY

The research project's overall purpose was to characterize the water quality of Abrams Creek and Town Run during baseline (i.e., normal or fair-weather) conditions and during storm conditions. In addition, this study attempted to relate land use activities and precipitation to changes in water quality measured during rainstorms. These findings serve as the basis for the authors' recommendations to restore the water quality of the two streams (see Section 7).

This section of the report, Section 4, explains how the procedures were selected and used to obtain water quality data for this investigation. It also describes the methods employed to gather information on supplementary factors such as weather conditions and wildlife activities.

Selecting Sampling Sites and Designing the Research Plan

In May 2000, The Opequon Watershed, Inc., (TOW) identified three sites for monitoring hydrology – specifically, rainfall and stream depth – in the Abrams Creek and Town Run watersheds. The organization's intention is to describe and understand changes in stream volume caused by rainstorms. The present Shenandoah University project was designed, in part, to supplement TOW's hydrology measurements with water quality data. The researcher, Elizabeth Johnston, met with several members of TOW to become familiar with their research plan. As a result, TOW's three hydrology monitoring sites became three of this study's five water quality sampling sites. (Technical difficulties with the hydrology equipment in 2002 prevented TOW's rainfall and stream depth data from being used in this project.)

As Johnston continued to plan this research project, she considered the potential need for additional water sampling sites to meet the study's purposes. She selected two additional locations upstream of TOW's sites on Town Run and Abrams Creek to include changes in the watershed's land uses that may affect the water quality in either stream. A rationale for the selection of each of the sites chosen appears below in the subsection entitled Descriptions of Sampling Sites.

During December 2001 and the first two weeks of January 2002, the researcher familiarized herself with the equipment and piloted laboratory analysis procedures in order to help assure her data's accuracy. Additional field equipment, including portable coolers and digital thermometers, were purchased.

The initial research plan was to measure nitrate, phosphate and turbidity levels at each of the five sampling sites. In addition, air temperature, water temperature, and the date and time of collection were recorded for each sample, since these factors can influence the three water quality parameters studied.

As the study progressed, Johnston recognized that other factors might influence water quality at the sample sites. She revised her data-recording form accordingly, based, in part, on water quality data sheets developed by the Friends of the Shenandoah River (FSR). The new forms added lines for recording past and current weather conditions, general water level and flow descriptions, and wildlife observations made when each water sample was collected. These modified data sheets were first used in May 2002. The form appears at the end of this report in Appendix A.

Descriptions of Sampling Sites*

As mentioned above, the researcher chose five sites for collecting water samples. A description and a rationale for the selection of each site appear below. Figure 2 depicts the locations of these sampling sites.

Route 50-Millwood Avenue Site (abbreviated AC-RT50)

Site AC-RT50 – the "AC" stands for Abrams Creek – is located just downstream of the U.S. Route 50 (Millwood Avenue) bridge as upper Abrams Creek begins to cross Shenandoah University's Main Campus (Figure 2). The stream enters the campus through a concrete box culvert as a wide, shallow run that is typically about 3 inches deep. It quickly narrows and deepens, maintaining a depth of approximately 10-12 inches through most of the University's property. Four point-source discharges from parking lots and roads empty into Abrams Creek in this stream segment. In an attempt to control the rapid rise in stream volume during storms, much of the stream bank has been covered with cobble- to small-boulder-sized limestone riprap. Shenandoah University has also constructed a five-foot dam near the end of this stream segment in order to divert stream water into the two small Racey Ponds in front of Gregory and Armstrong Halls. Immediately below the dam, the stream channel was recently lined with poured cement to reduce stream-bank erosion.

Plate 4. Abrams Creek Flooding at Shenandoah University Dam. This photo shows the drastic change in stream level that occurred when 1.25 inches fell in the area in less than half an hour on July 9, 2003. Photo by Mark Marion for *The Shenandoah SUN.*

Stream banks between Site AC-RT50 and the next sampling site are very steep to moderately steep, rising from less than 1 foot to approximately 2 feet above the water level upstream of the dam, and rising more than 5 feet above the water level below the dam. Grass is mowed up to the edge of the riprap or water throughout this stream segment, except in the most downstream area below the University's Shingleton Gymnasium parking lot and a soccer field. In many places, Abrams Creek has undercut both the riprap and the natural stream banks.

This sample site was chosen for its location and accessibility. Abrams Creek frequently floods Shenandoah University property (Plate 4). Runoff from University lawns and

* In this study Abrams Creek above its confluence with Town Run is termed upper Abrams Creek, while Abrams Creek below its confluence with Abrams Creek is termed lower Abrams Creek.

parking lots, outflow from drain pipes and the Racey Ponds, and sediment from the stream's bed and banks may contribute to the stream's status on the Virginia DEQ's Impaired Waters List. Thus, water samples taken at Site AC-RT50 and compared with those from the next site, AC-SHEN, would indicate whether water quality degradation occurs before and/or during the stream's flow through campus.

Shenandoah University Campus Site (AC-SHEN)

Site AC-SHEN is one of the TOW's three hydrology sample sites, so it contains electronic stream-depth monitoring equipment. Located on Shenandoah University property approximately 20 feet upstream from upper Abrams Creek's convergence with Town Run, this sampling site is the shallowest of all sites in this study. Stream depths under fair-weather conditions run approximately 4 inches here.

In this stream segment, Abrams Creek runs adjacent to Wilkins Lake and University Drive. Its bed is covered by cobbles and pebbles of shale and limestone that create abundant riffle zones. Stream banks slope moderately on the east (Lowry Drive) side but steeply on the west (campus) side. Small cottonwood trees (averaging about 5 inches in diameter) and mowed grass grow on the west bank, while the east bank is covered with an unmowed thicket of shrubs and small trees. This area shows evidence of erosion from storm flooding: new flood debris often appears on the tree trunks. Both banks at site AC-SHEN are undercut and drop vertically approximately 1–2 feet above the stream's surface.

This site represents the final opportunity to measure water quality in upper Abrams Creek before its waters mix with those from Town Run just downstream. Furthermore, as explained above, water samples taken at AC-SHEN and compared with those of Site AC-RT50 upstream will indicate whether any water quality changes – positive or negative – occur during the stream's flow through the Shenandoah University campus.

Abrams Delight Site (TR-ADEL)

Sampling site TR-ADEL – the "TR" stands for Town Run – is located in the City of Winchester's Duncan Park, which is adjacent to historic Abrams Delight and the Winchester-Frederick County Convention and Visitors Bureau. See Figure 2. Town Run here maintains a depth of approximately 12 inches under normal-flow conditions. Various sizes of limestone and shale rock fragments characterize the streambed. These fragments, ranging from pebble to boulder size, become fewer as Town Run continues its path toward Abrams Creek, some 200 feet downstream of Site TR-ADEL. The height of the stream's banks varies from a few inches to 3 feet or more.

The researcher originally intended to situate this sampling site at the Pleasant Valley Road bridge. This location would have been upstream of Rouss Spring Run and upstream of storm water runoff that crosses through Jim Barnett Park from the Forest Hills neighborhood to the northwest. This site also marks the end of Town Run's artificial channelization by limestone walls and, further upstream, by a concrete liner. Unfortunately, concrete walls and wire fencing prohibited access to Town Run at this point. As a result, Site TR-ADEL was set at the nearest accessible location below Pleasant Valley Road that would also provide the least interference from storm runoff and springs.

During the growing season, this site is almost completely shaded by medium-sized trees and by some shrubbery along the banks. In addition, two previously unidentified spring sources were discovered during this project; they are located approximately 3 feet and 9 feet downstream from the sampling site. (Water emerging from these springs was not analyzed during this investigation, although the quality of their water may have some effect on Town Run as it flows through this location.)

Town Run Mouth Site (TR-MTH)

As one of the TOW's three hydrology stations, Site TR-MTH contains electronic equipment for stream-depth studies. This site is located approximately 20 feet upstream of the convergence with Abrams Creek. This location is downstream of Wilkins Lake, which is fed by Rouss Spring and flows over its dam into Town Run.

Town Run here is approximately of 15 inches deep under normal stream-flow conditions. Coarse cobbles and pebbles characterize its bed. A few large boulders upstream create surface riffles and have formed two small sediment bars between the University Drive bridge and this sampling site, a distance of approximately 20 feet. At the time of this writing (August 2003), the bars had grown large enough to redirect the flow of Town Run; they have increased erosion in some nearby areas. Overall, the stream banks in this area slope steeply and range from approximately 6 inches to 6 feet in height. A few medium-sized deciduous trees, stream-bank vegetation that appears to be cut annually, and a high north-facing stream bank shade the TR-MTH site moderately for most of the year.

This site represents the final opportunity to sample Town Run before it joins Abrams Creek. In addition, comparing water samples taken here at TR-MTH with those from Site TR-ADEL upstream will help researchers characterize any changes that occur because of inputs from Wilkins Lake, surface runoff and/or subsurface springs.

Jim Barnett Park Site (AC-JBP)

After Town Run merges with upper Abrams Creek below Site TR-MTH, the stream – known from here to its mouth as <u>lower</u> Abrams Creek – turns sharply to the east. It forms the approximate boundary between Jim Barnett Park**,** which is operated by the Winchester Parks and Recreation Department**,** and Shenandoah University. Along this boundary, the creek passes the final sampling site: AC-JBP, located on the creek's north bank (Figure 2).

The stream's depth in this segment ranges from a shallow 2 inches to approximately 20 inches as water meanders among gravel bars. Gravel and pebbles characterize the streambed itself. In addition, this stretch of Abrams Creek contains numerous stream-tumbled glass fragments that have been carried as urban runoff or discarded as litter on University or Park property. The stream banks are steeply sloping to nearly vertical, most likely a result of the scouring floodwaters that rush through the creek.

At sampling location AC-JBP, the stream surface lies approximately 6 feet below the bank's top, but during storms in 2002 Abrams Creek often rose to within a few inches of the bank's edge here. Even under normal-flow conditions, a gravel bar located on the south bank opposite the sample site directs the stream's flow toward the north bank and deepens the stream channel. The high stream banks, plus the shrubs and medium-sized trees that grow on these banks, shade this segment of Abrams Creek. However, much of the level property beyond the bank-tops on both sides of Abrams Creek in this area is mowed at least annually.

Several other factors might also affect water quality in this stream segment. A few feet below its convergence with Town Run, Abrams Creek makes a sharp 90-degree turn to the east. The creek here is several feet deep, but it quickly regains the typical, much shallower, depth it maintains upstream. During warm weather, children and dogs were often observed wading in these shallow stretches. Unfortunately, the stream's bend also happens to occur at what appears to be an old dumpsite. (Attempts to locate historical information about this dump were unsuccessful.) Erosion of the north bank has uprooted trees and exposed miscellaneous junk such as oil tanks, bottles, and automobile parts dumped here in the past. It may be possible, though, those larger embedded items actually help reduce erosion in this area. Between this bend and sampling site AC-JBP, a gully fed by a drainpipe empties into Abrams Creek. This gully remained dry through most of the study, except when storm water runoff gushed from the pipe. As the dry 2002 summer turned into a wet fall season, however, the pipe discharged what appeared to be clear spring water.

Water characteristics at Site AC-JBP will reflect the combined input of Town Run, upper Abrams Creek, and lower Abrams Creek from the confluence to the sampling point.

Criteria for Selecting Water Sample Collection Times

The first objective of this study, as Section 1 explained, was to measure baseline levels of nitrates, phosphates and turbidity for Abrams Creek and Town Run. This type of data is useful for two reasons. First, it enables investigators to describe and understand month-to-month and season-to-season changes in stream characteristics. In addition, such baseline measurements provide a basis for describing changes caused by rainstorms, which was this research project's second objective. To address these two objectives, the researcher developed a schedule of sampling times that had to meet several scientific and practical criteria.

The lingering effects of even a small storm can affect water quality readings if water samples are taken too soon after a rainstorm. Science, however, demands a consistency in data collection so that research can be repeated. Therefore, this project's sampling schedule required a balance – a balance between the uncertainties of nature and the consistencies demanded by the scientific method. The researcher decided to collect baseline data within two days of the 15th of each month. This choice was convenient but arbitrary; any consistent monthly sampling time would have been appropriate. If a storm was predicted for the 48-hour period before the intended sampling time, baseline samples were instead taken just prior to the storm or at least two days after the storm to minimize any lasting effects the storm might have on the water quality measurements.

The extensive amount of time required to collect and analyze a series of water samples during a rainstorm posed additional logistical, and even psychological, challenges. Here again, this study's methodology reflects a balance. The research plan was to collect water samples at two-hour intervals for a storm's first 24 hours (minus time off for sleep) and then collect a single sample 48 hours after the first sample had been gathered. Storms that began, for example, at 3:00 am or were expected to last for several days were beyond the capabilities of the lone student researcher who was juggling part-time work and a full-time academic schedule. As a result, the rainstorms most suited to this project were those that began after sunrise and ended within 12 hours. Over the course of this project the researcher still found herself collecting samples in the dark, soaked for hours at a time and even pelted by hail.

Although storm samples were collected as often as possible during the year-long research period, factors such as the time of day the storm began, the predicted duration of rainfall and the time required to analyze the samples influenced the researcher's decision to collect – or not collect – storm samples. Despite the researcher's efforts to blend consistency, certainty and convenience while capturing The Perfect Storm, Mother Nature still threw occasional curveballs. Surprise weather conditions (such as too little rain or a second storm that began within 24 hours after the first had ended) ended a storm-sampling series early.

Water Quality Assessment Methods

As discussed in Section 3, previous local water quality investigations conducted by volunteer, professional and student groups helped determine the chemical and physical factors – nitrates, phosphates, and turbidity – that were studied in this project. As this investigation progressed, the researcher refined her data forms to account for the potential influence of several additional or "supplementary" factors such as weather conditions and changes in stream velocity. These procedures are outlined below.

Gathering water samples for analysis was not simply a matter of locating the nearest empty jar and plunging it into the stream. Sample bottles not only had to be sterilized according to specific requirements[*], they also had to be handled properly to prevent contamination. Samples were chilled until laboratory analysis could be performed, then they were warmed to room temperature to prevent condensation on the optical equipment used for measurement.

Nitrate Concentrations

In accordance with the Hach Company's instructions (Hach 1992), Johnston used the cadmium reduction method and the Hach DR/2010 spectrophotometer adjusted to read at the 400 nm (nanometer) wavelength to measure nitrate concentrations in the water samples. This method utilizes several chemical processes that first convert nitrate ions in the sample into stable nitrite molecules. Nitrites then react with cadmium to produce a red-brown color that the spectrophotometer measures for intensity. Higher nitrate levels produce a darker (i.e., more intense) color than lower nitrate levels.

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[*] Several sources were used to determine the correct sterilization and storage requirements for water samples tested for nitrates and phosphates. Sterilization procedures were obtained from the *Water Analysis Handbook* (Hach 1992) and verified through telephone interviews. Karen Anderson of the FSR also verified sterilization and storage methods suitable for this project. Plastic sample bottles were cleansed with a 1:1 hydrochloric acid solution and then rinsed with deionized water, which is an EPA-approved sterilization method for phosphate sampling bottles. After used bottles were emptied, they were rinsed with tap water, and then with distilled water, before they were sterilized again for future use. Bottle caps received identical treatment.

Phosphate Concentrations

The researcher used the ascorbic acid method and the Hach DR/2010 spectrophotometer adjusted to read at the 890 nm wavelength to test for phosphate levels (Hach 1992). This method is a two-step chemical process that reacts orthophosphate ions in the sample with molybdate ions to form a yellow complex. This chemical complex is then reduced by ascorbic acid, producing a blue color. The spectrophotometer then measures the color intensity; a more intense coloration indicates a higher phosphate concentration.

Turbidity Levels

Once again following the manufacturer instructions (Hach 1991), Johnston used the Hach Turbidimeter (model 2100P) to determine turbidity levels. Since suspended particles in water samples settle out rapidly once the sample is removed from the stream current, samples were inverted several times to re-suspend particles for analysis. The samples were then measured three times for light refraction; the average of the readings was listed as the turbidity measurement for that sample. High turbidity measurements indicated lower water clarity.

Supplementary Factors

Four factors – although not the primary focus of this study – were also recorded in order to help explain variations in water characteristics. These supplementary factors were water temperature, weather, hydrology and wildlife activities. The data form appears in Appendix A.

Water temperature was measured in the field immediately after gathering the sample. A digital thermometer (Corning model TMP-50), which is very sensitive to changes in temperature, was inserted into the sample bottle to obtain a reading. In order to be consistent, thermometer readings were allowed to stabilize for ten seconds before the temperature was recorded. Air temperature was also measured in the field with an Acu*Rite digital thermometer (Chaney Instrument Co., model 00888W). The thermometer was placed adjacent to the stream in conditions representative of the sampling site. (For instance, if the majority of the site was located in filtered sunlight, the thermometer was also placed in filtered sunlight to more accurately represent temperature.) A recording was taken as soon as the temperature reading had stabilized for ten seconds.

This study was initiated on the premise that weather conditions, such as rainstorms, can substantially alter the water quality of streams and rivers. After the first few sample runs, the researcher realized just how quickly weather conditions could change and how lasting those changes could be. When she modified her data collection form, she added two weather descriptors – present weather conditions, and precipitation in the past 48 hours – to help explain any abrupt changes that might later appear in the data.

Water level and stream flow conditions were also observed and recorded at each site at the time of sample collection. These factors were judged solely on the researcher's familiarity with "normal" clear-weather stream characteristics at each sampling site. Lines for both water level and stream flow conditions were included on the data collection form to help explain any trends in sample data. (For instance, consistently high nitrate levels over a period of time may be a consequence of low water levels. Likewise, high turbidity levels may be related to rapid stream flow conditions.)

Disturbances in the streambed by wildlife can influence water quality factors associated with soil particles, such as phosphate and turbidity levels, if the disturbance occurs shortly before a sample is taken. In addition, waterfowl urine and feces may increase nitrate levels. For these reasons, the data collection form included a blank for wildlife observations.

Research Schedule

The study followed the research schedule presented in Table 1 below.

Fall 2001	Several meetings with TOW members held to visit their three sampling locations and become familiar with their field testing procedures and equipment. Examined Abrams Creek and Town Run to determine if additional sampling sites were needed. Added three sampling sites.
December 2001-January 2002	Practiced equipment handling and lab analysis procedures.
16 January 2002	First baseline samples gathered and tested.
24 January 2002	First storm samples gathered and tested.
16 February 2002	Baseline samples collected and tested.
17 February 2002	One sample site (AC-I81) deleted from the research project.
2-3 March 2002	Storm samples collected and tested.
13 March 2002	Storm samples collected and tested.
15 March 2002	Baseline samples collected and tested.
20-22 March 2002	Storm samples collected and tested. Began design of supplementary data form.
9-10 April 2002	Storm samples collected and tested.
16 April 2002	Baseline samples collected and tested.
17 May 2002	Baseline samples collected and tested. Supplementary data form added.
26-27 May 2002	Storm samples collected and tested.
15 June 2002	Baseline samples collected and tested.
June-July 2002	Abrams Creek dam (on Shenandoah University property) banks reinforced.
27-29 June 2002	Storm samples collected and tested.
17 July 2002	Baseline samples collected and tested.
15-17 August 2002	Baseline and storm samples collected.
14 September 2002	Baseline samples collected and tested.
17 October 2002	Baseline samples collected and tested.
15 November 2002	Baseline samples collected and tested.
17 December 2002	Baseline samples collected and tested.
December 2002	Data analysis completed.
January-October 2003	Interpreted results, developed recommendations and prepared report.

Table 1. Research Schedule and Accomplishments.

Data Analysis

The data collected in this study constituted an entire year's worth of information. The records were too complex and numerous to drop into a single chart or two for analysis. Instead the researcher, Elizabeth Johnston, displayed data for her 5 sampling sites, 12 months of baseline samples and 5 rainstorms as separate line graphs and tables. Assisted by faculty advisor Woodward Bousquet, she calculated and evaluated averages, medians, ranges and standard deviations for the water quality measurements.

To address the research objectives, Johnston examined month-to-month and season-to-season patterns in the baseline data. Rainstorms were considered as five separate case studies. In each of these situations, Johnston and Bousquet identified patterns within and between the sampling sites and the stream segments. Standards and recommendations established by the EPA and Virginia DEQ for nitrates and phosphates allowed the authors to characterize the water quality of upper Abrams Creek, Town Run, lower Abrams Creek, and the five sampling sites combined to represent the watershed. Records for temperature, weather and other supplementary factors enabled Johnston and Bousquet to identify relationships between water quality and external influences. These findings are presented and interpreted in Section 5, the next part of this report.

Section 5.
BASELINE WATER QUALITY CONDITIONS

This project's objectives were: 1.) to characterize water quality in Abrams Creek and Town Run during fair-weather (baseline) conditions, and 2.) to describe the changes caused by rainstorms, and 3.) to develop recommendations for restoring the streams' water quality. Accordingly, the researcher took samples from five sites on the two streams during fair-weather and storm conditions from January through December 2002. She tested these samples for nitrates, phosphates and turbidity in Shenandoah University's Environmental Studies Laboratory.

Sections 5 and 6 of this report present the findings for baseline conditions and storm conditions, respectively. Data appear as pie graphs, line graphs and, at the end, in a summary table. For readers who may be interested, statistical tables are provided in Appendices C and D.

The authors found it useful to group and compare data sets in three different ways: by sampling sites, by stream segments and for the entire Abrams Creek watershed. In ecological terms, these three approaches represent three **spatial scales** (Morris 1987), that is, three ways of dividing up the Abrams Creek-Town Run landscape into units for analysis. See box below.

Spatial Scales for Water Quality Analysis

Sampling Sites. Water samples from each of the five sampling sites (listed below) are considered separately instead of being added together**:**

- Route 50-Millwood Avenue (AC-RT50)
- Town Run Mouth (TR-MTH)
- Shenandoah University Campus (AC-SHEN)
- Jim Barnett Park (AC-JBP)
- Abrams Delight (TR-ADEL)

This approach reveals the effects of land use changes and input from drainage pipes and other sources between sampling sites.

Stream Segments. Water samples are grouped by the stream section**:**

- Upper Abrams Creek – Sites AC-RT50 and AC-SHEN.
- Town Run – Sites TR-ADEL and TR-MTH.
- Lower Abrams Creek – Site AC-JBP.

This approach reveals the effects of the different conditions in the watershed's sub-watersheds – upper Abrams Creek, Town Run and lower Abrams Creek.

Watershed. Water samples from all five sampling sites are combined**:**

- Abrams Creek Watershed – AC-RT50, AC-SHEN, TR-ADEL, TR-MTH, AC-JBP.

This approach provides an overall picture of water quality in the study area.

As the box indicates, these scales provide different perspectives on the data, on the streams and on land use conditions in the watershed.

The findings presented in Section 5 and Section 6 are intended to help the reader understand three aspects of water quality in Abrams Creek and Town Run**:** 1.) how clean or polluted the streams are, 2.) how rainstorms alter the streams' water quality, and 3.) how conditions in different portions of the watershed may affect the water quality levels found in this study. The authors' recommendations based on these findings appear in the final section, Section 7.

It is important to bear in mind that nitrates, phosphates and sediments are natural components of stream habitats. Each factor can have beneficial, neutral or detrimental effects, depending on the levels (concentrations) at which they occur. Human activities can alter the levels of all three of these factors. The key, then, is recognizing what levels of nitrates, phosphates and turbidity threaten stream health, human health or the social and economic well-being of communities in the watershed and beyond. For further information, see the discussion of water pollutants that was presented above in Section 2.

Overview of the Data Obtained

As Table 2 shows, baseline samples were taken and analyzed on 12 dates – one per month – from January through December 2002. On each of these dates, the researcher and her assistants collected a sample at each of the sampling sites, making a total of 62 baseline sample collections. A total of 155 samples were collected at time intervals during storms in March, April, May, June and August. Temperature measurements and observations of weather, wildlife and other conditions were made and recorded in the field. In the laboratory, each water sample was tested for nitrate concentrations, phosphate concentrations and turbidity levels – a total of 651 tests for the research project.

Since the researcher was unable to gather rainfall data at the study site itself, this investigation relied on data from two local sources. The WINC FM radio station and the former Virginia Agricultural Research & Extension Center in Winchester both used standard meteorological equipment to record precipitation in 2002. These facilities are located approximately 1.8 miles and 8.7 miles,* respectively, from the confluence of Abrams Creek and Town Run.

Given the often haphazard manner in which showers occur, it was not surprising to discover that precipitation measurements from these two stations in 2002 did not always match each other or correspond to conditions at the study site. On several occasions, one station received no rain even though rain fell at the other weather station and at the study site. The authors, consequently, decided to combine precipitation records from these two facilities and calculate averages when precipitation totals were needed for a given rainstorm or a given month. Records from both weather stations and a bar graph comparing their data appear in Appendix B.

* The Center moved to Frederick County in 2003.

	Baseline Samples												Storm Samples					
Date	Jan 16	Feb 16	Mar 15	Apr 16	May 17	Jun 15	Jul 17	Aug 15	Sep 14	Oct 17	Nov 15	Dec 17	Mar 20-22	April 9-10	May 26-27	June 27-29	Aug 15-17	Total
Sampling Sites (#)	6	6	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	
Samples Collected (#)	1	1	1	1	1	1	1	1	1	1	1	1	8	4	5	8	6	43
Laboratory Tests (#)	18	18	15	15	15	15	15	15	15	15	15	15	120	60	75	120	90	651

Table 2. Number of Samples Collected and Laboratory Tests Conducted During 2002. January and February baseline samples were also taken from a sixth sample site (AC-I81) that was later dropped from the study. Data from this deleted site were not included in analysis.

Nitrate Concentrations

Nitrate Concentrations for the Watershed

Baseline information viewed at the watershed scale revealed interesting trends in nitrate levels for the study year 2002. Figure 3 shows that the lowest nitrate levels occurred during the winter months of January through March. Nitrates began to rise in April and remained high for the year, with a slight drop in late summer.

The highest reading was 3.5 ppm at Site TR-ADEL, July, while the lowest readings of 0.6 ppm occurred in March at Sites AC-RT50 and AC-SHEN. (See Table A in Appendix C). The pie graph in Figure 4 reveals that nitrate concentrations in the Abrams Creek watershed exceeded the EPA's recommended maximum concentration of 1.0 ppm in 88% of the samples taken.

Plant growth, temperature, precipitation, and human activities can all affect nitrate levels in a stream. First, plants take up nitrates as they grow, thereby reducing concentrations of this nutrient in streams. Second, however, humans often fertilize their golf courses, farm fields and lawns during the warm growing season, sometimes increasing a stream's nitrate level through surface runoff and groundwater infiltration. Rainfall can also affect nitrate concentrations in opposite ways: it can wash nitrates from the land into the water, but it can also dilute nitrates already present in a river or stream.

In this study, the lowest nitrate levels for the year occurred during January through March, periods of cold weather and low precipitation. Surface runoff and groundwater infiltration (and plant growth) would have been low. A noticeable increase in nitrate levels from April through July occurred during the months when people were likely to be fertilizing their growing plants. The slight drop in nitrate levels in August and September might perhaps be attributed to a decreased use of fertilizers coupled with the continued nitrogen uptake by plants flourishing through the summer's warmth. Although air and water temperatures in October through December (see Appendix A) were as low or lower than those recorded for the first three months of the year, nitrates did not drop correspondingly as one might expect. Rainfall levels during this period (Appendix B) matched those in January through March. Fertilizing would not be a factor. What, then, was responsible for the high nitrate concentrations at the end of the year? Field measurements and lab tests from this study do not provide the authors with a clear answer.

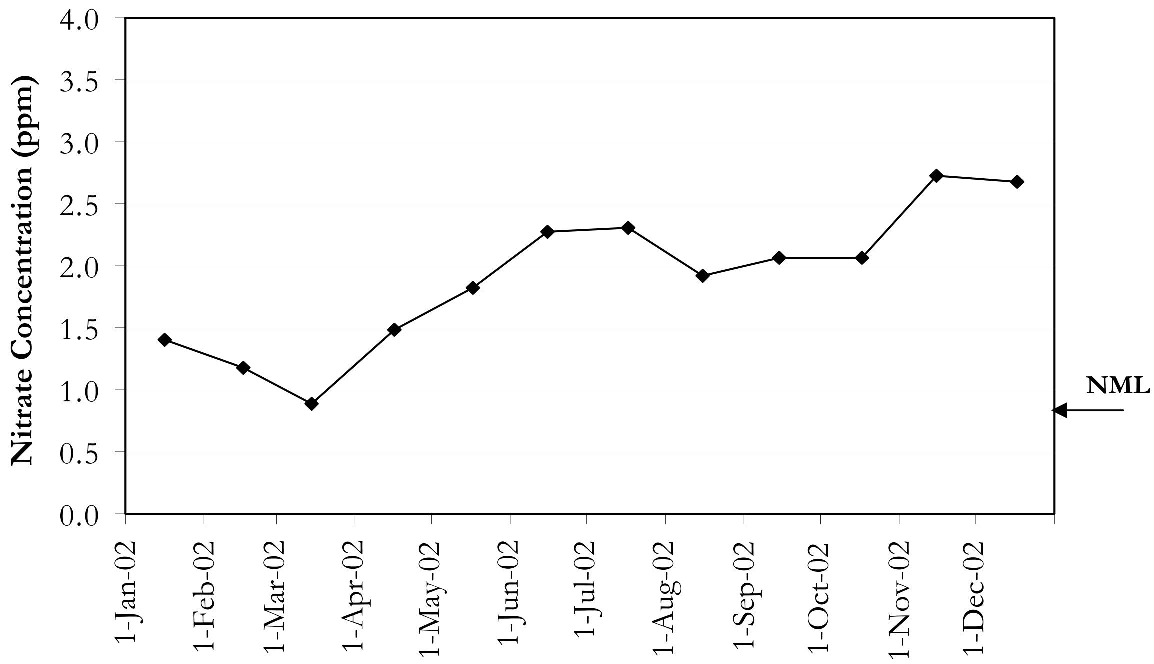

Figure 3. Baseline Nitrate Concentrations for Abrams Creek Watershed for 2002 (i.e., all 5 sampling sites combined). NML = Natural Maximum Level of 1.0 ppm.

Environmental Studies Program, Shenandoah University (2003)

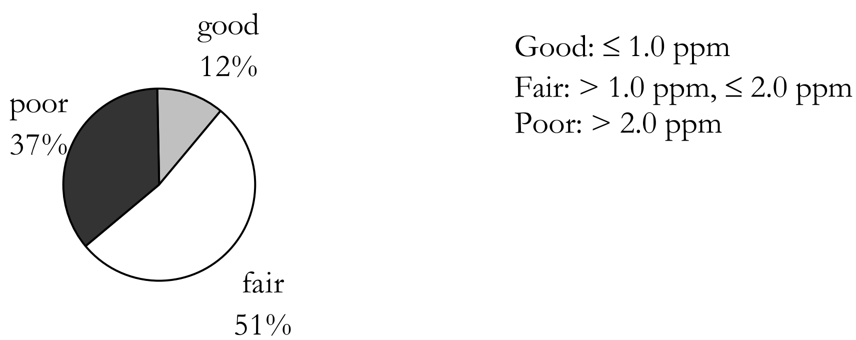

Figure 4. Water Quality of Baseline Nitrate Concentrations for Abrams Creek Watershed for 2002 (i.e., all 5 sampling sites combined)**.**

Nitrate Concentrations by Stream Segment

Comparing nitrate data by stream segments revealed which portion of the study area was the most impaired by nitrate concentrations. Although all three stream segments usually exceeded the maximum natural background level of 1.0 ppm, Figure 5 shows that Town Run maintained the highest nitrate levels throughout the year (with the exception of ranking a close second in February). As one might expect, the nitrate levels in lower Abrams Creek usually fell between those of Town Run and upper Abrams Creek.

From its headwaters to its confluence with Abrams Creek, the Town Run watershed encompasses small farms and orchards, a medical center, a residential area, an historic estate, an urban-commercial zone and then a high-density residential area. Clearly, a closer look at nitrate sources entering lower Abrams Creek from various points along Town Run is needed. Further sampling upstream from the study area should help pinpoint the problems.

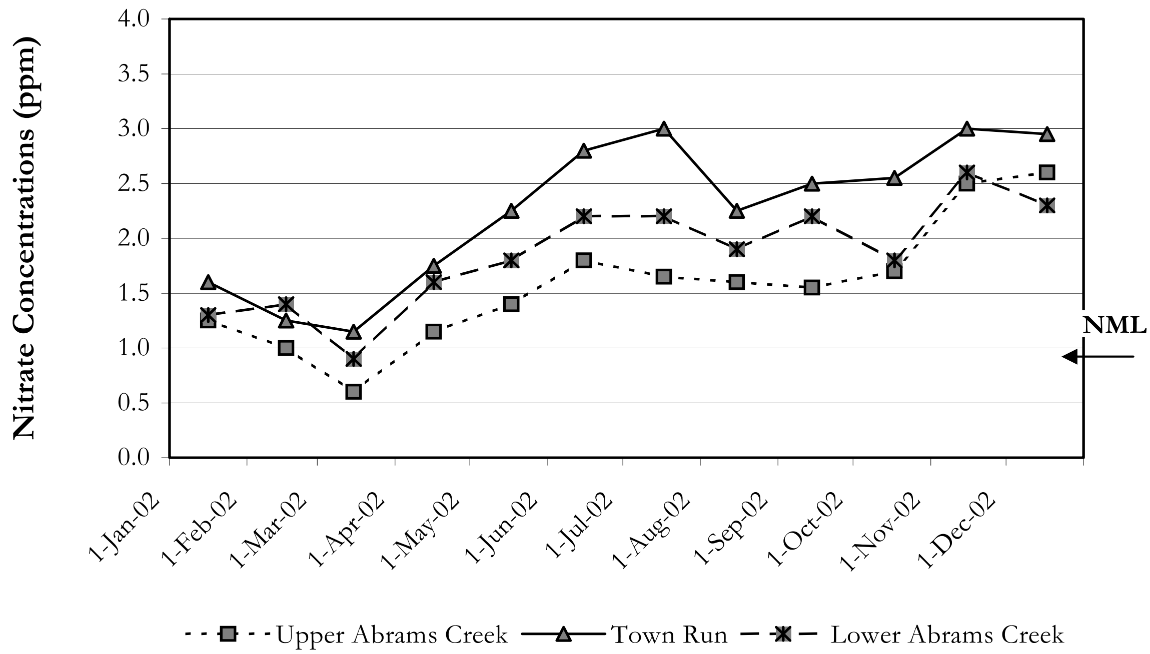

Figure 5. Baseline Nitrate Concentrations by Stream Segment for 2002.
NML = Natural Maximum Level of 1.0 ppm.

Environmental Studies Program, Shenandoah University (2003)

Nitrate Concentrations by Sampling Site

When examined on a site-to-site basis, this investigation's results (Figure 6) showed that nitrate concentrations decreased as Town Run and Upper Abrams Creek flowed downstream within the research area. Readings from TR-ADEL and AC-RT50 were usually lower than nitrate levels at their downstream stations TR-MTH and AC-SHEN, respectively.

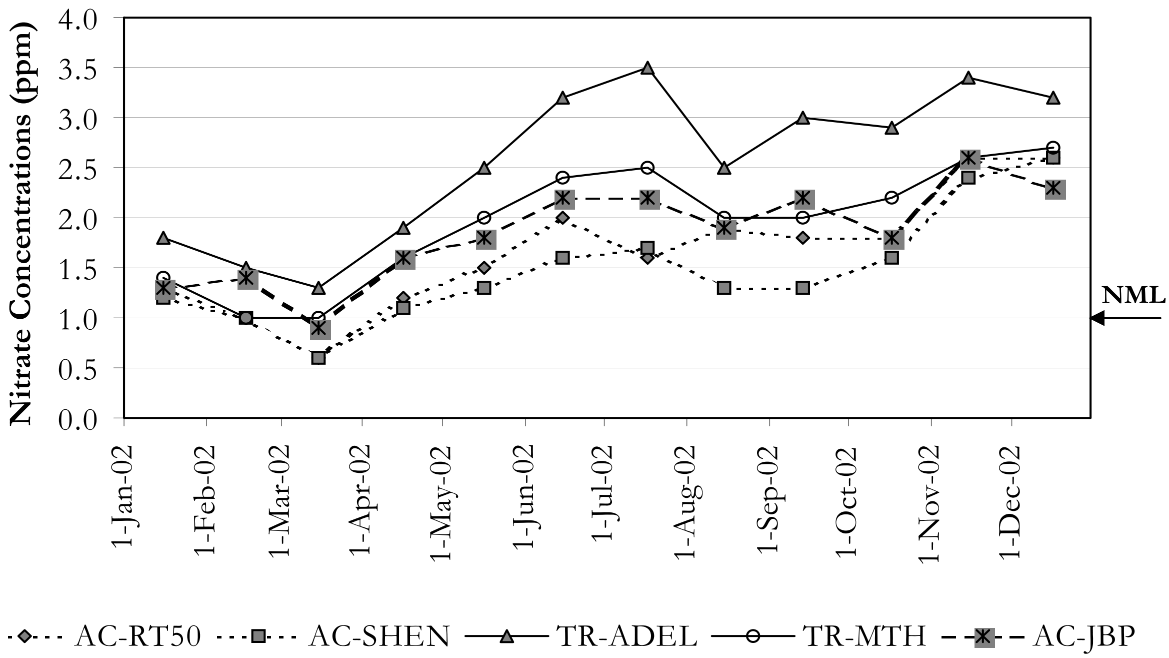

Figure 6. Baseline Nitrate Concentrations by Sampling Site for 2002.
NML = Natural Maximum Level of 1.0 ppm.

Environmental Studies Program, Shenandoah University (2003)

The consistency in this pattern leads the authors to conclude that the data represent a real phenomenon rather than an error in procedure. The likely explanations for these decreasing nitrate levels downstream are uptake by vegetation and dilution by spring sources.

Immediately prior to crossing under the U.S. Route 50 (Millwood Avenue) bridge and passing by Site AC-RT50, upper Abrams Creek flows through commercial areas with vegetated streambanks. The plants in these riparian areas may absorb some of the nitrates that Abrams Creek carries, and they probably take up other nitrate ions that storms wash from pavement and mowed areas towards the stream. Once beyond the bridge, Abrams Creek receives runoff from university lawns and two storm drain pipes that may carry heavy loads of nitrates. Offsetting these potential nutrient inputs, however, could be nutrient uptake by the aquatic vegetation in Racey Ponds (through which much of the creek's water is diverted) and, perhaps, the riparian vegetation further downstream as Abrams Creek approaches Site AC-SHEN.

Unlike upper Abrams Creek, Town Run does not have a high percentage of vegetated stream banks upstream of the study area. After it leaves Glen Burnie, concrete and limestone walls line Town Run through downtown Winchester, past Shawnee Springs Preserve and through the bridge beneath Pleasant Valley Road. (See the description of the study area in Section 3 of this report.) The lack of plant growth immediately beside the waters of Town Run may explain why Site TR-ADEL possesses the highest baseline nitrate levels found in this study. As the stream flows beyond TR-ADEL and towards Site TR-MTH, both herbaceous and woody vegetation grow on the stream banks. This vegetation could possibly account for some of the reduction in nitrate levels found between the two Town Run sites.

Dilution may also explain these reduced nitrate concentrations. Although no obvious springs enter upper Abrams Creek as it flows through Shenandoah University's Main Campus, Johnston identified a seep between AC-RT50 and AC-SHEN during dry weather in Fall 2002. Under these conditions, many parts of Abrams Creek's streambed were dried and cracked. The stream water's flow stopped until a moist area appeared about 60 feet downstream from the dam. This heretofore hidden seep fed the creek through a stream-bottom pool approximately 2 inches deep. A somewhat less dramatic explanation probably accounts for the drop in Town Run's nitrate levels between Sites TR-ADEL and TR-MTH. Between these sites lie no less than four sources of water that feed into Town Run: Rouss Spring, two seeps and Wilkins Lake. Each is capable of diluting nitrate concentrations, although each is also likely to add nitrates from groundwater and external sources (such as waterfowl waste). Findings from this study suggest that the diluting water from these sources overcame the potential nitrates they might add during the year-long research period in 2002.

Phosphate Concentrations

Phosphate Concentrations for the Watershed

In several respects, baseline levels for orthophosphates followed a pattern similar to that reported above for nitrates. Figure 7 reveals that the lowest phosphate concentrations occurred January through April. They began to increase noticeably in May and then dropped substantially after July.

The lowest individual phosphate readings were 0.01 ppm, taken at AC-JBP in January and then matched at TR-MTH in March and AC-SHEN in May. See Table B in Appendix C. The highest level measured was 0.14 ppm for Site TR-ADEL in November. For the study year, baseline readings averaged 0.05 ppm. In Figure 8, the pie graph compares these results to the current EPA standard of 0.10 ppm for orthophosphates. Only 7% of the baseline readings exceeded the EPA standard.

Examination of supplementary factors such as temperature, rainfall, observed stream disturbances and flow levels (Appendix A) did not readily account for the elevated readings in June and July. The month of June was not one of the two warmest months of the study year, nor did the researcher note any stream disturbances at the time she gathered water samples. A heavy rainstorm, which dropped over an inch of water on the study area the day before, may well have affected phosphate readings for June. (As discussed below, elevated orthophosphate levels caused by storms can persist for 24 hours after the cessation of rain.) However, the observed elevated levels for July cannot be explained in this manner. Since 93% of the baseline readings – including the five-site averages for June and July – are classified in Figure 8 as "good," further discussion may be moot.

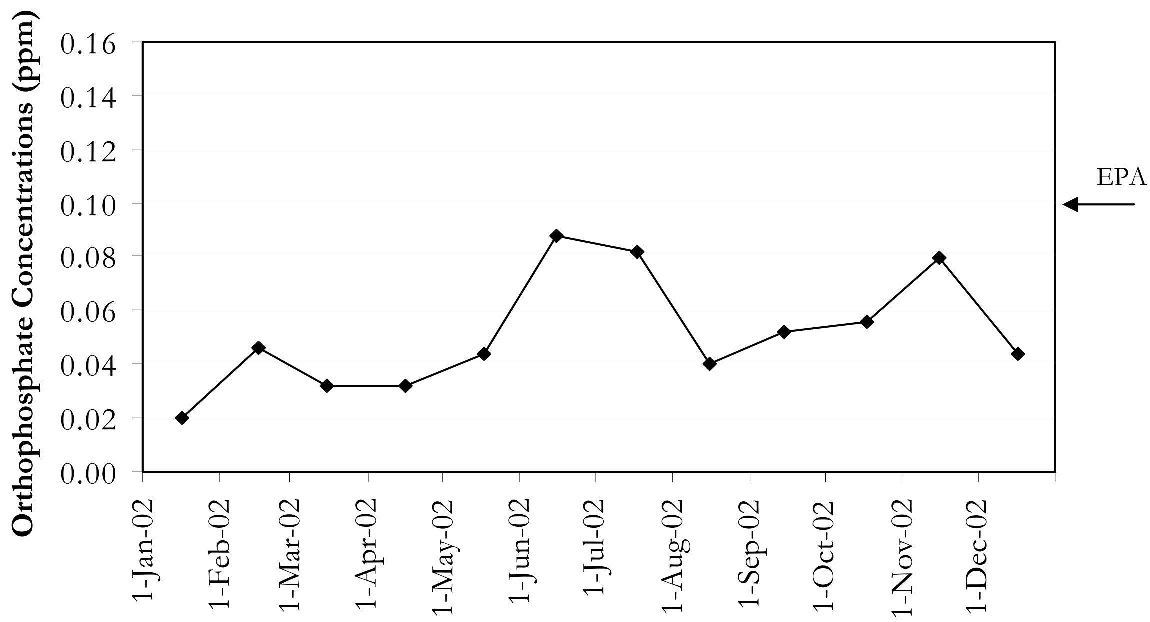

Figure 7. Baseline Phosphate Concentrations for Abrams Creek Watershed for 2002 (i.e., all 5 sampling sites combined). EPA = EPA standard of 0.10 ppm for orthophosphate concentrations.

Environmental Studies Program, Shenandoah University (2003)

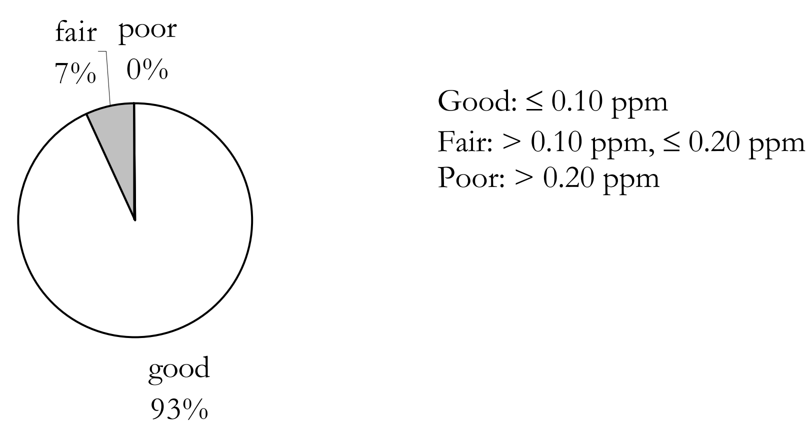

Figure 8. Water Quality of Baseline Phosphate Concentrations for Abrams Creek Watershed for 2002 (i.e., all 5 sampling sites combined)**.**

Phosphate Concentrations by Stream Segment

Examination of baseline data revealed few clear trends in orthophosphate levels for the three stream segments – upper Abrams Creek, Town Run and lower Abrams Creek – over the course of the 2002 study year. The data points displayed in Figure 9 do show that Town Run carried slightly higher phosphorous concentrations than the other two stream segments when baseline levels rose after April.

The year-long average for orthophosphates in the Town Run segment was 0.06 ppm, while both Abrams Creek segments were slightly lower at 0.05 ppm. The sources of the higher phosphorous levels in Town Run may merit further investigation.

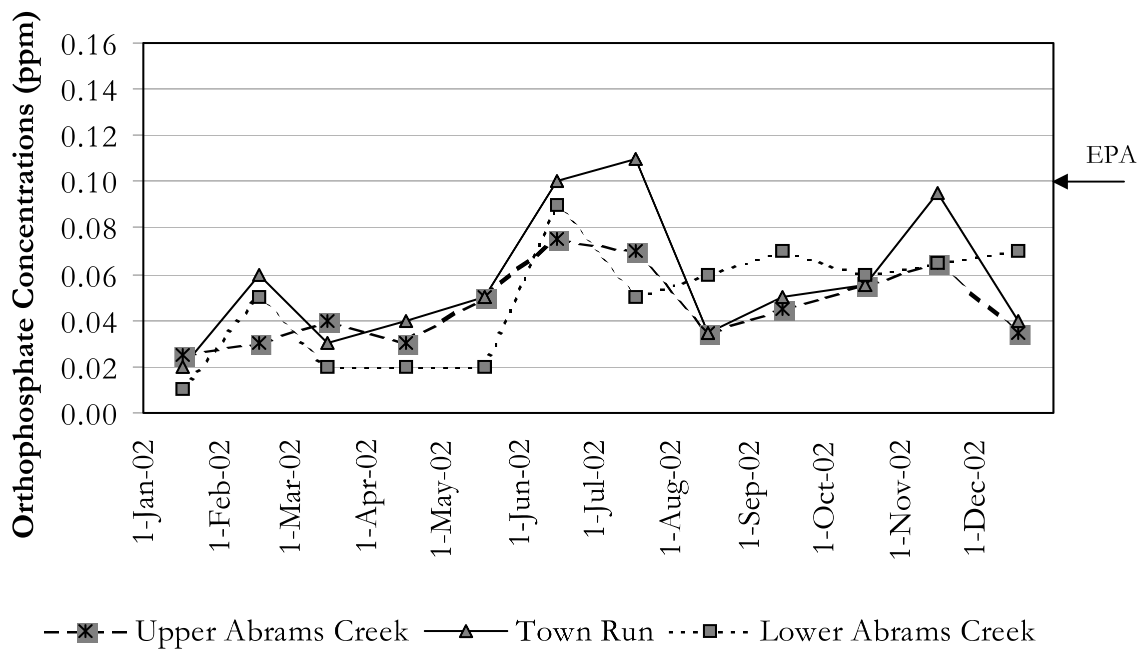

Figure 9. Baseline Phosphate Concentrations by Stream Segment for 2002. EPA = EPA standard of 0.10 ppm for orthophosphate concentrations.

Environmental Studies Program, Shenandoah University (2003)

Phosphate Concentrations by Sampling Site

Site-by-site data trends for the five sampling locations (Figure 10) confirmed that phosphate levels varied during the year but without a recognizable seasonal pattern. The EPA standard of 0.1 ppm was exceeded in June, July and November at site TR-ADEL.

Since the majority of the baseline phosphate readings fell into the "good" category (Figure 8), variations between one site and another might simply indicate natural fluctuations in orthophosphate levels. However, they may instead reflect minor effects of rainstorms, low stream flow or chemical enhancement from the sources described above in connection with nitrate concentrations.

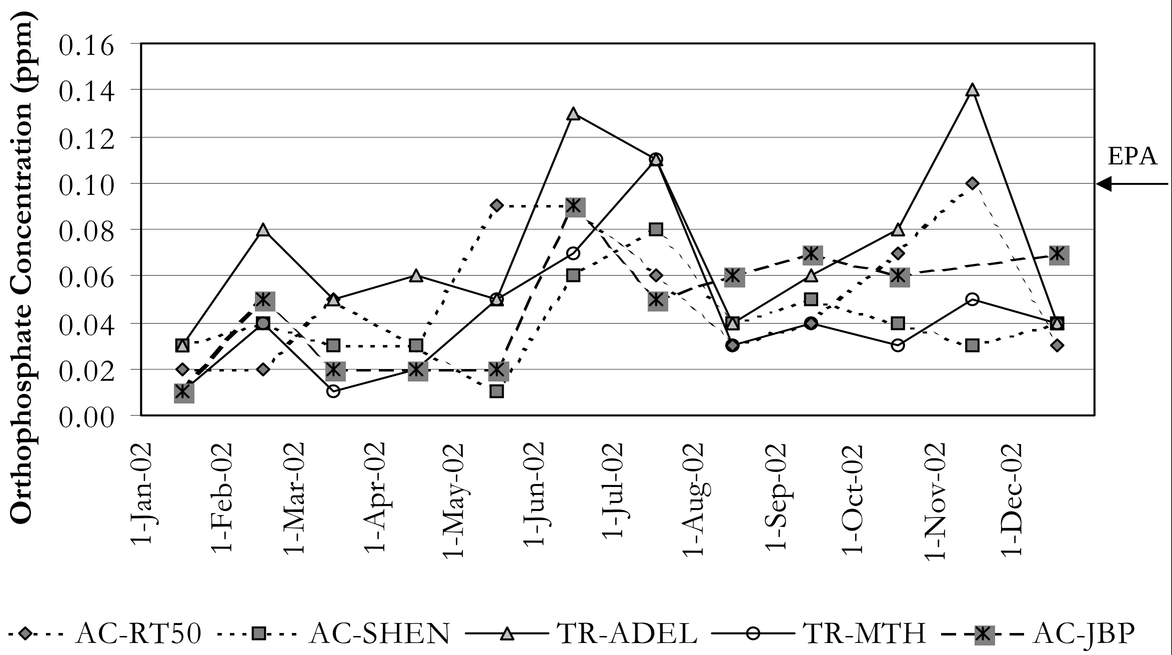

Figure 10. Baseline Phosphate Concentrations by Sampling Site for 2002. EPA = EPA standard of 0.10 ppm for orthophosphate concentrations. An anomalous point (AC-JBP, November) was excluded from the study.

Environmental Studies Program, Shenandoah University (2003)

Turbidity Levels

Not surprisingly, the vast majority (97%) of turbidity readings for Abrams Creek and Town Run during clear-weather baseline conditions in 2002 were either clear (0.0 to 2.0 NTU) or cloudy (2.0 to 7.0 NTU). See Figure 11.

In the Shenandoah Valley people have established residential neighborhoods, commercial districts, industries and agriculture, so the land's surface in most areas is disturbed by human activities. Wind and gravity deposit dust and soil in local streams. Even in fair weather, stream turbulence disturbs the stream's bed and its banks. These factors cause minor turbidity at times and readily explain the baseline findings of this study.

Since the readings were low, line graphs for the three stream segments and five sampling sites are not reported separately here. They do appear in Appendix C, along with Table C, which contain the statistical details.

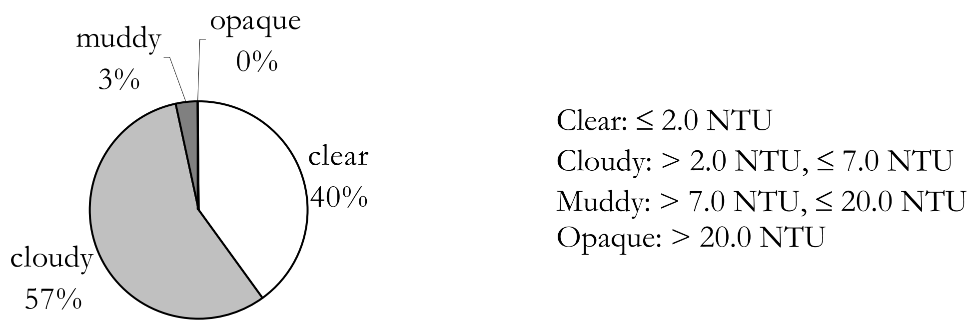

Figure 11. Water Quality of Baseline Turbidity Levels for Abrams Creek Watershed for 2002 (i.e., all 5 sampling sites combined).

Summary of Baseline Water Quality Findings

To summarize the water quality findings presented and discussed above, Table 3 displays the data used to produce the watershed-scale line graphs and pie graphs that have appeared in this section. The table's additional statistics – median, average and standard deviation – represent the central tendencies and variability in the data. See Appendix C for complete baseline data.

For clear-weather conditions, our research findings for Abrams Creek and Town Run are mixed. The vast majority of nitrate readings exceeded the natural levels expected – and recommended by the EPA – for ecologically healthy streams. They are a cause for concern. Phosphate concentrations, on the other hand, generally met EPA and Virginia DEQ standards. Similarly, virtually all of the turbidity measurements fell into the low ranges expected in areas of human settlement.

What happens to Abrams Creek and Town Run when it rains? See Section 6.

Nitrate

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Sample Avg.	1.4	1.2	0.9	1.5	1.8	2.3	2.3	1.9	2.1	2.1	2.7	2.7

High	Low	Median	Average	Std. Dev.
2.7	0.9	2.0	1.9	0.57

Number of Samples Meeting Good/Fair/Poor Water Quality Criteria

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Good	0	3	4	0	0	0	0	0	0	0	0	0
Fair	5	2	1	5	4	2	2	4	3	3	0	0
Poor	0	0	0	0	1	3	3	1	2	2	5	5

Orthophosphate

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Sample Avg.	0.02	0.05	0.03	0.03	0.04	0.09	0.08	0.04	0.05	0.06	0.08	0.04

High	Low	Median	Average	Std. Dev.
0.09	0.02	0.05	0.05	0.02

Number of Samples Meeting Good/Fair/Poor Water Quality Criteria

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Good	5	5	5	5	5	4	3	5	5	5	3	5
Fair	0	0	0	0	0	1	2	0	0	0	1	0
Poor	0	0	0	0	0	0	0	0	0	0	0	0

Turbidity

Number of Samples Meeting Clear/Cloudy/Muddy/Opaque Water Quality Criteria

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Clear	4	4	4	2	3	1	0	1	2	0	3	0
Cloudy	1	1	1	3	2	4	5	3	3	5	2	4
Muddy	0	0	0	0	0	0	0	1	0	0	0	1
Opaque	0	0	0	0	0	0	0	0	0	0	0	0

Table 3. Summary Table of Baseline Water Quality Data for Abrams Creek Watershed for 2002 (i.e., all 5 sampling sites combined).

Section 6.
WATER QUALITY
DURING AND AFTER RAINSTORMS

This report's cover page poses the question *What Happens When It Rains?* Section 6 attempts to respond by presenting the results of tests that were performed on water samples drawn from Abrams Creek and Town Run during and after five rainstorms.

As the reader will recall from Section 4 of this report, the research plan was to collect water samples at two-hour intervals for a storm's first 24 hours (allowing time off for sleep) and then collect a single sample 48 hours after the first sample had been gathered. A total of 155 samples were drawn during five storms that occurred in March, April, May, June and August 2002. In Shenandoah University's Environmental Studies Laboratory, the researcher and her assistants tested each sample for nitrate concentration, phosphate concentration and turbidity level.

Results of the tests appear below as line graphs. In order to compare storm readings with baseline conditions, an arrow on each graph's right-hand margin shows the **average baseline level (ABL)** for the factor – nitrates, phosphates or turbidity. These levels were determined from this study's data and are discussed above in Section 5. A second arrow indicates the **recommended maximum level (RML)** or **water quality standard (WQS)** set by the EPA and/or the Virginia DEQ for the factor. In addition, each line graph includes data points for the **baseline readings** that were taken at the five sampling sites for the month during which the storm happened.

To identify and help explain the water quality changes that occurred between upstream and downstream locations, results are depicted in one scale only: by sampling site. (Since readings peaked and dropped at different times, the authors decided that combining storm records into a single line graph for the entire watershed would be misleading.)

The subsections below present the storms as five separate case studies. They contain brief descriptions of each storm and its effects on nitrate, phosphate and turbidity levels in Abrams Creek and Town Run. They describe the rainstorm's intensity and duration, identify the lowest and highest readings for each factor, and compare the effects at various parts of the watershed. While the five storms examined in this study exhibited interesting differences, they also shared some noticeable trends. These patterns are summarized at the end of this section.

March 20: A Brief but Heavy Downpour

This brief heavy rainstorm dropped just over 1 inch of rainfall in the study area. (See Appendix B for precipitation data.) Sample collection began approximately twenty minutes after the storm, and a total of eight sample sets were collected.

As Figure 12 illustrates, nitrate concentrations slowly increased over the 48-hour sample period. Levels ranged from 0.60 ppm of nitrates on March 20 at 8:00 a.m. to 2.6 ppm on March 22 at 9:00 a.m.   The two extremes both occurred at the Abrams Delight site on Town Run (TR-ADEL), and nitrate levels may have continued to rise after the sampling period. An interesting trend is the comparatively rapid increase in Town Run's nitrate concentrations. As Figure 12 reveals, Site TR-ADEL had the lowest nitrate concentration of the five sites at the start of the storm, but over the next few hours nitrates at this site quickly increased to the highest among the five sites. In contrast, concentrations at the two sample sites in upper Abrams Creek – Sites AC-RT50 and AC-SHEN – increased only slightly. All but a few of the first samples exceeded the EPA's recommended maximum levels for nitrate concentration.

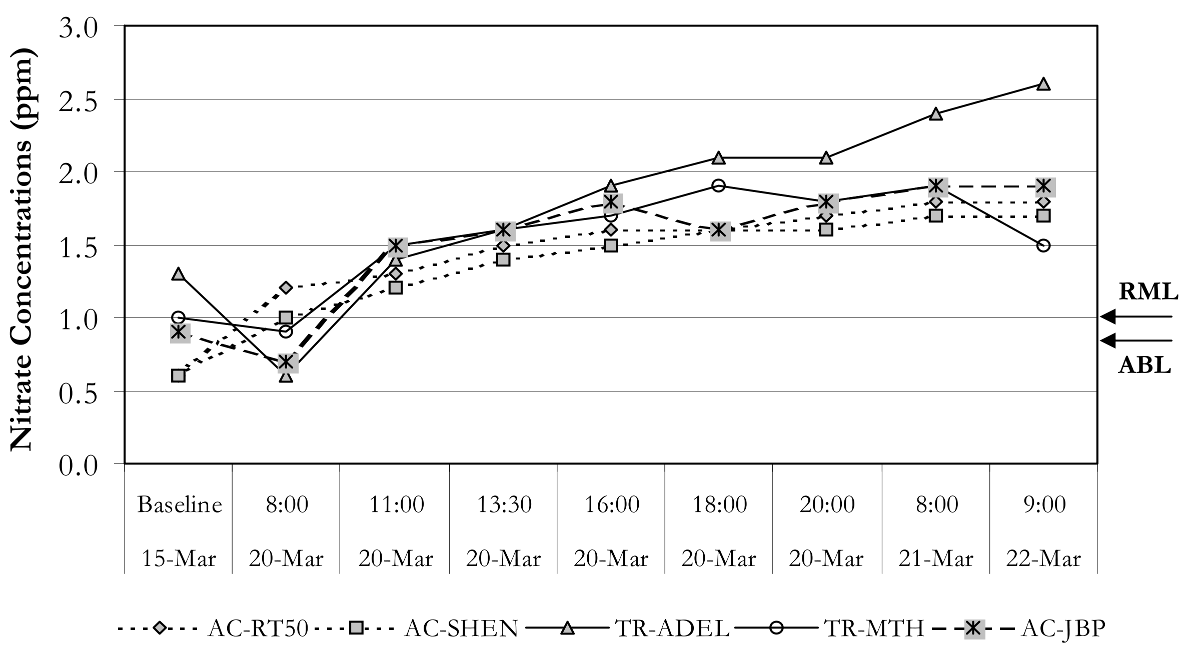

Figure 12. Nitrate Concentrations for March 20 Storm. Arrows to the right of the graph indicate the average March baseline level of 0.88 ppm (ABL) and the recommended maximum level of 1.0 ppm (RML).

Environmental Studies Program, Shenandoah University (2003)

The pattern of slowly increasing nitrate concentrations during and after the March 20 rainstorm suggests that nitrate ions, which are water-soluble, infiltrated the groundwater sources that feed both Abrams Creek and Town Run. The rapid increase in Town Run's levels reveals that nitrates entered this stream much more rapidly than they entered upper Abrams Creek. Land use might explain this difference. Many springs and seeps that feed Town Run underlie Winchester's developed urban areas, which may contain sizable quantities of nitrate-bearing fertilizer. If this were the case, even a small rainstorm would raise nitrates in groundwater that eventually finds its way to Town Run.

Orthophosphate concentrations exhibited a different pattern. As Figure 13 indicates, high levels appeared at the first sampling time, shortly after the onset of this rainstorm. Concentrations returned to baseline levels within 24 hours. Phosphate levels ranged from a high of 0.34 ppm at Town Run's mouth (Site TR-MTH) near the storm's beginning to a low of 0.02 ppm at the most downstream site (AC-JBP) a day later. The two upper Abrams Creek sites and Site TR-ADEL peaked after the storm's initial strong downpour ended. As was the case for nitrates, phosphate levels were highest in Town Run. Phosphates spiked above the EPA standard of 0.10 ppm during the first portion of the storm, then they gradually dropped below this level. Concentrations at Site TR-ADEL, however, remained above the standard in all but one sample.

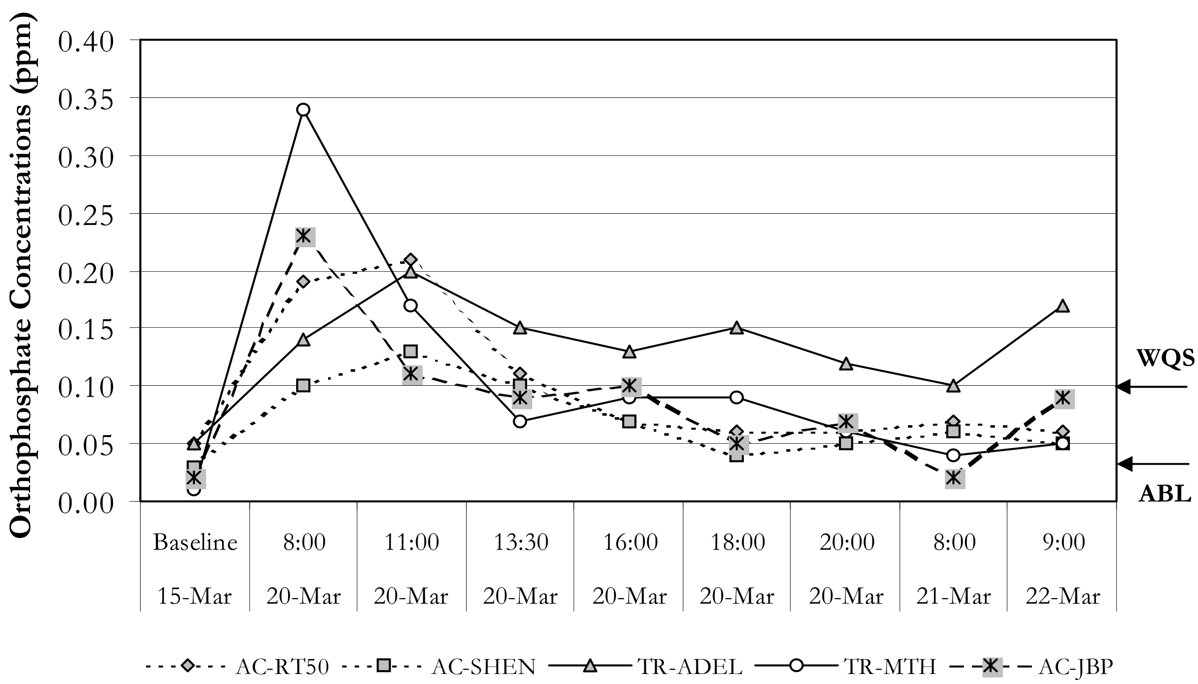

Figure 13. Phosphate Concentrations for March 20 Storm. The arrow to the right of the graph indicates the average March baseline level of 0.03 ppm (ABL) and the water quality standard of 0.1 ppm (WQS).

Environmental Studies Program, Shenandoah University (2003)

The early phosphate peaks indicate that the rapid flow of storm water runoff – not the slow percolation of groundwater – apparently plays the greater role in carrying this ion into Abrams Creek and Town Run. The second peak found at upper Abrams Creek and Site TR-ADEL, although small, suggests that storm water may have to accumulate enough to rise over a physical barrier, such as an elevated storm pipe or retention-pool spillway, before it can enter these creeks.

Turbidity levels in both Abrams Creek and Town Run were greatly affected by this rainstorm. Like orthophosphate concentrations, high turbidity levels were recorded at the beginning of the sample. See Figure 14. After the initial spike, turbidity levels in the opaque range (i.e., > 20 NTU) quickly dropped within 24 hours into the acceptable clear to cloudy range, although some fluctuation in turbidity occurred as readings neared baseline amounts. The highest level recorded was 250 NTU – well into the opaque range – at Site AC-JBP at the first sampling time. The lowest turbidity level occurred two days later: 2.32 NTU at Site TR-ADEL. Upper Abrams Creek's turbidity levels fell to near-baseline levels more rapidly than did the other stream segments.

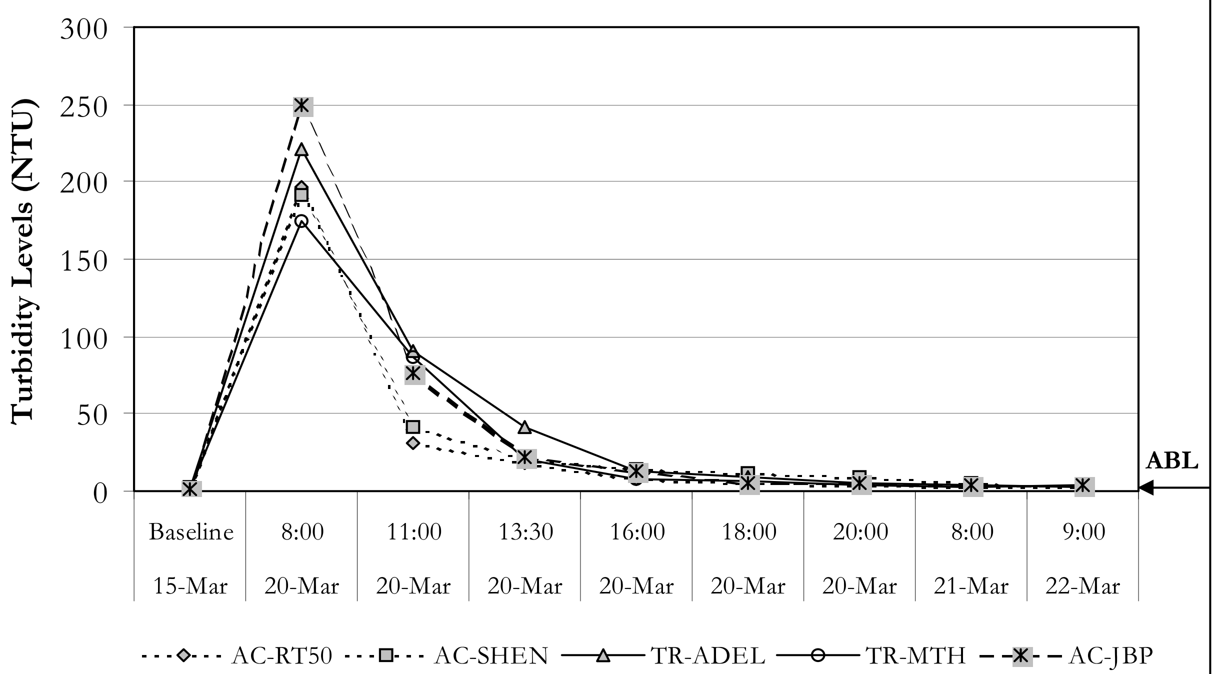

Figure 14. Turbidity Levels for March 20 Storm. The arrow to the right of the graph indicates the average March baseline level of 1.73 NTU (ABL).

Environmental Studies Program, Shenandoah University (2003)

The early peaks in turbidity levels show that turbidity is associated with surface runoff and the disturbance of a stream's banks and channel during periods of increased water volume. The similar turbidity and orthophosphate patterns recorded for this storm are not surprising; they affirm that phosphate ions bind readily to soil particles. The high turbidity at Site AC-JBP indicates disturbance below the creek's confluence with Town Run. Channel and streambank erosion along Abrams Creek as it makes a sharp turn to the east is the likely source. (See the cover page's lower right-hand photograph.)

April 9: A Ten-Minute Sprinkle

As Johnston headed to the research site at noon to collect pre-storm water samples, the skies looked ominous. Much to her dismay, however, this late-afternoon storm turned out to be a ten-minute sprinkle. Approximately 0.17 inches of rain fell that day, but an additional 0.34 inches fell the following afternoon. The sample series, consequently, was terminated before the 48-hour mark to eliminate the potential influence of the second, larger storm on nitrate, phosphate and turbidity levels that had resulted from the April 9 precipitation.

Figure 15 illustrates nitrate concentrations before, during and after this rainstorm. Although this storm was much smaller than the four other rainstorms studied, the changes in Abrams Creek and Town Run are worth noting for comparative purposes. When the rain fell at 4:00 p.m., nitrate levels dropped in Abrams Creek but rose in Town Run. None of the changes at the five sampling sites was greater than 0.4 ppm, however. The line graphs in Figure 15 may simply reflect small fluctuations in water characteristics that would have occurred even without a 0.17-inch rainstorm.

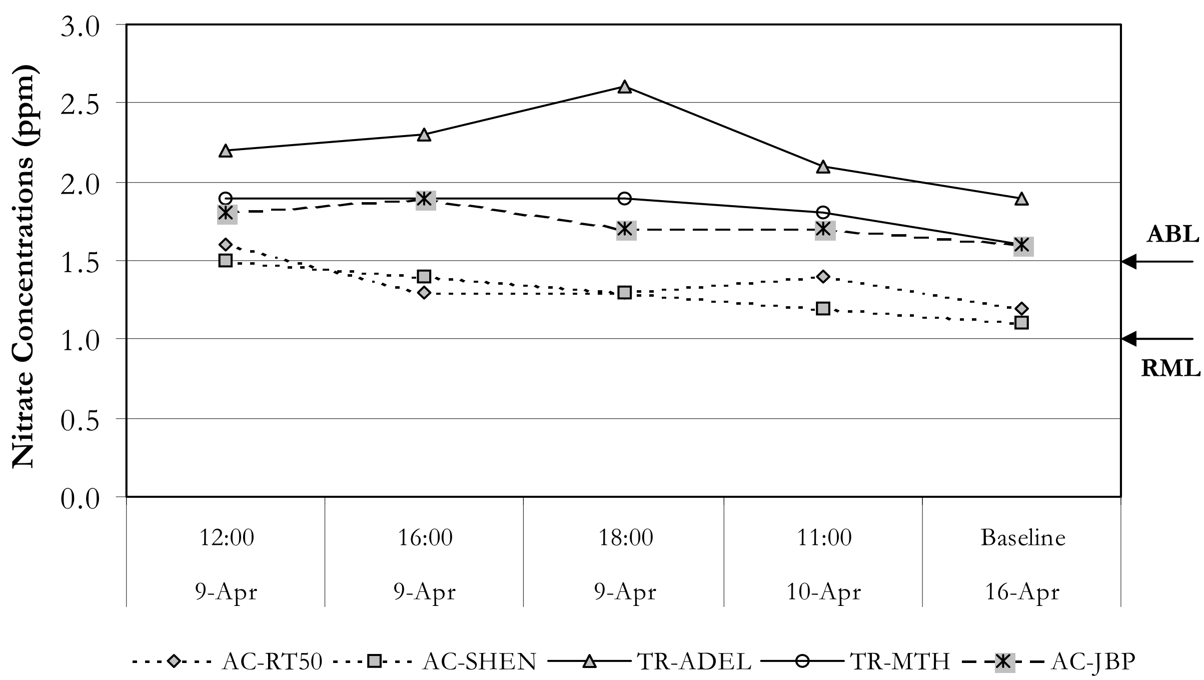

Figure 15. Nitrate Concentrations for April 9 Storm. Arrows to the right of the graph indicate the average April baseline level of 1.5 ppm (ABL) and the recommended maximum level of 1.0 ppm (RML).

Environmental Studies Program, Shenandoah University (2003)

Nitrate levels were already above the EPA-recommended maximum of 1.0 ppm prior to any rain. The gradual rise in Town Run's readings could indicate the slow entry of nitrates via groundwater, even when precipitation is slight. If this interpretation is correct, future attempts to improve water quality Town Run will have to account for urban sources of nitrates in the groundwater.

Surprisingly, this small rainstorm affected orthophosphate concentrations (Figure 16) noticeably. Phosphate levels peaked at 4:00 p.m., during the storm itself. By the following morning, these levels were almost back to pre-storm concentrations. Levels ranged from 0.48 ppm at site TR-ADEL as the rain fell at 4:00 p.m. to 0.02 ppm at Site AC-RT50 two hours later at 6:00 p.m. As Figure 16 indicates, orthophosphate concentrations in Town Run quickly rose above the 0.10 ppm water quality standard, while the upper Abrams Creek sites (AC-RT50 and AC-SHEN) were barely affected.

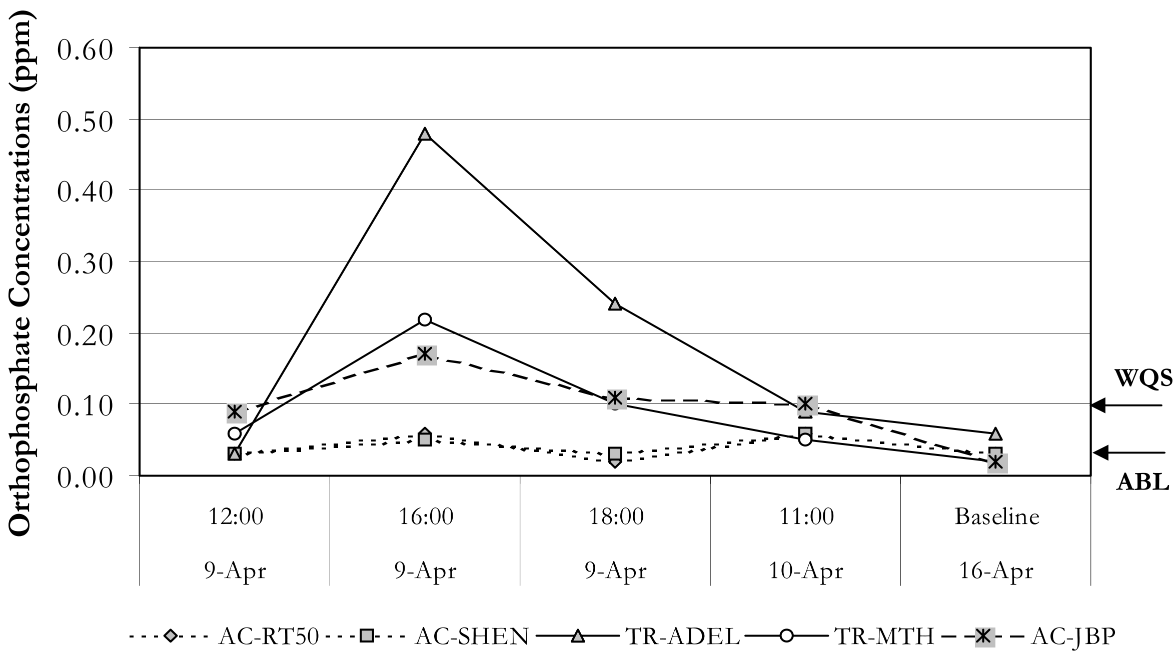

Figure 16. Phosphate Concentrations for April 9 Storm. The arrow to the right of the graph indicates the average April baseline level of 0.03 ppm (ABL) and the water quality standard of 0.1 ppm (WQS).

Environmental Studies Program, Shenandoah University (2003)

The early peak and gradual decline in phosphate concentrations in Town Run indicates that this nutrient was probably entering the stream via surface runoff. The rapid increase suggests the presence of excess fertilizer and/or soil erosion beyond what the rainfall could dilute. Different patterns for upper Abrams Creek and Town Run could be the result of different land uses (more rural versus more urban) or, perhaps, simply more rainfall in Town Run on April 9.

Figure 17 reveals that turbidity levels in both Abrams Creek and Town Run were also affected by the small amount of rain from the April storm. Similar to the March 20 storm, orthophosphate and turbidity levels followed identical patterns. High turbidity readings occurred early in the storm and seemed to affect the upstream sites (AC-RT50 and TR-ADEL) more than their downstream counterparts. The lowest recorded reading was 1.70 NTU (clear) at Site AC-RT50 prior to the rainstorm, though turbidity levels returned close to their pre-storm levels by the April 11 sampling period. The highest turbidity measurement was 71.7 NTU (opaque) at TR-ADEL at 4:00 p.m. during the storm itself. Turbidity measurements at Town Run were nearly twice those of upper Abrams Creek.

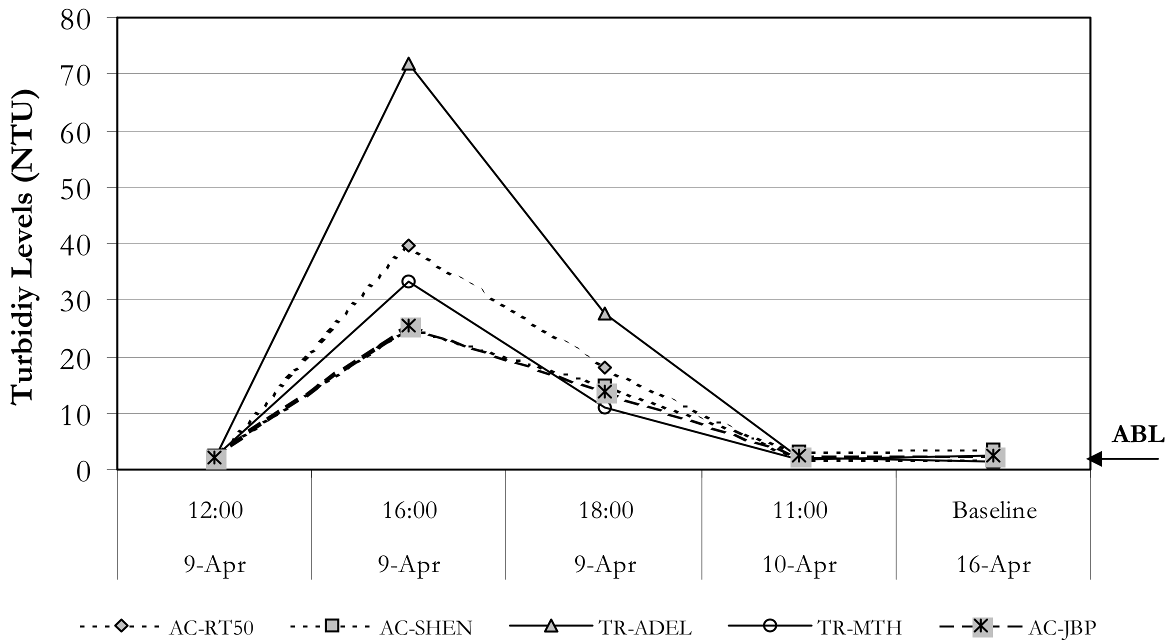

Figure 17. Turbidity Levels for April 9 Storm. The arrow to the right of the graph indicates the average April baseline level of 2.05 NTU (ABL).

Environmental Studies Program, Shenandoah University (2003)

The early peaks in both orthophosphate and turbidity during the April 9 storm suggest that the high turbidity levels are associated with surface runoff. Since Town Run flows through a more urban setting than Abrams Creek, its higher turbidity levels may reflect storm water runoff from paved surfaces that flows into Town Ruin unfiltered by vegetated riparian areas. Again, these spikes in Town Run's readings indicate that the watershed cannot absorb even a small change, such as a 0.17-inch sprinkle.

The lower turbidity levels observed at the two downstream sites of Town Run and upper Abrams Creek (i.e., TR-MTH and AC-SHEN, respectively) may be explained by physical changes in the streams themselves. Suspended solids carried by Abrams Creek may settle out in the slower water backed up by Shenandoah University's dam or held in the neighboring Racey Ponds. Town Run's constructed channel ends at site TR-ADEL, so stream velocity slows and particles can settle, decreasing turbidity downstream.

May 26: A Heavy Thunderstorm Followed by Intermittent Showers

On May 26, a prolonged thunderstorm inundated the study area with heavy rains and occasional hail between 3:00 and 4:00 p.m. before tapering off to intermittent showers and sprinkles for the next several hours. Johnston began sampling approximately 30 minutes after rain started. A lighter shower fell just before she drew the third set of samples at 7:30 p.m. She eventually obtained five samples from each site. As had happened during the April 9 storm, the sample period for the May 26 storm was cut short because a second, even heavier, storm struck before the final sample set could be collected. During this storm, Town Run's high choppy flow displaced several boulders at Site TR-ADEL and rose above its banks at Site TR-MTH by 7:30 p.m.

Figure 18 displays only moderate changes in nitrate concentrations. However, comparing sample sites reveals potentially useful information about each portion of the streams. Nitrate concentrations in upper Abrams Creek (i.e., AC-RT50 and AC-SHEN) decreased in the early stages of the storm, then gradually increased. Nitrates in Town Run (Sites TR-ADEL and TR-MTH) fluctuated at elevated levels from the baseline reading through the storm sampling period. In lower Abrams Creek (Site AC-JBP), nitrate levels also fluctuated but exhibited a general increase during the storm. The lowest nitrate concentration recorded during the storm period was 1.1 ppm from the first storm sample at Site AC-JBP. The highest level was 3.0 ppm at Site TR-ADEL on May 26 at 5:30 p.m., after the heavy rains tapered off.

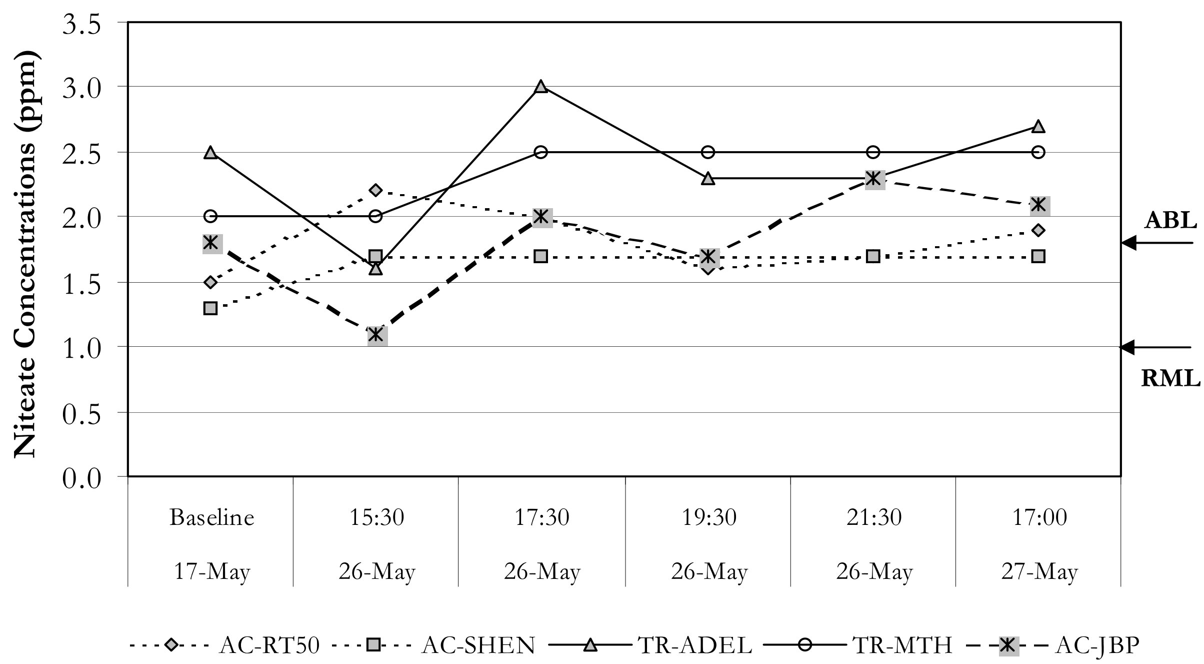

Figure 18. Nitrate Concentrations for May 26 Storm. Arrows to the right of the graph indicate the average May baseline level of 1.8 ppm (ABL) and the recommended maximum level of 1.0 ppm (RML).

Environmental Studies Program, Shenandoah University (2003)

The rainfall pattern during the sampling period for the May 26 storm may account for these fluctuating nitrate concentrations. Unlike the two previous storms, this rainstorm did not end quickly. Surface runoff from the initial thunderstorm could have affected nitrate concentrations during subsequent periods of lighter rain. After the early heavy rains flushed nitrates from lawns, roads and parking lots into Town Run, the subsequent cleaner runoff may have slightly diluted the nitrate concentrations later in the sampling period. Increased nitrate readings from the last two sample runs at AC-RT50 and AC-JBP, when there was no rainfall to supply surface runoff, suggest that nitrates were entering Abrams Creek and Town Run from groundwater sources.

Orthophosphate levels followed a different pattern during this May 26 storm. As Figure 19 shows, phosphates peaked early in the storm period and did not fall back to baseline levels until the rain ceased. These storm concentrations exceeded the EPA standard of 0.10 ppm but fell under that level after storm had run its course. Phosphate levels ranged from a low of 0.02 ppm at Site AC-SHEN to an unusually high 0.70 ppm at site TR-ADEL. Overall, Town Run was most affected by elevated phosphate concentrations, and the two upstream sites (AC-RT50 and TR-ADEL) were more affected than their downstream counterparts.

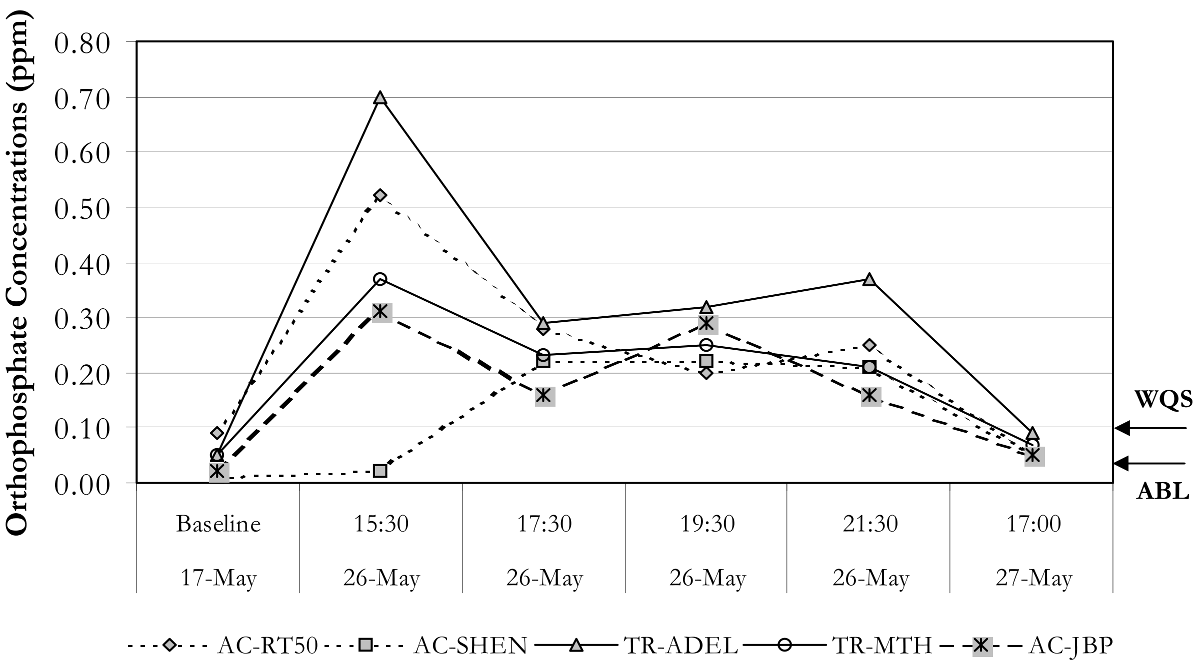

Figure 19. Phosphate Concentrations for May 26 Storm. Arrows to the right of the graph indicate the average May baseline level of 0.04 ppm (ABL) and the water quality standard of 0.1 ppm (WQS).

Environmental Studies Program, Shenandoah University (2003)

This pattern in Figure 19 – early peak, higher upstream readings – appears to fit the chemical behavior of phosphorous and the hydrologic behavior of groundwater in limestone regions. Phosphates entered Abrams Creek and Town Run quickly via surface runoff. Some of these ions were dissolved in the runoff, but greater quantities were probably attached to soil particles that washed into the streams. Soil erosion and stream channel erosion from the turbulent storm were also likely sources of phosphates. Downstream dilution by groundwater may be responsible for the decreased phosphate levels at the downstream sampling sites. Intermittent rainfall could have caused phosphate levels to remain high throughout the sample period.

The higher concentrations in Town Run suggest that this watershed released greater levels of phosphates into the stream from sources such as fertilizers. This likely possibility, plus the elevated levels and rapid phosphate peaks at all sampling sites, point to the need for riparian buffers and improved storm water management.

As Figure 20 reveals, the May storm produced two turbidity peaks. Unexpectedly, the higher peak occurred during the period of intermittent rainfall that followed the initial storm. Turbidity then fell to pre-storm baseline levels by the end of the sampling period after all rain had ceased. Readings ranged from 387 NTU (opaque) at site TR-MTH down to 1.89 NTU (clear) at site TR-ADEL. As in previous storms, Town Run was affected more than upper or lower Abrams Creek.

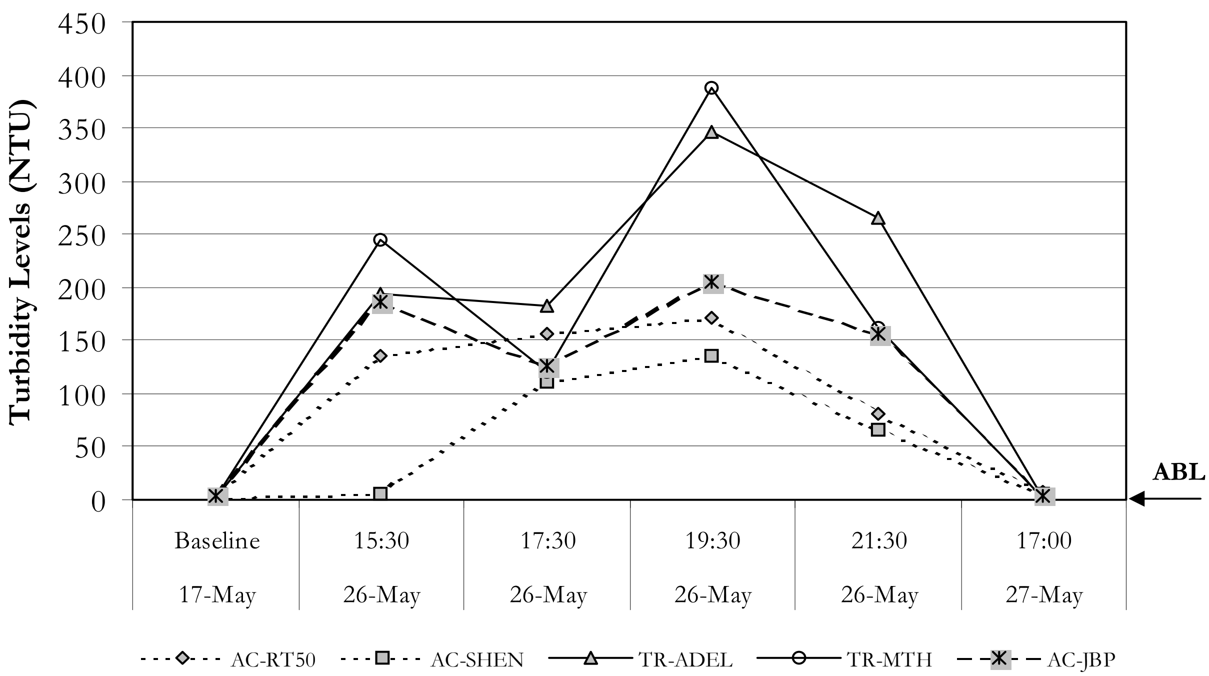

Figure 20. Turbidity Levels for May 26 Storm. The arrow to the right of the graph indicates the average May baseline level of 1.86 NTU (ABL).

Environmental Studies Program, Shenandoah University (2003)

The first turbidity peak during the intense start of the May 26 storm is easily explained by surface runoff. The second peak, substantially higher (especially in Town Run) than the first, was somewhat surprising, given the gentler nature of the rainfall that followed the initial thunderstorm. Erosion of the stream's channel and banks by its turbulent waters may be responsible. Water levels had not yet subsided, and the lingering rains caused the streams to surge onto banks already wet from the earlier precipitation. As noted previously, Site TR-MTH was flooded by 7:30pm on May 26, and several boulders were displaced at Site TR-ADEL by the high, choppy waters moving through this area. (These in-stream disturbances also help explain the prolonged phosphate levels observed during this storm and discussed above.)

June 27-29: Prolonged Light Rains Produce Erratic Results

The June 27-29 rainstorm was noteworthy in two respects. First, precipitation was light and intermittent but prolonged. Second, the rain began about 18 hours before Shenandoah University drained the area upstream of the Abrams Creek dam to carry out some light construction on the dam. The storm initially dropped about 0.08 inches of rain on the study area, followed by an additional 0.35 inches over the next two days. The dam was opened at approximately 11am on June 28. Construction continued for several more hours that day. The first water quality sample was drawn 20 minutes after rain began falling on June 27; eight sampling runs were completed during the 48-hour period.

Except at Site TR-ADEL, nitrate levels did not rise a great deal during this period. See Figure 21. Nitrates actually dropped for a period of time at AC-SHEN. Site TR-ADEL had the highest recorded level of 3.1 ppm, while the lowest reading of 1.1 ppm occurred at site AC-SHEN.

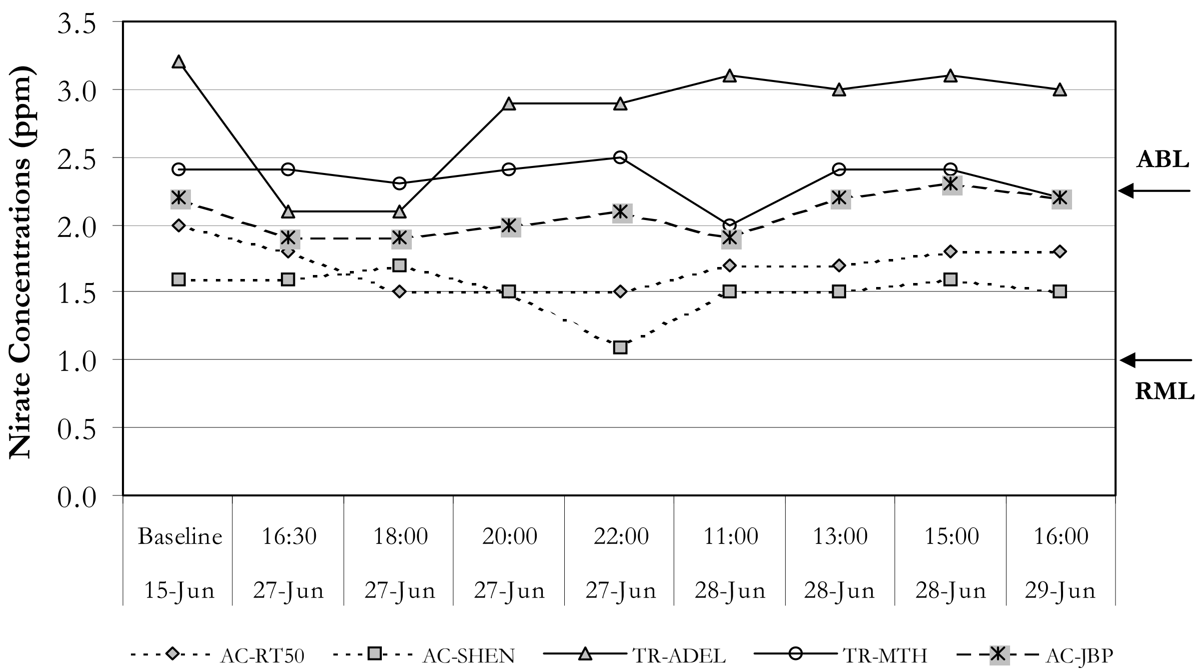

Figure 21. Nitrate Concentrations for June 27 Storm. Arrows to the right of the graph indicate the average June baseline level of 2.3 ppm (ABL) and the recommended maximum level of 1.0 ppm (RML).

Environmental Studies Program, Shenandoah University (2003)

Despite the low rainfall at the beginning of the storm period, the Abrams Delight site on Town Run (TR-ADEL) conformed to the pattern of rising nitrate levels found in Town Run for previous storms. Although nitrate levels at Site TR-MTH increased with additional rain on the 28th, nitrate concentrations decreased slightly both before and after this time, showing little overall effect from the storm.

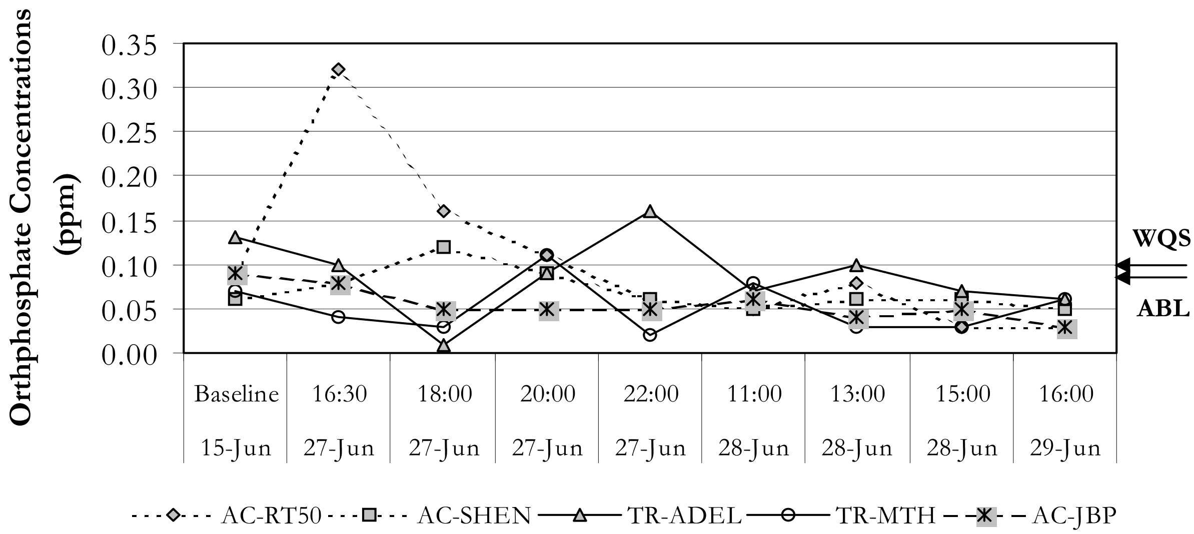

Figure 22. Phosphate Concentrations for June 27 Storm. Arrows to the right of the graph indicate the average June baseline level of 0.09 ppm (ABL) and the water quality standard of 0.1 ppm (WQS).

Environmental Studies Program, Shenandoah University (2003)

As in previous storms, nitrate levels in upper Abrams Creek tended to decrease, and then gradually rise. This pattern raises the possibility that accumulating rain eventually flushes stored nitrates out of retention areas such as Racey Ponds and the still-water area upstream from Shenandoah University's dam. The lack of a similar increase on the 28th after the dam was opened is difficult to interpret.

Orthophosphate levels (Figure 22) varied erratically between streams and sample sites during the June 27-29 storm. Most readings stayed below the EPA standard of 0.10 ppm. Despite the fluctuating readings, phosphate concentrations overall did not change a great deal, except for the spike at Site AC-RT50 at the beginning of the storm. Phosphate trends in previous storms show that the spike observed at Site AC-RT50 was expected, but other sites did not follow the same pattern. Site TR-ADEL spiked more than 5 hours later.

Given the small amount of rain that fell during this storm, it may be possible that phosphate concentrations in some parts of the watershed were unaffected by surface runoff that would have carried additional phosphates into the stream. The erratic fluctuations observed at these sites during this storm might simply have been natural variations in phosphate levels. No effects of construction are discernable.

As Figure 23 indicates, turbidity levels peaked early in the sample period and rapidly fell back to near-baseline levels in less than 4 hours. This pattern is typical. Turbidity levels ranged from 280 NTU (opaque) at site AC-JBP to 1.15 NTU (clear) at site TR-ADEL. Construction work performed on the dam on June 28 did not appear to alter turbidity levels downstream at Sites AC-SHEN or AC-JBP.

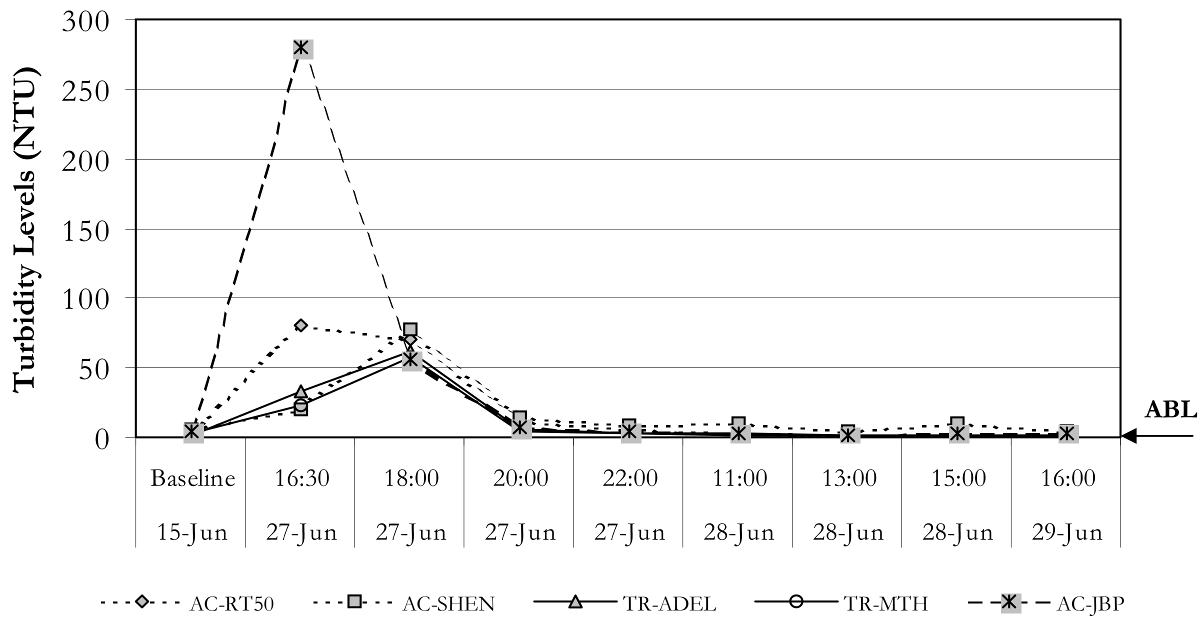

Figure 23. Turbidity Levels for June 27 Storm. The arrow to the right of the graph indicates the average June baseline level of 3.64 NTU (ABL).

Environmental Studies Program, Shenandoah University (2003)

It is interesting to note that turbidity and phosphate spikes (see Figure 22 for the latter), which generally coincide, did not occur at the same site in this case. If the readings are valid, this situation may indicate that phosphates were entering the stream in dissolved form rather than attached to soil particles or stream-channel sediment. The circumstances on June 27-29 make generalizations from this storm difficult to draw.

August 15: A Moderate But Forceful Rainstorm

During the August 15 rainstorm, approximately 0.16 inches of rain fell in the study area. Most of this rain occurred around 2:30pm, although a small amount added to the total near 9:30pm. Baseline samples for the month had been collected that morning, so the unexpected afternoon storm allowed the baseline readings to double as pre-storm samples. Johnston then collected storm samples 20 minutes after the storm began, and she drew five more sample sets during the next 48 hours.

Shortly after the storm began at 2:30 p.m., Abrams Delight at Site TR-ADEL was flooded. Water levels were still rising at 3:00 p.m. when Johnston gathered her first storm sample from this site. She distinctly remembers thinking, “I don’t want to go anywhere near this stream!” as she heard the sounds of tumbling boulders and watched the water’s forceful display as it crashed through Town Run. By the following day, a portion of the north bank downstream of Site TR-ADEL had been washed away and a freshly broken boulder sat in the streambed.

The line graphs in Figure 24 reveal that nitrates rose at most sites during this storm. Concentrations in both Town Run and lower Abrams Creek exhibited initial drops before gradually increasing. Nitrate levels ranged from a high of 3.4 ppm at site TR-ADEL to four low readings of 1.3 ppm at site AC-SHEN. Typically, Town Run, showed the greatest effects.

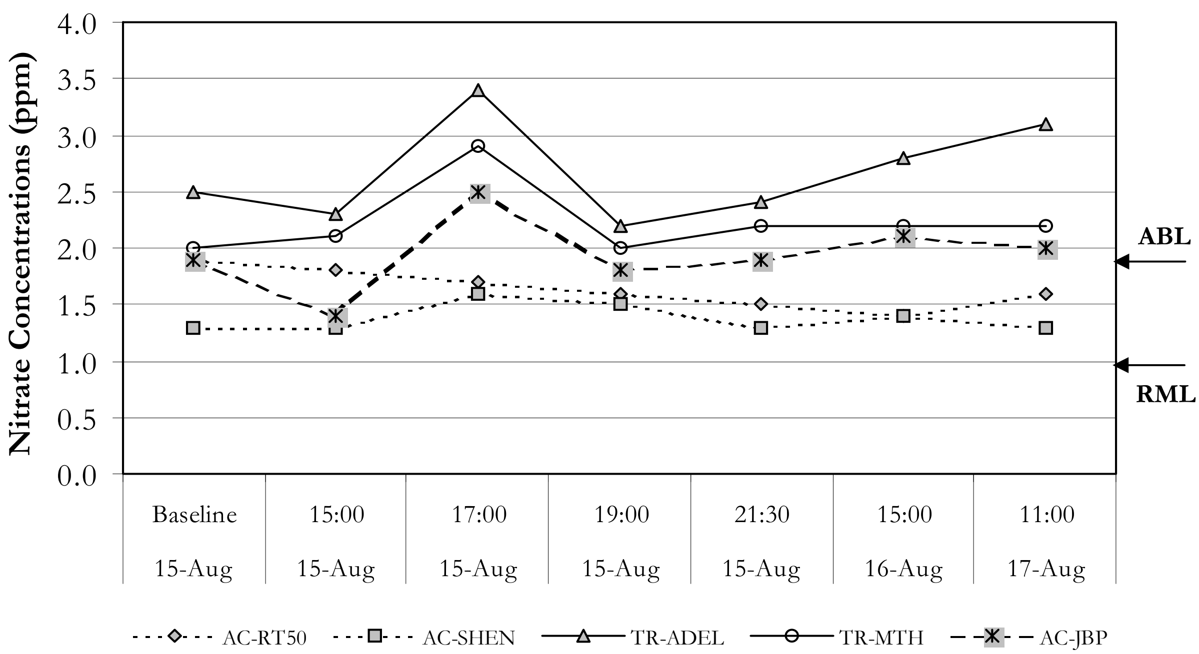

Figure 24. Nitrate Concentrations for August 15 Storm. Arrows to the right of the graph indicate the average August baseline level of 1.9 ppm (ABL) and the recommended maximum level of 1.0 ppm (RML).

Environmental Studies Program, Shenandoah University (2003)

The early peak and fall in nitrate levels suggests that nitrates entered Town Run and lower Abrams Creek primarily through surface runoff at this time. Although this nutrient peak did not coincide with the flood conditions observed in these areas just two hours earlier, all sites had high stream volumes when nitrate levels peaked. It is likely that the delay between the rainfall at 2:30 p.m. and the nitrate peaks at 5:00 p.m. means that nutrient loads traveled some distance before entering the Abrams Delight site on Town Run and then reaching lower Abrams Creek downstream. If this was the case, then storm water runoff from the adjacent Forest Hills community (see Figure 2 in Section 4) or even neighborhoods further upstream may be the culprit. This runoff from residential lawns and streets travels beneath Pleasant Valley Road and then through retention areas in Jim Barnett Park's southwestern corner before entering Town Run.

The second peaks in nitrate levels were probably due to groundwater infiltration, which takes longer than surface runoff to enter a stream. The lack of an increase in upper Abrams Creek (Sites AC-RT50 and AC-SHEN) is difficult to explain, however. Once again, the dramatic changes in Town Run (and, subsequently, in lower Abrams Creek) by the August storm shows that the Town Run watershed cannot handle the nitrate loads carried by storms. This consistent finding calls for improved storm water management in Town Run's riparian zone and upland areas.

Figure 25 shows that orthophosphate concentrations peaked early then gradually subsided over the 48-hour sampling period. Sites TR-ADEL and AC-JBP peaked during the worst of the storm, while the other four sites followed suit two hours later. Phosphate readings ranged from 0.47 ppm at Site TR-ADEL (August 15 at 3:00 p.m.) down to 0.02 ppm at Site AC-RT50 at the same time. Both Town Run and lower Abrams Creek were most affected by this storm, although phosphate levels at site TR-MTH were not affected as much as those upstream at site TR-ADEL.

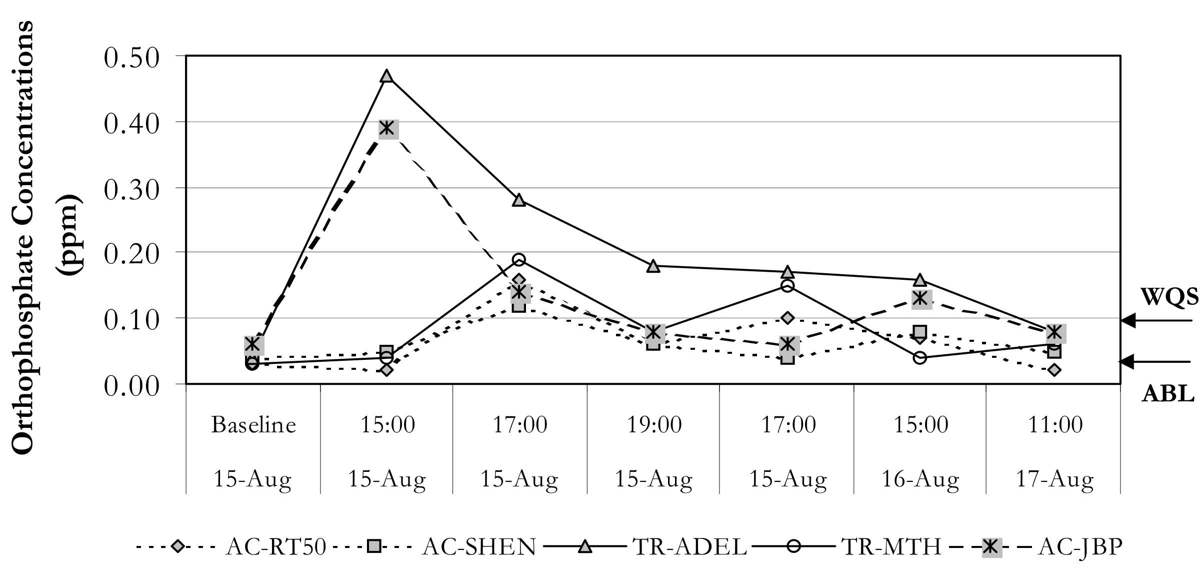

Figure 25. Phosphate Concentrations for August 15 Storm. Arrows to the right of the graph indicate the average August baseline level of 0.04 ppm (ABL) and the water quality standard of 0.1 ppm (WQS).

Environmental Studies Program, Shenandoah University (2003)

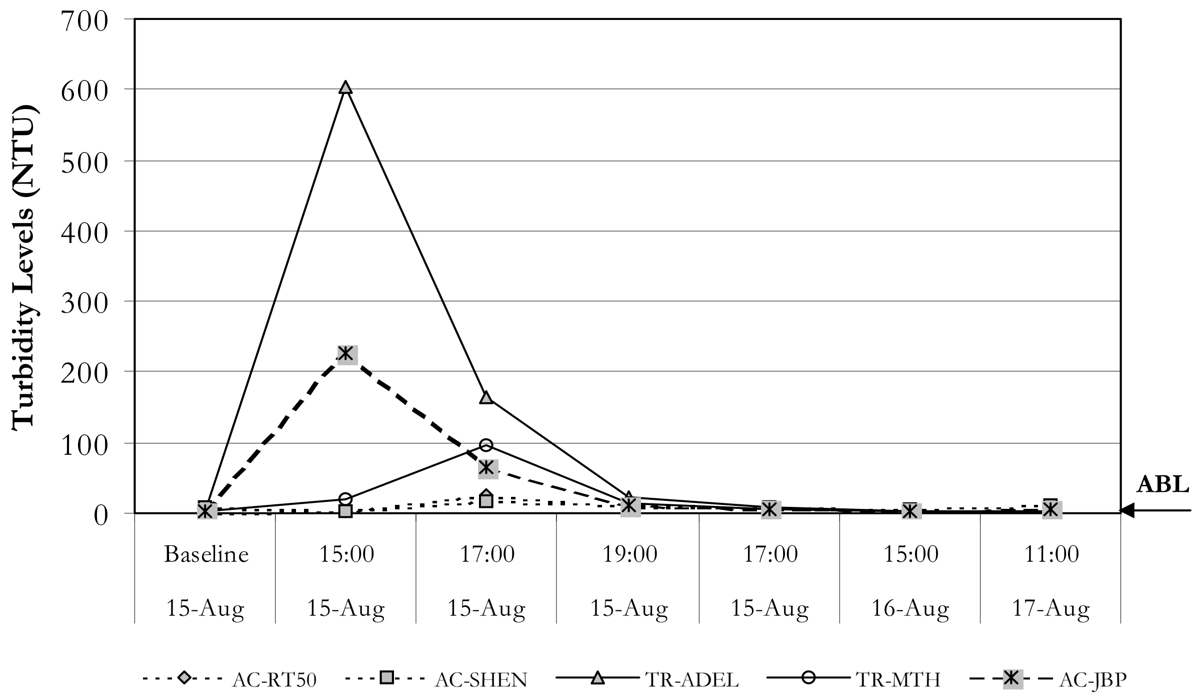

Figure 26. Turbidity Levels for August 15 Storm. The arrow to the right of the graph indicates the average August baseline level of 3.32 NTU (ABL).

Environmental Studies Program, Shenandoah University (2003)

The rapid rise in stream volume, coupled with the early peak and prolonged decrease in phosphate concentrations over the entire length of the sample period, indicate that phosphate ions were carried into the streams by surface runoff and were associated with soil erosion. (See turbidity discussion below.) The drop in phosphate levels between sites TR-ADEL and TR-MTH could have been caused by a reduction in suspended solids (specifically soil particles) once Town Run emerged from its constructed channel.

The downstream increase in phosphate levels at Site AC-JBP is curious; it suggests that an additional source of phosphates enters the stream after upper Abrams Creek and Town Run converge. Figure 25 shows that neither of the upper Abrams Creek sites, nor Town Run, fully explain the high phosphate levels at the Jim Barnett Park site. Phosphates must be entering lower Abrams Creek through surface runoff or soil erosion from Shenandoah University or Jim Barnett Park.

Turbidity levels during the August 15 storm peaked early but experienced a somewhat prolonged fall, probably due to the lengthy and moderately high period of precipitation. See Figure 26. As one might expect, the lowest turbidity level was recorded prior to the rain event: 0.760 NTU at site AC-RT50. After the storm began turbidity levels rose as high as 605 NTU (opaque) at site TR-ADEL just after the storm started. Town Run was the stream segment most affected by this storm, particularly at Site TR-ADEL.

Turbidity levels, as Figure 26 reveals, changed in a pattern similar to that for the orthophosphate concentrations. This finding supports the interpretation that phosphates entered the streams via soil erosion rather than the wash of a chemical additive such as artificial fertilizers. Spikes in phosphate and turbidity levels at Sites TR-ADEL and AC-JBP suggest that soil disturbances were taking place at or just upstream of the sample sites. Undoubtedly, the majority of the soil erosion found at site TR-ADEL was caused by the displacement of boulders in the streambed. Turbidity levels at Site AC-JBP were probably affected by soil erosion, particularly of the north bank of lower Abrams Creek as it turns sharply to the east.

* * *

The August 15 storm's results affirm the finding drawn from previous storms' data: Town Run cannot handle storm water without being degraded. Conditions in the watershed are inadequate to counteract the increased nutrient and sediment input from surface runoff. Similarly, Town Run's concrete- and limestone-walled channels prohibit the riparian growth that mitigates the problems. While the situation during rainstorms does not appear to be as serious at the upper Abrams Creek sites– i.e., the 0.36-mile portion of Abrams Creek from Route 50 (Millwood Avenue) to its confluence with Town Run – it must be borne in mind that most <u>pre</u>-storm nitrate concentrations <u>already</u> exceed the EPA's recommended maximum.

Recommendations for goals and improved management practices for both streams appear in Section 7.

Summary of Rainstorm Data and Trends

Nitrate concentrations were generally affected during two periods of the storm-sampling period. With adequate rainfall, the nitrate levels would peak and fall early in the storm period. Over time, however, nitrate levels continued to rise for days after the event as the nutrient infiltrated groundwater sources and made its way into the streams. Town Run consistently carried the highest nitrate levels during a storm-sampling period.

Although average nitrate concentrations varied little between baseline and storm levels (baseline grand average: 1.9 ppm; storm grand average range: 1.6 – 2.1 ppm), nitrate concentrations at individual sites were noted to double, triple or even quadruple over the course of the storm sampling period. Analysis of standard deviations (the amount of variability between data points) for nitrate concentrations revealed some interesting trends. Not surprisingly, standard deviations for a storm period were usually much lower than the standard deviations calculated for the baseline period, which encompassed an entire year rather than a few days. For all five storms, standard deviation was calculated for two data ranges: for each site during the length of the storm sample period, and for all five sites during the course of a single sample run. Comparison of the two sets of data showed that variability was often greater between all five sites than for a single site during the course of the storm sample period. This indicated the changes in nitrate concentrations at each site fluctuated gradually over the course of the sample period, although each site may have reacted differently than other sites at given times during a storm. Further details appear in Appendix D.

Orthophosphate levels moved much more quickly than nitrates. Phosphate concentrations peaked very early during a rainstorm and would fall just as quickly, nearing baseline levels within 24 hours. Town Run, overall, was most affected by surges in phosphate concentrations, though the highest levels were often only found at site TR-ADEL (Abrams Delight). Phosphate levels were also high in lower Abrams Creek (AC-JBP). Although high levels at this location might have been contributed to high phosphate concentrations from Town Run, such was not generally the case. High amounts of the nutrient were often recorded for TR-ADEL (Abrams Delight) and AC-JBP (Jim Barnett park), but not for the intermediary site TR-MTH (Town Run Mouth). This suggests that phosphate levels were affected by a localized source at these sites.

Baseline orthophosphate concentrations averaged 0.05 ppm for the study year. These concentrations, similar to observed nitrate levels, increased during the storm events studied. (Storm grand averages ranged from 0.07 to 0.24 ppm.) Unlike nitrate concentrations discussed above, however, the calculated standard deviations for orthophosphate concentrations for baseline data were higher than those calculated for all five studied storms. The standard deviation for baseline data was 0.03 ppm, while storm standard deviations ranged from 0.04 to 0.14 ppm. The increases between standard deviations for baseline and storm data indicate that orthophosphate concentrations increase to levels far above those found during any fair-weather day of the year. The differences between baseline and storm standard deviations (Appendix D) also indicate that streams receive a wider range of orthophosphate concentrations during storm events.

Turbidity levels in Abrams Creek and Town Run generally moved with orthophosphate fluctuations. The parallel movement of the two factors—one physical, one chemical—indicate that increases in turbidity levels are likely to be associated with soil erosion prompted by rainstorms. Turbidity levels peaked early and fell back to near-baseline levels within 24 hours.

The graphs presented above reveal that – on a percentage basis – turbidity levels are affected more than the other two water quality factors studied. Baseline turbidity levels for the study year averaged 2.79 NTU, while storm levels jumped to a grand average range of 15.1 to 138 NTU—an increase of nearly 5000% at the peak of this range. Standard deviations also increased dramatically from baseline to storm levels. For the study year, the standard deviation for baseline levels was 1.44 NTU. This figure was significantly lower than the standard deviations calculated from storm data, which ranged from 17.5 to 75.6 NTU. (These are grand standard deviations; see data tables in Appendix D for individual standard deviations by sample site or sample run). The high standard deviations found for some of the storms examined in this project indicates that turbidity levels varied greatly during these events, a finding displayed clearly in the line graphs above.

Section 7.
SUMMARY AND RECOMMENDATIONS

The preceding sections of this report have presented a year-long study of Abrams Creek and its principal tributary, Town Run. Both of these streams are located in Frederick County and Winchester, Virginia. The research focused on three water quality characteristics: nitrate concentrations, phosphate concentrations, and turbidity levels. Five sites at and near the confluence of Town Run and Abrams Creek were sampled during clear weather and rainstorms through the 2002 calendar year.

In Section 5 above, the investigators described the baseline conditions – that is, the normal or fair-weather water quality – of the two streams for the year. Section 6 documented how five rainstorms affected Abrams Creek and Town Run during the research period. The study's principal findings, summarized in the box below, were drawn from the 43 sampling runs, 217 samples, and 651 laboratory tests conducted over the course of the investigation.

Water Quality in Abrams Creek and Town Run

PRINCIPAL FINDINGS

During baseline (fair-weather) conditions (see Section 5)**:**

- Nitrates exceed the natural levels expected in ecologically healthy streams.
- Phosphate levels are generally acceptable.
- Turbidity levels are generally acceptable.

During rainstorm conditions (see Section 6)**:**

- Both streams handle the storm-borne pollutants they receive poorly.
- Nitrates increase slowly to readings far above their already-high baseline levels.
- Phosphates increase quickly to levels above EPA and DEQ water quality standards.
- Turbidity levels increase quickly and dramatically.
- Town Run is more impaired than Abrams Creek in its ability to absorb and break down pollutants transported by rainstorms.

In this, the closing section of the report, we propose goals for addressing water quality problems in Abrams Creek and Town Run. In addition, we offer recommendations, based on existing laws and programs, to help achieve these goals. Suggestions for further research and monitoring follow.

Discussion and Implications

The investigation's findings are not particularly surprising. They are consistent with other investigations of local water quality conditions (e.g., Virginia Tech 2003, Fitzgerald 2000, Barnes et al., 1999). They reflect, in many respects, the typical consequences of modern development. As people settled this valley, we cleared away the native forests, constructed houses and built highways. Today we fertilize lawns, cut and mow stream-side vegetation, alter stream banks and try to channel storm water through Town Run and Abrams Creek as quickly as possible.

As a result, rainwater carries excess nitrates into the groundwater. The same storms sweep phosphates and sediments over paved impervious surfaces through drainage channels and pipes. Eventually, these substances reach our local surface waters in quantities too large for the streams to absorb or break down naturally. Town Run empties its pollutants into Abrams Creek. Abrams Creek adds its loads of nitrates, phosphates and sediment to the Opequon Creek. In turn, the Opequon flows into the Potomac River, and the Potomac empties into the Chesapeake Bay. The damage – to water quality, to ecological health and to human use – extends from Round Hill in western Frederick County to Virginia Beach and Cape Charles at the Chesapeake's mouth. Fish die, harmful bacteria thrive, stream valleys erode, attractive creeks become little more than storm-drainage channels, water treatment costs increase, and economic development suffers.

While these findings may be typical, the consequences are not inevitable. Conservation has deep historical roots in Virginia and the Shenandoah Valley. Thomas Jefferson recognized the problems of soil erosion at his Charlottesville farm. The Civilian Conservation Corps – with its first camp located just 30 miles south of Winchester near Edinburg – demonstrated in the 1930s that decades of damage to land and water resources can be reversed. In recent years homeowners, local governments, farmers, and community volunteers have implemented modern conservation's Best Management Practices (BMPs) to restore Valley streams and protect riparian zones.

It is indeed possible to modify the conditions that are the likely causes of the nitrate, phosphate and turbidity pollution documented in this report and elsewhere. Some solutions require the cooperation of individual and corporate property owners. Other approaches depend on local governments to revise their ordinances, modify their inspection programs and incorporate more conservation practices into their planning and development procedures. No programs will succeed without an increased public understanding of the benefits of better watershed management and the costs of allowing the water quality in Abrams Creek and Town Run to deteriorate further.

Proposed Goals

Goal 1: Prevent further deterioration of water quality in Abrams Creek and Town Run.

Before water quality can improve, citizens, business owners and local decision-makers must first agree to prevent <u>additional</u> damage. Several steps (see recommendations below) can be taken to assure that conditions in Abrams Creek and Town Run do not get any worse than they are already.

Goal 2: Improve Abrams Creek and Town Run enough to remove the two streams from the Impaired Waters List and meet other applicable water quality protection standards.

As Section 2 of this report explained, laws to improve water quality date back to 1899. Three state, regional and federal programs today are particularly applicable to the kinds of water pollution problems – nitrates, phosphates and sediment – investigated in this study.

Impaired Waters Listing and the TMDL Process

Congress, through the Water Quality Act of 1987, requires states to identify major sources of nonpoint pollution and develop plans to correct these problems. Based on its water monitoring data, the Virginia Department of Environmental Quality (DEQ) places water bodies that do not meet the standards for their designated uses on its Impaired Waters List. In 1996, the DEQ added Abrams Creek* and Opequon Creek to the list because of high bacteria counts and the low numbers and low diversity of aquatic life.

In 2003, the DEQ began a Total Maximum Daily Load (TMDL) process for Abrams and Opequon Creeks. The TMDL approach establishes a "pollution budget" for each impaired stream and for each responsible pollutant. Following four public meetings that took place at Shenandoah University (Eller 2003, Van Meter 2003), Virginia Tech's Department of Biological Systems Engineering drafted a TMDL for Abrams and Opequon Creeks (Virginia Tech 2003). Subsequently, the Virginia Department of Conservation and Recreation (DCR) will work with local governments and citizens to develop plans for cleaning up Abrams Creek enough to have it removed from the state's Impaired Waters List (Virginia DEQ et al., 2003).

Storm Water Regulations and NPDES Permits

Congress also mandates that the EPA address storm water discharges that degrade the quality of the nation's waters. Through the National Pollution Discharge Elimination System (NPDES), the EPA requires that certain water quality control measures are in place in order to obtain a permit to operate a storm water discharge system. In Virginia, the DEQ administers these storm water regulations and the NPDES permitting process. This program applies to municipalities, industrial facilities and many highway and construction projects but not to agricultural operations, which are covered by the TMDL process and other programs. For further information, see US EPA (2003c) and Virginia DEQ (2003b).

The City of Winchester is now developing storm water management practices in response to the requirements of Phase 2 of the EPA's Storm Water Regulations. The City's program will not only address the quantity of storm water runoff – as it has done in the past – to help control downstream flooding. The current plan must also manage the runoff's quality, that is, the concentration of pollutants that it carries into our local creeks.

* The DEQ does not monitor Town Run.

Chesapeake Bay Tributary Strategy

As a partner in the regional Chesapeake Bay Program, Virginia signed the first Chesapeake Bay Agreement in 1983 and the more recent watershed restoration plan called Chesapeake 2000. The focus of these initiatives is to improve the Bay as a living resource by reducing excess quantities of nitrogen, phosphorus and sediments that enter the Chesapeake and its tributaries (Chesapeake Bay Program 2003). In 1992, Virginia began developing plans for rectifying the nutrient and sediment problems in each of the bay's major tributary watersheds. Virginia completed its Shenandoah-Potomac Nutrient Reduction Tributary Strategy in 1996. To achieve the goals of the tributary strategy, each city and county in the Chesapeake Bay watershed will need to implement measures that prevent the entry of nitrates, phosphates and sediment into local streams and rivers. Reductions will come from a variety of sources including sewage treatment, agriculture, food processing, construction, neighborhoods, shopping centers and other rural, suburban and urban land uses.

* * *

Although these three programs contain a lengthy series of regulations, requirements and strategies, they all attempt to address the causes of the water quality problems that this study has documented in Town Run and Abrams Creek. The programs can, in practice, complement one another. For instance, controlling runoff from construction sites through methods required by the Storm Water Phase 2 regulations also helps prevent the soil erosion identified as a concern in the TMDL process; the same measures support the sediment reduction goals of the Chesapeake Bay Tributary Strategy.

Goal 3: Increase the public's knowledge of water resources and aquatic environments, their understanding of water pollution problems, and their participation in activities for appreciating, protecting and restoring the watershed.

The first two goals cannot be attained without the public's understanding, support and involvement. A diverse set of approaches are required to engage all ethnic and economic groups in addressing the varied sources of pollution and the many ways in which water quality can be improved. Pollution prevention needs to occur in homes, neighborhoods, workplaces and communities.

Management Recommendations

Recommendation A: Restore the Stream Environment.

Stream restoration projects in Abrams Creek and Town Run will **. . .**

- Reduce stream-channel erosion by reducing stream velocity.

- Help prevent the erosion of stream banks by stabilizing the banks with vegetation, carefully placed boulders, log walls, brush deflectors and other structures.

- Improve streams as habitats by providing riffle zones, plunge pools, varied substrates and additional ecological features that support fish and other aquatic life.

- Engage citizens in transforming a neglected neighborhood eyesore into a celebrated community resource, and an opportunity for walking, bicycling, fishing and nature study.

The term **stream restoration** encompasses activities that improve the total stream environment. It is "the re-establishment of the general structure, function and self-sustaining behavior of the stream that existed prior to disturbance" (Doll et al., no date, p. 2). Stream restoration requires modifying some or all of a stream's characteristics: its width, depth and meanders; its aquatic flora and fauna; and its channels and banks. Stream restoration also involves improvements to the riparian areas located adjacent to a stream. As Riley (1998) explains, stream restoration practices have evolved substantially over the past two decades. The experiences of hundreds of communities, coupled with hydrologic research, have demonstrated which approaches are effective and which are weak or even counterproductive.

The three stream segments investigated in this study – upper Abrams Creek, Town Run and lower Abrams Creek – each require some form of restoration. Our observations in the watershed indicate that several types of projects are necessary to counteract the effects of disturbance and the resulting changes to nutrient and sediment levels that have been documented in Sections 5 and 6 of this report. Below, under Recommendations E, F and G, we offer specific suggestions for each stream segment.

The good news is that several resources exist to help assure that stream restoration efforts succeed. These include Ann L. Riley's fact-filled sourcebook *Restoring Streams in Cities: A Guide for Planners, Policymakers, and Citizens* (1998), the North Carolina Stream Restoration Institute's *Stream Restoration. A Natural Channel Design Handbook* (Doll et al., no date), and *Stream Corridor Restoration: Principles, Processes, and Practices* developed by the Federal Interagency Stream Restoration Working Group (2001). All three publications contain methods, examples and restoration principles.

Recommendation B: Protect the Riparian Zones.

Protected riparian (stream-side) buffer zones along Abrams Creek and Town Run will help . . .

- Trap sediments carried by storm water runoff.

- Filter and break down nitrates, phosphates and many other pollutants (such as road salt, pesticides, animal wastes and automobile fluids) before they reach the streams.

- Support the growth of streamside vegetation that a.) reduces stream bank erosion, and b.) shades streams, which lowers water temperatures and reduces the growth of harmful algae.

- Absorb water during floods and gradually release it during drier periods.

- Protect wetland and floodplain habitats.

- Provide attractive strips of open space in the community.

Riparian zones are the narrow strips of land adjacent to rivers, streams, ponds and other bodies of fresh water. In protected riparian zones – often called **riparian buffers** – vegetation grows naturally and the soil is undisturbed by human activities. In addition to providing food and protection for wildlife, riparian vegetation reduces flood damage by holding stream banks in place and slowing stream velocity. Vegetated stream banks also act as sponges, much like wetlands do, as they store excess water during floods and rainy periods and then slowly release that water into streams during droughts. These processes help maintain normal water levels, which are vital to aquatic life.

Several studies have shown that even narrow riparian buffers improve water quality by removing nutrients – particularly nitrates and phosphates – from adjacent stream water (see Cooper and Gilliam 1987, Gilliam and Skaggs 1987, Riley 1998, Gilliam et al., 1986). Guidelines for the Conservation Reserve Enhancement Program (CREP) require that forested riparian buffers be at least 35 feet wide, or 30 percent of the width of the floodplain, whichever is greater (Natural Resources Conservation Service 2003). In addition to this undisturbed riparian buffer, many authorities (e.g., Heraty 1993, Stormwater Manager's Resource Center 2003) recommend protecting an additional 50-to-200-foot-wide area. In this zone, construction is still prohibited but some tree clearing and forest management is allowed.

As a first step, preventing livestock from wading into the rural headwaters of Abrams Creek and Town Run will reduce animal wastes in the creeks and allow natural processes to establish streamside vegetation. Second, the remaining wetlands must be protected from future development. Each lost acre represents a lost opportunity to reduce water pollution. Buffer zones of undisturbed vegetation need to be established adjacent to the wetlands to preserve their ecological functions.

Third, riparian buffers should be designated in urban Winchester along the two streams and their tributary drainage channels. Establishing "no mow" areas will permit the growth of trees and shrubs. Their extensive root systems and high nutrient demands are much more effective at holding soil in place and taking up nitrates and phosphates than the shallow root systems of lawns or grassy swales.

Recommendation C: Review and Revise Storm Water Management Policies.

Among the policy options for officials in Winchester and Frederick County to consider for protecting water quality through storm water management are measures that would **. . .**

- Establish stream corridor overlay districts for Abrams Creek and Town Run.
- Incorporate setback requirements and other measures into development ordinances to minimize disturbance to stream banks, floodplains, riparian zones and wetlands.
- Minimize the percent of impervious surfaces (such as parking lots, buildings and roads) after new development, and minimize the extent of unbroken expanses of impervious surfaces.
- Encourage and support the protection of open space, including riparian buffers.

In addition to restoring the aquatic environments of Abrams Creek and Town Run and protecting the areas adjacent to them, measures need to be taken to manage storm water. Historically, **storm water management** has addressed the quantity of storm water. Development companies construct retention ponds that hold back runoff to prevent downstream flooding. Public agencies straighten streams and line them with concrete or riprap to channel away the storm water as quickly as possible. While managing the quantity of storm-caused runoff is an understandable goal, scant attention has been paid to storm water's quality. Storm runoff can carry harmful nutrients, sediment, animal wastes from pets and livestock, and toxic concentrations of metals, organic chemicals and pesticides.

Improving the water quality in our two local streams will require modifications in both practices and policies that pertain to storm water management. Fortunately, dozens of municipalities have utilized one or more of the policy approaches listed above, so working examples are available for review. For instance, river or stream corridor overlay districts have been implemented in several jurisdictions including Saginaw, Michigan; St. Paul, Minnesota and Loudoun County, Virginia. Stream setback ordinances are much more widespread, and many have been established on a statewide basis.

Recommendation D: Implement Structural Controls to Manage Storm Water.

The US EPA (2003c) has identified a variety of features that can be built to reduce pollutants in storm water. These structural **best management practices (BMPs)** include **. . .**

- Grassed swales, sand filters and filter strips adjacent to roads and parking lots. Unlike conventional curbs, gutters and drain pipes, these recommended BMPs spread out storm water, trap sediment and break down many pollutants.

- Infiltration ponds, infiltration trenches and extended-detention outlet basins. These excavated structures temporarily retain storm water, allowing much of it to percolate into the ground instead of running directly into streams and rivers.

- Bioretention areas (Davis 2003) and rain gardens (Rain Garden Network 2003, Virginia Department of Forestry 2002). These BMP structures use soil and plants to absorb excess nutrients and bacteria from storm water runoff before it enters a stream. In addition to trapping and breaking down pollutants, bioretention areas and rain gardens are designed to disperse and reduce the velocity of storm water flow.

Structural BMPs are built between a stream and adjacent potential sources of polluted runoff such as roads, parking lots, neighborhoods, commercial zones and industrial areas. They utilize physical processes to prevent or delay the entry of storm water into streams. Most also take advantage of natural biological processes that improve the quality of storm water before it reaches a water body. Bioretention areas and rain gardens have the added benefit of their aesthetic appeal as landscaping elements.

Together, these storm water management practices are part of what has become known as **low-impact development or LID technology**. LID is intended to support environmental protection goals while achieving economic development objectives at the same time. Websites sponsored by the Low Impact Development Center (2003) and the US EPA (2003c) provide further information, examples and perspectives on this emerging concept. Studies evaluated by Prince George's County, Maryland (2000) have demonstrated that impressive levels of pollution reduction and hydrologic control can be achieved by implementing various LID technologies.

Recommendation E: Undertake Specific Projects for Upper Abrams Creek
(from Abrams Creek's headwaters downstream to its confluence with Town Run)

Upper Abrams Creek extends from the creek's headwaters on the eastern slopes of Round Hill to its confluence with Town Run between Jim Barnett Park and Shenandoah University's Main Campus. The measures described above under Recommendations A-D pertain to practices throughout the watershed.

Plate 5. Upper Abrams Creek on Shenandoah University's Main Campus.
Note the dam and riprapped stream banks. (See also Plate 4, page 22.)

Below, we focus on the portion of Upper Abrams Creek that we examined in this study. This section runs north from Millwood Avenue (U.S. Route 50) through Shenandoah University's Main Campus to the Town Run confluence just east of Wilkins Lake, a distance of approximately 0.4 miles. (For a map of this area, see Figure 2 in Section 4.) Our specific recommendations are as follows . . .

- Place boulders in Abrams Creek's stream channel to reduce stream velocity. The boulders will cause the stream to drop some of its sediment load and improve the habitat for aquatic life.

- Consider adding aquatic moss colonies, such as those that grow in Shawnee Springs and at Glen Burnie, to support aquatic life.

- Replace the dam near the Racey Ponds (Plate 5) with a series of step-pools to reduce the risk of flooding the lawns and parking lots adjacent to Abrams Creek. Move the intake pipe for the ponds upstream. This set of changes will diminish the erosive power of the present dam's overflow, continue to provide water for the Racey Ponds, create a series of aesthetically appealing pools and improve the creek's ability to support aquatic life.

- Modify current attempts to stabilize the stream bank. At present, Shenandoah University uses **riprap**, that is, 8-to-12-inch limestone rocks dropped along Abrams Creek's banks, to reduce soil erosion. The landscaping staff periodically cuts away the vegetation that grows in the soil trapped in the riprap. Unfortunately, this combination of practices has several negative consequences. As Lancaster, Lutyens and Austin (2000) assert,

> *Ironically, even man's own attempts to manage storm water and control erosion have added to the problem. The use of "hard armor" materials such as rock riprap, concrete and asphalt to line and stabilize drainage channels inhibits water infiltration, reduces filtration of sediment and other potential pollutants, and increases run-off volumes. The result - more polluted water feeding into our over-burdened streams and reservoirs at a faster pace. In addition to adverse environmental effects, hard armor erosion control materials pose other concerns, prompting today's engineers and designers to employ more natural, vegetative solutions.*

Several independent research studies (e.g., Hewlett et al. 1987, Northcutt 1997) have demonstrated that vegetation and turf reinforcement products provide a longer-lasting and more cost-effective, aesthetically appealing and ecologically sound solution to stream bank erosion. Such native stream-side plants as cardinal flower, blue lobelia, royal fern, silky dogwood and buttonbush can be planted along Abrams Creek and trimmed to maintain the neat appearance that a university campus requires. Boulders along the stream's banks will also help, but they must be placed individually and need to be large enough to avoid being moved by a flooding stream (Riley 1998). Boulders should be used only in combination with vegetation and an erosion control blanket such as the JMD Company's C350 TRM or Enkamat R2M by Colbond Geosynthetics.

- Utilize storm water BMPs in the riparian zone. Abrams Creek traverses Shenandoah University's manicured lawns, which are mowed all the way to the stream banks east of the Ohrstrom-Bryant Theatre and west of Smith Library. In 2001, landscape architect Dawn Biggs and The Opequon Watershed (TOW), Inc., proposed a wetland garden for part of this area. Their plan features attractive native plants – primarily wildflowers and low-growing shrubs that would not obstruct views across the campus. This garden would be more effective than a lawn at protecting the creek and its banks from storm runoff. A portion near the dam could be modified into a rain garden to help absorb and break down the smelly effluent that gushes out of the sewer line cap below Smith Library during heavy rainstorms. Although such a garden may not be practical everywhere campus lawns come close to Abrams Creek, the Biggs-TOW proposal demonstrates that Abrams Creek can be better protected without interfering with campus aesthetics. Other opportunities for reducing nutrient runoff and implementing storm water BMPs on campus should also be investigated.

- Refer to Recommendations A-D above for additional measures pertaining to stream restoration, riparian zone protection, storm water management policies and storm water management practices. These apply to the entire length of Upper Abrams Creek.

Recommendation F: Undertake Specific Measures for Town Run
(from Town Run's headwaters downstream to its mouth at Abrams Creek)

Town Run begins its southeastward journey at the base of Little North Mountain, near Albin in western Frederick County. It enters Winchester as it crosses below Route 37. After flowing

Plate 6. Town Run below South Kent Street. Town Run travels through a concrete channel like this for much of its length through Winchester. Note the small pool and water aeration created by a boulder that fell into the channel. Such beneficial "disturbances" can slow down the stream's velocity and support aquatic life.

through the Winchester Medical Center complex, a residential neighborhood and the Glen Burnie estate, Town Run passes through – and, in several cases, beneath – downtown Winchester. It is confined until its last quarter-mile in a concrete channel. (For a map, see Figure 2 in Section 4.)

Given this urban setting, it was not surprising to find that Town Run showed the greatest water quality impairment among the three stream segments investigated in this study. The concrete that forms Town Run's bed and banks for most of its length through Winchester is, in many ways, an ecological straightjacket (Plate 6). It transfers the erosive force of rushing flood waters downstream. It strangles the very processes that could most easily improve the stream's water quality: the reduction in stream velocity by a meandering, rocky streambed; the biological and chemical breakdown of washed-in nutrients; and the creation of diverse habitats for aquatic life (Botkin and Keller 1998, Laasonen and Muotka 2002).

While it is tempting to advocate removing the concrete channel, this "obvious" solution may not be the best choice. Land surrounding Town Run has been developed, many of the slopes are steep, and soil has settled against the concrete. Severe streambed erosion and bank slumping will occur once the concrete is demolished unless carefully engineered preventative measures are taken. (Log crib walls, root wads and stepped-back stone walls have been used successfully to stabilize stream banks elsewhere. See Riley, 1998.) The removal itself would undoubtedly carry a high price tag; the task is more difficult than one might assume because the concrete has hardened substantially during the decades since it was poured.

Removing the concrete in areas where the banks are not inordinately steep and the floodplain has not been heavily developed – such as in parts of Shawnee Springs Preserve – may well be worth trying. However, the channel will probably have to be accepted as it is for most of its length, making other measures to improve water quality that much more imperative to undertake . . .

- Allow the concrete and limestone bank linings of Town Run to deteriorate naturally in areas where the walls are not high and where doing so would not produce a safety hazard. This would include leaving in place the stones that fall into the stream channel.

- Place native boulder- and cobble-sized rocks in the stream channel to diminish the velocity of the churning water during storms and create habitats for aquatic life (Plate 6). The boulders would help prevent soil erosion and trap some stream debris, supporting natural processes that absorb and break down storm-carried pollutants. Town Run would look more natural and aesthetically appealing as well – an important consideration as the Green Circle Linear Park is developed along the stream and through Shawnee Springs Preserve.

- Utilize storm water BMPs and protect the less-developed portions of Town Run's riparian zone. See Recommendation D, above. Glen Burnie Historic House and Gardens has enhanced a substantial portion of Town Run's riparian zone on its property through the Conservation Reserve Enhancement Program (CREP). Other potential sites, although smaller, include the riparian areas near Stewart Street, Hollingsworth Drive Pleasant Valley Drive and Wilkins Lake. Storm water that now runs directly into Town Run at Cork Street, Stewart Street and in other locations needs to be filtered through bioretention areas to reduce velocity and pollutant loads.

- Avoid diverting Town Run into the natural wetlands in the central and northern sections of Shawnee Springs Preserve. Wetlands in regions floored by limestone bedrock are rare; the marshy area surrounding the Shawnee Springs is likely to qualify as a critically endangered natural community under criteria established by the Virginia Natural Heritage Program. Although diverting some of Town Run's flood waters into this preserve's marshes might indeed improve water quality, it would also substantially alter the site's distinctive wetland habitats. Fields and lawns located downstream of the wetlands might be able to serve as floodwater detention areas, however.

- Apply storm water BMPs to modify the drainage channel that runs through the Forest Hills subdivision and into the southwestern corner of Jim Barnett Park. This channel eventually joins Town Run a short distance upstream of this study's TR-ADEL sampling site near Abrams Delight. (See Figure 2 in Section 4.) At present, only a grassy swale is in place to trap sediment and absorb nutrients from storm water runoff. Unfortunately, this measure is not always effective. During periods of prolonged rain, the constant wash of water kills the grass and leaves behind an unsightly streak of mud. This channel, which runs approximately a third of a mile and is clearly visible from Pleasant Valley Drive, could be enhanced by a series of bioretention features. Using native trees, shrubs, grasses and wildflowers would improve the quality of water flowing into Town Run and provide a more attractive feature in Jim Barnett Park.

- Take additional steps to reduce the nutrient and bacteria loads entering Town Run from fertilizers and animal feces. Educate citizens and business owners along Town Run about ways to reduce their use of fertilizers on lawns and gardens. Enforce pooper-scooper ordinances in the city and the prohibition of waterfowl-feeding at Wilkins Lake.

- Refer to Recommendations A-D above for other measures pertaining to stream restoration, riparian zone protection, storm water management policies and storm water management practices.

Recommendation G: Undertake Specific Measures for Lower Abrams Creek.
(from Abrams Creek's confluence with Town Run downstream to its mouth at Clarke County line)

Lower Abrams Creek extends from the Abrams Creek-Town Run confluence through eastern Frederick County, where it eventually empties into Opequon Creek at the Clarke County line. It inherits elevated nutrient levels and turbidity spikes from Town Run and Upper Abrams Creek. In addition (although beyond the scope of this study), land parcels in this portion of the watershed undoubtedly contribute their own loads of nitrates, phosphates and sediment to the creek.

Readings that placed this water body on the state's Impaired Waters List were taken at the Virginia DEQ's monitoring site, which is situated near the downstream end of this segment a short distance above Abrams Creek's terminus at Opequon Creek. Accordingly, the authors recommend the following measures for improving water quality in Lower Abrams Creek . . .

- Address problems upstream in Town Run and Upper Abrams Creek. See Recommendations E and F.

- Place boulders and root wads near the stream's 90-degree turn to the east in Jim Barnett Park, just downstream of the Town Run convergence, to deflect stream flow away from the eroding north bank. The north bank also requires some vegetation and structural stabilization to reduce the erosion caused by surface runoff in this area. See front cover, lower right-hand photo.

- Eliminate mowing and encourage native vegetation in a riparian buffer no narrower than 35 feet as Abrams Creek runs eastward through Jim Barnett Park and Shenandoah University property.

- See Recommendations A-D for measures pertaining to stream restoration, riparian zone protection, storm water management policies and storm water management practices. Apply them, as appropriate, to areas downstream from this project's study sites.

Recommendation H: Educate and Involve the Public.

In order to restore the quality of our local streams and protect their watersheds, people of all walks of life need to be convinced that these goals merit their support and participation (U.S. EPA 2003c). Among the topics to address are the following . . .

- Designing construction projects to minimize the runoff of sediment and nutrients, and avoiding other water quality problems

- Steps for reducing home-related water pollution such as correctly using and disposing of fertilizers and pesticides, appropriately disposing of household chemicals and motor oil, and controlling storm water runoff

- Ways that individual, institutional and corporate owners of stream-side property can protect stream banks and develop riparian buffers

- How to design, organize and take part in local stream and watershed improvement projects

- The impacts of pet feces, livestock wastes and waterfowl droppings on water quality, and how to minimize these problems

- How commercial, institutional and industrial entitles can avoid significant water quality impacts of oil discharges, improper waste disposal, excessive cutting or mowing in riparian zones and other practices

- The benefits that good water quality can provide including higher property values (Coughlin and Hammer 1973, Schurr et al., 1985), habitat protection, reduction of water-borne bacteria in neighborhood streams (Bender and Schurr 1993), recreational opportunities and aesthetic appeal

Pollution prevention, as stated previously, needs to occur in homes, neighborhoods and workplaces. Members of the public should be involved in designing outreach programs for their communities. To communicate information about water quality and its protection, several educational approaches are available . . .

- Brochures, flyers, websites and fact sheets
- Lectures, speakers and workshops
- Interpretive signs and trails
- Field trips, festivals and celebrations
- Media coverage and public service announcements
- Educational curricula, lesson plans and activity guides for school-age children
- Watershed surveys, restoration projects and cleanups
- Programs intended for specific target audiences such as developers, farmers, homeowners, construction supervisors and members of planning boards

Suggestions for Further Research

This report has presented the objectives, design, findings and recommendations of the present investigation. Important questions were addressed, and the methodology provided useful data. The results documented here can help measure future changes in water quality, especially those associated with attempts to control storm water runoff. Nonetheless, this study represents only a small fraction of the water quality research that can be undertaken in Abrams Creek and Town Run. The investigation's outcomes suggest several additional research opportunities as well as some possible modifications in procedure.

A single sample may not adequately characterize a site's water quality for an entire month. Ideally, baseline water quality sampling should be performed twice or more each month. Samples need to be taken at approximately the same time each day, if at all possible, in order to control for daily patterns of temperature and biological activity.

To avoid the impacts of any previous storms, samples should be gathered, as they were in this study, at least 48 hours after the end of a storm. Spacing sample periods two hours apart during and after a storm proved to be workable but tiring for a single researcher; the findings indeed captured revealing trends in water quality. The prolonged rises in nitrate concentrations that occurred after some of the storms examined in this research suggest that post-storm sampling could extend beyond two days to more completely account for a storm's effects on water characteristics.

A larger research team would obtain a more detailed picture of the water quality changes caused by rainstorms. Changes observed over the course of this research project indicate that samples should be drawn at 20-minute intervals until runoff is no longer observed. Afterwards, the sampling interval can increase to two hours for the next 24 hours. Samples could then be taken after additional periods of 48, 72 and 96 hours. Two people alternating sample collection and lab analysis cannot do such intensive work; this type of monitoring would require a group of at least four.

This study focused on the stretches of Abrams Creek and Town Run adjacent to Wilkins Lake, Jim Barnett Park and the main campus of Shenandoah University. Investigations of baseline and storm-influenced water characteristics need to be carried out both upstream and downstream of the five sites selected for this research project.

A comparatively easy but important research activity would be to identify and map the sources of urban runoff (e.g., from paved surfaces, residential areas and buildings) and sewage contamination that feed more or less directly into Abrams Creek and Town Run. Once these sources are found, best management practices (BMPs) can be implemented to eliminate, or at least mitigate, the damage.

Identifying sources of bacterial contamination in Abrams Creek and Town Run was beyond the scope of this project. However, since bacterial impairments are one of the two violations of water quality standards that have placed Abrams Creek on the DEQ's Impaired Waters List, the sources of excess bacteria need to be examined. Sampling procedures used in this study to determine the influence of storms on water quality could be utilized to investigate contamination by bacteria. We would also recommend that both the City and County examine the potential water quality problems that may occur when rain water infiltrates sewer lines. In more than one location, raw sewage occasionally spurts up through manhole covers and washes into Abrams Creek during heavy rainstorms.

Aquatic life is more varied and abundant in some portions of the Abrams Creek-Town Run watershed than it is in this study's sampling sites. The benthic macroinvertebrate (BMI) community is particularly diverse in Lower Abrams Creek near Valley Mill Road in eastern Frederick County. Interesting communities of aquatic mosses and small crustaceans (isopods, amphipods) flourish in the cold waters of Glen Burnie and Shawnee Springs, while rainy March nights reveal a dense population of northern red salamanders (*Pseudotriton r. ruber*) at Merrimans Spring. What conditions are responsible? How do water characteristics in these areas change during rainstorms? It may turn out that some of the conditions at these locations can be duplicated elsewhere in the watershed to better support aquatic life.

The speeds at which storm waters surge through Abrams Creek and Town Run can be terrifying and, at times, hazardous. Understanding the channel characteristics and velocities of stream flow during storms will not only aid in developing erosion control measures, but also provide insight into the dangers of stream channelization and other modifications. Citizens of Winchester and Frederick County need to be made aware of the safety hazards of urban streams. Such information would also help evaluate future stream restoration projects.

The numerous groundwater sources that feed Abrams Creek and Town Run also need to be studied. In this limestone-floored terrain, knowing the chemical characteristics of the groundwater is particularly vital in any attempts to restore water quality. Johnston's 2002 study of Shawnee Springs Run – a tributary to Town Run – and measurements at Merrimans Spring in the Abrams Creek Wetlands by Barnes et al., (1999) revealed that nitrate levels were higher at the springs than they were downstream. These findings are consistent with nationwide data reported by McKinney and Schoch (1998): about 25% the groundwater used in the U.S. for drinking is contaminated, primarily by excess nitrates. If a substantial proportion of a stream's contaminants enter from the groundwater, plans for improving water quality need to take this pollution pathway into account. Studies of groundwater movement would be an asset to the communities of Winchester and Frederick County. Well-water surveys would help determine possible sources of nonpoint groundwater pollutants.

Identifying unknown seep and spring tributaries to both creeks would be an additional benefit of groundwater surveys. At the time this report is being written (October 2003), the U.S. Geological Survey is working on a detailed aquifer appraisal for Winchester and Frederick County. The information provided by their study should help explain the quality of available groundwater as well as identify possible sources of contamination (U.S. Dept. of the Interior, 2002).

* * * * *

It is estimated that nearly 85 percent of the population [is now] concentrated in urban areas. What this suggests is that the economic values of natural environments in urban areas are going to continually increase because of the increased demand for them.

– Ann L. Riley, *Restoring Streams in Cities: A Guide for Planners, Policymakers, and Citizens*, 1998.

As Winchester City Councilman Steve Bauserman observed, "Abrams Creek and Town Run are impaired, but they are not irreparable." The citizens of Winchester and Frederick County can act now restore two of this community's most important natural assets. Voluntary efforts made today can avoid the higher costs of mandatory changes that may be required tomorrow.

This modest pair of streams – located in the upper reaches of the Potomac River and Chesapeake Bay watersheds – links together our community's homes, workplaces, commercial districts and historic sites. The care with which we treat these flowing waters reflects our values and priorities. In turn, the streams' health affects our quality of life. What statements shall we make about our values and priorities? What images do we want to present to tourists? What legacies do we wish to leave to future generations?

The puzzling aspect is that the existence of obligations over and above self-interest is taken for granted in such community enterprises as the betterment of roads, schools, churches, and baseball teams. . . . Land-use ethics are still governed wholly by economic self-interest. . . .

No important change in ethics was ever accomplished without an internal change in our intellectual emphasis, loyalties, affections, and convictions. . . . In our attempt to make conservation easy, we have made it trivial.

-- Aldo Leopold, *A Sand County Almanac, with Essays on Conservation*, 1949.

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APPENDICES

Appendix A. Supplementary Data and the Data Collection Form

In the first few months of this study, the researcher believed that time, air temperature and water temperature taken at the time of sample collection would be adequate supplementary information for later data analysis. After the first storm sample run, however, she realized that additional information would need to be recorded in order to help explain the changes that took place at each sample site during storm events.

Data collection forms used by the Friends of the Shenandoah River and subsequent adaptations of their forms created by the Abrams Creek-White's Pond research group (Barnes et al., 1999) strongly influenced the format of the data collection form used in this project. Multiple-choice lines were added for weather conditions, surface water descriptions (hydrology) and wildlife observations. A portion of the data form was set aside to record lab results specific to this project so that analytical data could easily be referenced to the site conditions that existed at the time the sample was taken.

Supplementary data fields that were added to the study are each discussed below. Data collected appear in Tables A – G following a blank copy of the data form.

Weather Conditions

After the first few storm runs had been analyzed, it became apparent that changes in water quality could occur shortly after a storm began and, in the case of nitrate concentration, such changes can last for days. When the data collection form was modified, two weather descriptors were included to help explain any changes that might later appear in the data: precipitation in the last 48 hours, and present weather conditions at the time of sample collection. These factors were based on observation rather than measurement, though there was a place to record precipitation amounts from previous days in the hopes that the electronic rain gauges would eventually be working.

Precipitation in the Last 48 hours. This line was added when it became evident that nitrate levels from previous rain events could persist and affect water quality readings. By listing any storm events that occurred 48 hours prior to a sample's collection, possible influences on baseline nitrate levels could be explained. The type and degree of the event were also noted, ranging from none through varying degrees of liquid and frozen precipitation.

Present Weather Conditions. This section was added to the data from to help account for any meteorological influences on water quality. If collected on a long-term basis, weather conditions observed at the time of sample collection may reveal a seasonal influence on nitrates, phosphates or turbidity. Immediate weather conditions, such as hail and water runoff during a storm, may also influence water quality and were recorded, since chemical factors rapidly fluctuate during these events. Site observations were judged and recorded by the monitor at the time of sample collection. General humidity levels were recorded based on the researcher's general perceptions at each site, which were then referenced to the SPER humidity monitor (Model #800017) located at Shenandoah University.

Hydrology

Water level and stream flow conditions were also observed at each collection site at the time of sample collection. Both conditions were added to the data collection form to help explain any trends in data. For instance, consistently high nitrate levels over a period of time may be related to consistently low water levels. Likewise, high turbidity levels may correlate with rapid stream velocities. These factors were again judged simply on the basis of the researcher's familiarity with the typical hydrologic characteristics at each sample site.

Water Level. Although sampling sites varied in stream depth, this information was based on changes from the "normal" water level at each site. This factor was added to the study because seasonal and storm influences may cause changes in a stream's water level. Recorded variations in water level ranged from dry to flooded. Because bank height varied among sample sites, a dramatic increase in stream volume at any location could be described as either high or flooded regardless of actual stream volume. For instance, at Site AC-SHEN there was a distance of approximately 6 feet between normal stream level and the bank-top sampling location. During storms, the water level at this site would rise to within inches of the bank's edge, but if the stream did not overflow its banks and create a flood, the water level at this site was described then as high rather than flooded

Water Flow. This descriptor was included because of its potential influence on orthophosphate and turbidity levels at each sample location. Flow descriptors varied from stagnant to choppy to frozen solid. Guidelines for deciding which condition existed were established and are as follows:

Stagnant conditions were those in which no water movement was detected and there was no apparent input of additional water into a site's immediate area.

Calm described a body of moving water that appeared to stand still, but where closer inspection revealed that the deeper water was, in fact, moving. This held true for sites such as TR-MTH where the surface water movement was so smooth the stream surface seemed to be gelled in place, but the force of the current below constantly shifted the bed load.

Slow flow, on the other hand, existed when there was obviously surface flow but where the influx of new water was much too slow to make the streambed develop visible ripples.

Pooled stream conditions described an area where there was an influx of water into an area that was blocked from the majority of the stream's flow. (This condition, created by the accumulation of vegetative or trash debris, usually creates a backflow of current, which allows for accumulation of chemical ions that could influence sample data.)

Ripples described any site that had stream debris, such as rocks, logs or rusted bicycles, close enough to the surface to create a soft churning motion or wake.

Rushing and *choppy* described somewhat similar situations, though it was determined that they were separate influences on stream conditions. The term rushing was used to describe any high or flooded condition in which the stream's surface was softly rippled in appearance, while choppy reflected a high or flooded condition in which the surface water was marked with wave crests or extremely large ripples. To illustrate this difference, rushing water would sweep a floating object away while choppy water usually pulled the floating object under the surface. These two similar stream situations might scour or gouge the streambed at a given sample site, possibly influencing water quality.

Partly frozen and *frozen solid* were included in cold weather months when stream flow might slow enough to freeze. If the stream surface was completely covered by ice, then frozen solid was recorded, whereas partly frozen was recorded for any frozen condition resulting in less than complete ice coverage.

Wildlife

Wildlife could easily influence water quality factors associated with soils (such as orthophosphate and turbidity levels) by simply wading upstream of the sampling location at the time a sample was collected. Nesting and feeding grounds for waterfowl may also produce an increase in measured nitrate levels at a given sample site due to the excessive amounts of fecal material that can be washed into nearby streams. Additionally, monitoring of wildlife in the study area may prove useful for future researchers. Wildlife was noted only for being present in an area, as it was neither practical nor necessary for this project to specifically identify an animal.

Water Quality Collection Report & Data Form

Environmental Studies Program
Shenandoah University Winchester, VA

Monitors: ______________________ **Date:** ______________

Site Name: ______________ **Sample ID:** ______________ **Time:** ______________ am pm
Air (°C) ______________ **Water (°C)** ______________

I. Precipitation in the Last 48 hrs? (circle all that apply)
None Intermittent Drizzle Mist Sprinkle Sleet Hail Snow
Steady Rain Heavy Rain Other: ______________ Amount: ______________

II. Present Weather Conditions: (circle all that apply)
Sunny Windy Overcast Cloudy Rain Sleet Hail Snow
Humidity: low medium high Other: ______________

III. Water Level: (circle one)
Dry Pooled Low Normal High Flooded
Other: ______________ Amount: ______________

IV. Water Flow: (circle one)
Stagnant Calm Slow Flow Pooled Ripples
Rushing Choppy Partly Frozen Frozen Solid

V. Wildlife Sighted? (list) ______________________

VI. Comments: ______________________

VII. Lab Results:
Nitrate: ______________ ppm Phosphate: ______________ ppm
Turbidity: 1st ______ 2nd ______ 3rd ______ Average: ______________ NTU

Site Name: ______________ **Sample ID:** ______________ **Time:** ______________ am pm
Air (°C) ______________ **Water (°C)** ______________

I. Precipitation in the Last 48 hrs? (circle all that apply)
None Intermittent Drizzle Mist Sprinkle Sleet Hail Snow
Steady Rain Heavy Rain Other: ______________ Amount: ______________

II. Present Weather Conditions: (circle all that apply)
Sunny Windy Overcast Cloudy Rain Sleet Hail Snow
Humidity: low medium high Other: ______________

III. Water Level: (circle one)
Dry Pooled Low Normal High Flooded
Other: ______________ Amount: ______________

IV. Water Flow: (circle one)
Stagnant Calm Slow Flow Pooled Ripples
Rushing Choppy Partly Frozen Frozen Solid

V. Wildlife Sighted? (list) ______________________

VI. Comments: ______________________

VII. Lab Results:
Nitrate: ______________ ppm Phosphate: ______________ ppm
Turbidity: 1st ______ 2nd ______ 3rd ______ Average: ______________ NTU

Baseline

	16-Jan	16-Feb	15-Mar	16-Apr	17-May	15-Jun	17-Jul	15-Aug	14-Sep	17-Oct	15-Nov	17-Dec	High	Low	Median	Average
AC-RT50	3.7	19.2	30.7	32.5	19.0	25.0	37.2	35.3	26.9	12.3	18.9	9.5	37.2	3.7	22.1	22.5
AC-SHEN	4.0	11.3	25.1	30.1	18.3	22.7	30.1	29.4	26.3	11.1	15.3	4.3	30.1	4.0	20.5	19.0
TR-ADEL	2.9	12.7	27.9	40.3	19.3	20.7	30.1	30.2	25.1	10.9	14.8	4.0	40.3	2.9	20.0	19.9
TR-MTH	1.9	11.6	26.7	28.1	18.4	22.1	30.7	29.1	25.5	11.0	18.8	3.7	30.7	1.9	20.5	19.0
AC-JBP	2.3	13.3	31.1	28.1	19.4	23.1	29.7	28.8	25.0	10.7	17.1	2.7	31.1	2.3	21.3	19.3
High	4.0	19.2	31.1	40.3	19.4	25.0	37.2	35.3	26.9	12.3	18.9	9.5				
Low	1.9	11.3	25.1	28.1	18.3	20.7	29.7	28.8	25.0	10.7	14.8	2.7		Grand Median		20.5
Median	2.9	12.7	27.9	30.1	19.0	22.7	30.1	29.4	25.5	11.0	17.1	4.0		Grand Average		19.9
Average	3.0	13.6	28.3	31.8	18.9	22.7	31.6	30.6	25.8	11.2	17.0	4.8				

March 20

	15-Mar	20-Mar	20-Mar	20-Mar	20-Mar	20-Mar	20-Mar	21-Mar	22-Mar	High	Low	Median	Average
	Baseline	8:00	11:00	13:30	16:00	18:00	20:00	8:00	9:00				
AC-RT50	30.7	4.8	6.1	9.4	10.0	11.0	11.5	6.7	-3.8	11.5	-3.8	8.1	7.0
AC-SHEN	25.1	4.3	5.9	8.2	9.7	10.1	10.7	8.7	-1.4	10.7	-1.4	8.5	7.0
TR-ADEL	27.9	4.7	6.1	7.9	12.0	9.9	10.1	8.2	-0.3	12.0	-0.3	8.1	7.3
TR-MTH	26.7	4.2	7.1	8.5	9.8	10.6	10.7	6.7	-3.7	10.7	-3.7	7.8	6.7
AC-JBP	31.1	4.9	5.9	8.2	10.3	10.4	10.3	7.7	-4.1	10.4	-4.1	8.0	6.7
High	31.1	4.9	7.1	9.4	12.0	11.0	11.5	8.7	-0.3				
Low	25.1	4.2	5.9	7.9	9.7	9.9	10.1	6.7	-4.1		Grand Median		8.1
Median	27.9	4.7	6.1	8.2	10.0	10.4	10.7	7.7	-3.7		Grand Average		7.0
Average	28.3	4.6	6.2	8.4	10.4	10.4	10.7	7.6	-2.7				

April 09

	9-Apr	9-Apr	9-Apr	10-Apr	16-Apr	High	Low	Median	Average
	12:00	16:00	18:00	11:00	Baseline				
AC-RT50	21.3	17.5	16.5	14.7	32.5	21.3	14.7	17	17.5
AC-SHEN	21.3	16.5	16.8	13.5	30.1	21.3	13.5	16.65	17.025
TR-ADEL	20.3	16.4	17.2	19.5	40.3	20.3	16.4	18.35	18.35
TR-MTH	21.1	16.3	16.7	11.9	28.1	21.1	11.9	16.5	16.5
AC-JBP	19.9	16.8	17.5	12.3	28.1	19.9	12.3	17.15	16.625
High	21.3	17.5	17.5	19.5	40.3				
Low	19.9	16.3	16.5	11.9	28.1		Grand Median		16.9
Median	21.1	16.5	16.8	13.5	30.1		Grand Average		18.7
Average	20.8	16.7	16.9	14.4	31.8				

Table A. Supplementary Data for Air Temperature (°C), 2002. Areas shaded in gray denote data used to calculate statistics.

May 26

	17-May	26-May	26-May	26-May	26-May	27-May	High	Low	Median	Average
	Baseline	15:30	17:30	19:30	21:30	17:00				
AC-RT50	19.0	18.7	19.5	17.0	17.1	24.3	24.3	17.0	18.7	19.3
AC-SHEN	18.3	18.9	18.7	17.0	16.8	23.1	23.1	16.8	18.7	18.9
TR-ADEL	19.3	18.3	18.1	16.3	16.5	22.3	22.3	16.3	18.1	18.3
TR-MTH	18.4	18.2	18.3	16.1	16.7	22.5	22.5	16.1	18.2	18.4
AC-JBP	19.4	18.7	17.9	15.5	16.4	22.4	22.4	15.5	17.9	18.2
High	19.4	18.9	19.5	17.0	17.1	24.3				
Low	18.3	18.2	17.9	15.5	16.4	22.3		Grand Median		18.3
Median	19.0	18.7	18.3	16.3	16.7	22.5		Grand Average		18.6
Average	18.9	18.6	18.5	16.4	16.7	22.9				

June 27-29

	15-Jun	27-Jun	27-Jun	27-Jun	27-Jun	28-Jun	28-Jun	28-Jun	29-Jun	High	Low	Median	Average
	Baseline	16:30	18:00	20:00	22:00	11:00	13:00	15:00	16:00				
AC-RT50	25.0	25.8	23.8	23.1	21.9	25.1	27.5	33.5	29.3	33.5	21.9	25.5	26.3
AC-SHEN	22.7	24.3	23.6	23.3	22.4	24.9	25.5	27.9	26.7	27.9	22.4	24.6	24.8
TR-ADEL	20.7	21.5	22.9	23.1	21.9	25.3	25.9	26.7	26.8	26.8	21.5	24.2	24.3
TR-MTH	22.1	23.7	23.2	23.4	22.7	24.3	25.5	27.4	26.7	27.4	22.7	24.0	24.6
AC-JBP	23.1	21.4	22.9	22.7	21.9	25.0	26.2	26.1	26.1	26.2	21.4	24.0	24.0
High	25.0	25.8	23.8	23.4	22.7	25.3	27.5	33.5	29.3				
Low	20.7	21.4	22.9	22.7	21.9	24.3	25.5	26.1	26.1		Grand Median		24.2
Median	22.7	23.7	23.2	23.1	21.9	25.0	25.9	27.4	26.7		Grand Average		24.8
Average	22.7	23.3	23.3	23.1	22.2	24.9	26.1	28.3	27.1				

August 15

	15-Aug	15-Aug	15-Aug	15-Aug	15-Aug	16-Aug	17-Aug	High	Low	Median	Average
	Baseline	15:00	17:00	19:00	17:00	15:00	11:00				
AC-RT50	35.3	25.6	25.7	24.7	23.2	28.7	28.9	28.9	23.2	25.7	26.1
AC-SHEN	29.4	24.1	25.6	24.6	22.7	27.8	27.9	27.9	22.7	25.1	25.5
TR-ADEL	30.2	22.9	24.7	24.3	22.3	26.0	26.9	26.9	22.3	24.5	24.5
TR-MTH	29.1	22.7	25.1	24.1	22.7	27.4	26.9	27.4	22.7	24.6	24.8
AC-JBP	28.8	23.0	25.0	23.6	22.4	26.7	26.7	26.7	22.4	24.3	24.6
High	35.3	25.6	25.7	24.7	23.2	28.7	28.9				
Low	28.8	22.7	24.7	23.6	22.3	26.0	26.7		Grand Median		24.6
Median	29.4	23.0	25.1	24.3	22.7	27.4	26.9		Grand Average		25.1
Average	30.6	23.7	25.2	24.3	22.7	27.3	27.5				

Table A (cont'd). Supplementary Data for Air Temperature (°C), 2002. Areas shaded in gray denote data used to calculate statistics.

Baseline

	16-Jan	16-Feb	15-Mar	16-Apr	17-May	15-Jun	17-Jul	15-Aug	14-Sep	17-Oct	15-Nov	17-Dec	High	Low	Median	Average
AC-RT50	6	12	21	22	18	21	27	24	22	14	14	7	27	6	20	17
AC-SHEN	7	12	18	21	17	20	24	24	20	14	13	7	24	7	18	16
TR-ADEL	9	13	20	20	16	19	24	22	20	14	14	9	24	9	18	17
TR-MTH	9	12	18	20	15	19	23	22	20	14	14	10	23	9	17	16
AC-JBP	8	12	18	20	17	19	23	22	20	14	14	9	23	8	18	16
High	9	13	21	22	18	21	27	24	22	14	14	10				
Low	6	12	18	20	15	19	23	22	20	14	13	7		Grand Median		18
Median	8	12	18	20	17	19	24	22	20	14	14	9		Grand Average		17
Average	8	12	19	21	17	20	24	23	20	14	14	8				

March 20

	15-Mar	20-Mar	20-Mar	20-Mar	20-Mar	20-Mar	20-Mar	21-Mar	22-Mar	High	Low	Median	Average
	Baseline	8:00	11:00	13:30	16:00	18:00	20:00	8:00	9:00				
AC-RT50	21	7	8	9	11	11	12	9	5	12	5	9	9
AC-SHEN	18	6	7	9	10	11	11	9	5	11	5	9	9
TR-ADEL	20	6	8	9	11	11	11	9.5	5	11	5	9	9
TR-MTH	18	6	8	10	11	12	12	10	7	12	6	10	10
AC-JBP	18	7	9	10	11	11	11	10	6	11	6	10	9
High	21	7	9	10	11	12	12	10	7				
Low	18	6	7	9	10	11	11	9	5		Grand Median		9
Median	18	6	8	9	11	11	11	10	5		Grand Average		9
Average	19	6	8	9	11	11	11	10	6				

April 09

	9-Apr	9-Apr	9-Apr	10-Apr	16-Apr	High	Low	Median	Average
	12:00	16:00	18:00	11:00	Baseline				
AC-RT50	17	18	17	15	22	18	15	17	17
AC-SHEN	16	17	17	14	21	17	14	17	16
TR-ADEL	17	16	17	15	20	17	15	17	16
TR-MTH	16	16	16	14	20	16	14	16	16
AC-JBP	16	16	16	14	20	16	14	16	16
High	17	18	17	15	22				
Low	16	16	16	14	20		Grand Median		16
Median	16	16	17	14	20		Grand Average		16
Average	16	17	17	14	21				

Table B. Supplementary Data for Water Temperature (°C), 2002. Areas shaded in gray denote data used to calculate statistics.

May 26

	17-May	26-May	26-May	26-May	26-May	27-May	High	Low	Median	Average
	Baseline	15:30	17:30	19:30	21:30	17:00				
AC-RT50	18	22	21	19	18	17	22	17	19	19
AC-SHEN	17	22	21	19	18	18	22	18	19	20
TR-ADEL	16	22	20	18	18	15	22	15	18	19
TR-MTH	15	20	19	18	17.5	16	20	16	18	18
AC-JBP	17	22	20	19	17	14.5	22	15	19	19
High	18	22	21	19	18	18				
Low	15	20	19	18	17	15		Grand Median		19
Median	17	22	20	19	18	16		Grand Average		19
Average	17	22	20	19	18	16				

June 27-29

	15-Jun	27-Jun	27-Jun	27-Jun	27-Jun	28-Jun	28-Jun	28-Jun	29-Jun	High	Low	Median	Average
	Baseline	16:30	18:00	20:00	22:00	11:00	13:00	15:00	16:00				
AC-RT50	21	30	26	25	24	24	25	27	27	30	24	26	26
AC-SHEN	20	25	25	24	23	23	24	25	25	25	23	25	24
TR-ADEL	19	24	25	22	20	20	21	22	22	25	20	22	22
TR-MTH	19	23	24	21	20	20	22	22	22	24	20	22	22
AC-JBP	19	24	24	21	21	21	22	22	23	24	21	22	22
High	21	30	26	25	24	24	25	27	27				
Low	19	23	24	21	20	20	21	22	22		Grand Median		23
Median	19	24	25	22	21	21	22	22	23		Grand Average		23
Average	20	25	25	23	22	22	23	24	24				

August 15

	15-Aug	15-Aug	15-Aug	15-Aug	15-Aug	16-Aug	17-Aug	High	Low	Median	Average
	Baseline	15:00	17:00	19:00	21:30	15:00	11:00				
AC-RT50	24	26	25	25	24	26	25	26	24	25	25
AC-SHEN	24	24	26	25	23	24	24	26	23	24	24
TR-ADEL	22	26	24	23	21	22	21	26	21	23	23
TR-MTH	22	23	24	24	23	22	21	24	21	23	23
AC-JBP	22	26	24	23	21	23	20	26	20	23	23
High	24	26	26	25	24	26	25				
Low	22	23	24	23	21	22	20		Grand Median		24
Median	22	26	24	24	23	23	21		Grand Average		24
Average	23	25	25	24	22	23	22				

Table B (cont'd). Supplementary Data for Water Temperature (°C), 2002. Areas shaded in gray denote data used to calculate statistics.

Baseline											
16-Jan	16-Feb	15-Mar	16-Apr	17-May	15-Jun	17-Jul	15-Aug	14-Sep	17-Oct	15-Nov	17-Dec
n/a	n/a	n/a	n/a	none	heavy rain	none	none	none	steady rain	steady rain	sprinkle

Storm				
20-Mar	9-Apr	26-May	June 27-29	15-Aug
n/a	n/a	none	heavy rain	none

Table C-a. Supplementary Data for Weather Conditions 48 Hours Prior to Sample Collection, 2002.

Baseline	16-Jan	16-Feb	15-Mar	16-Apr	17-May	15-Jun	17-Jul	15-Aug	14-Sep	17-Oct	15-Nov	17-Dec
AC-RT50					C	W,C	SU	SU	C	OC	C	SU
AC-SHEN					C	W,C	SU	SU	OC	OC	C	SU
TR-ADEL		Data not collected			C	W,C	SU	SU	OC	R	C	SU
TR-MTH					C	W,C	SU	SU	W,OC	R	C	SU
AC-JBP					C	W,C	SU,W	SU	OC	OC	C	C

May 26	17-May	26-May	26-May	26-May	26-May	27-May
	10:00	15:30	17:30	19:30	21:30	17:00
AC-RT50	C	R	C	R	C	OC
AC-SHEN	C	R,H	C	R	C	OC
TR-ADEL	C	C	R	C	C	C
TR-MTH	C	R	C	C	C	W,OC
AC-JBP	C	C	OC	R	C	OC

June 27-29	15-Jun	27-Jun	27-Jun	27-Jun	27-Jun	28-Jun	28-Jun	28-Jun	29-Jun
	13:00	16:30	18:00	20:00	22:00	11:00	13:00	15:00	16:00
AC-RT50	W,C	R	C	C	C	W,C	C	C	C
AC-SHEN	W,C	R	W,OC	C	C	OC	OC	W,C	C
TR-ADEL	W,C	W,R	C	C	C	OC	OC	C	C
TR-MTH	W,C	W,R	W,C	W,C	C	W,OC	OC	C	OC
AC-JBP	W,C	W,C	C	C	R	C	OC	C	C

August 15	15-Aug	15-Aug	15-Aug	15-Aug	15-Aug	16-Aug	17-Aug
	11:00	15:00	17:00	19:00	21:30	15:00	11:00
AC-RT50	SU	R	C	C	R	C	C
AC-SHEN	SU	R	C	C	OC	W,C	C
TR-ADEL	SU	C	C	C	OC	OC	C
TR-MTH	SU	C	C	C	R	C	C
AC-JBP	SU	C	C	C	OC	OC	C

Table C-b. Supplementary Data for Present Weather Conditions at Time of Sample Collection, 2002. Codes indicate the following: SU=sunny, W=windy, OC=overcast, C=cloudy, R=rain, SL=sleet, H=hail, SN=snow.

Baseline

	16-Jan	16-Feb	15-Mar	16-Apr	17-May	15-Jun	17-Jul	15-Aug	14-Sep	17-Oct	15-Nov	17-Dec
AC-RT50					M	L	M	M	M	L	L	L
AC-SHEN						L	H	M	M	L	L	
TR-ADEL		Data not	collected			L	H	M	M	L	L	
TR-MTH						L	H	M	M	L	L	L
AC-JBP						L	H	M	M	L	L	L

May 26

	17-May	26-May	26-May	26-May	26-May	27-May
	Baseline	15:30	17:30	19:30	21:30	17:00
AC-RT50	M	H	L	H	M	H
AC-SHEN		H	L	H	M	H
TR-ADEL			H	M	M	H
TR-MTH		H	L	M	M	H
AC-JBP		M	M	H	M	H

June 27-29

	15-Jun	27-Jun	27-Jun	27-Jun	27-Jun	28-Jun	28-Jun	28-Jun	29-Jun
	Baseline	16:30	18:00	20:00	22:00	11:00	13:00	15:00	16:00
AC-RT50	L	H	L	L	M	M	H	M	M
AC-SHEN	L	H	L	L	M	H	M	M	M
TR-ADEL	L	M	M	M	M	H	H	M	M
TR-MTH	L	M	L	L	M	M	H	M	M
AC-JBP	L	M	M	M	H	H	H	H	H

August 15

	15-Aug	15-Aug	15-Aug	15-Aug	15-Aug	16-Aug	17-Aug
	Baseline	15:00	17:00	19:00	21:30	15:00	11:00
AC-RT50	M	M	L	L	M	L	M
AC-SHEN	M	M	L	L	M	L	M
TR-ADEL	M	L	M	L	M	M	M
TR-MTH	M	L	M	L	M	M	M
AC-JBP	M	M	M	L	M	M	M

Table D. Supplementary Data for Humidity Levels at Time of Sample Collection, 2002. Codes indicate the following: H=high, M=medium, L=low.

Baseline

	16-Jan	16-Feb	15-Mar	16-Apr	17-May	15-Jun	17-Jul	15-Aug	14-Sep	17-Oct	15-Nov	17-Dec
AC-RT50					N	N	N	L	L	H	N	N
AC-SHEN					N	N	N	L	L	N	N	H
TR-ADEL	Data not collected				N	N	N	L	L	N	N	N
TR-MTH					N	N	N	L	L	N	N	N
AC-JBP					N	N	N	L	L	N	N	H

May 26

	17-May Baseline	26-May 15:30	26-May 17:30	26-May 19:30	26-May 21:30	27-May 17:00
AC-RT50	N	H	H	F	H	N
AC-SHEN	N	H	H	H	H	N
TR-ADEL	N	F	H	F	H	N
TR-MTH	N	F	H	F	H	N
AC-JBP	N	H	H	H	H	N

June 27-29

	15-Jun Baseline	27-Jun 16:30	27-Jun 18:00	27-Jun 20:00	27-Jun 22:00	28-Jun 11:00	28-Jun 13:00	28-Jun 15:00	29-Jun 16:00
AC-RT50	N	H	H	N	N	N	N	N	N
AC-SHEN	N	H	H	N	N	N	N	N	N
TR-ADEL	N	H	H	N	N	N	N	N	N
TR-MTH	N	N	H	N	N	N	N	N	N
AC-JBP	N	H	H	N	N	N	N	N	N

August 15

	15-Aug Baseline	15-Aug 15:00	15-Aug 17:00	15-Aug 19:00	15-Aug 21:30	16-Aug 15:00	17-Aug 11:00
AC-RT50	L	N	H	N	N	N	N
AC-SHEN	L	N	H	N	N	N	N
TR-ADEL	L	F	H	N	N	N	L
TR-MTH	L	N	H	N	N	N	L
AC-JBP	L	H	H	N	N	N	L

Table E. Supplementary Data for Observed Water Level at Time of Sample Collection, 2002. Codes indicate the following: D=dry, P=pooled, L=low, N=normal, H=high, F=flooded.

Baseline

	16-Jan	16-Feb	15-Mar	16-Apr	17-May	15-Jun	17-Jul	15-Aug	14-Sep	17-Oct	15-Nov	17-Dec
AC-RT50					RI	RI	RI	RI	SF	RI	RI	RI
AC-SHEN					RI	RI	RI	RI	RI	RI	RI	RI
TR-ADEL	Data not collected				RI	RI	RI	RI	RI	RI	RI	RI
TR-MTH					RI	RI	RI	RI	RI	RI	RI	RI
AC-JBP					RI	RI	RI	RI	RI	RI	RI	RI

May 26

	17-May	26-May	26-May	26-May	26-May	27-May
	Baseline	15:30	17:30	19:30	21:30	17:00
AC-RT50	RI	RU	RI	RU	RI	RI
AC-SHEN	RI	RU	RI	RU	RI	RI
TR-ADEL	RI	CH	RI	CH	RU	RI
TR-MTH	RI	RU	RI	RU	RI	RI
AC-JBP	RI	RU	RI	CH	RI	RI

June 27-29

	15-Jun	27-Jun	27-Jun	27-Jun	27-Jun	28-Jun	28-Jun	28-Jun	29-Jun
	Baseline	16:30	18:00	20:00	22:00	11:00	13:00	15:00	16:00
AC-RT50	RI	RU	RI	RI	RI	RI	RI	RI	RI
AC-SHEN	RI	RI	RI	RI	RI	RI	RI	RI	RI
TR-ADEL	RI	RI	RI	RI	RI	RI	RI	RI	RI
TR-MTH	RI	RI	RI	RI	RI	RI	RI	RI	RI
AC-JBP	RI	RU	RI	RI	RI	RI	RI	RI	RI

August 15

	15-Aug	15-Aug	15-Aug	15-Aug	15-Aug	16-Aug	17-Aug
	Baseline	15:00	17:00	19:00	21:30	15:00	11:00
AC-RT50	RI	RI	RI	RI	RI	RI	RI
AC-SHEN	RI	RI	RI	RI	RI	RI	RI
TR-ADEL	RI	CH	RI	RI	RI	RI	RI
TR-MTH	RI	RI	RI	RI	RI	RI	RI
AC-JBP	RI	RU	RI	RI	RI	RI	RI

Table F. Supplementary Data for Observed Water Flow at Time of Sample Collection, 2002. Codes indicate the following: ST=stagnant, CA=calm, SF=slow flow, PO=pooled, RI=ripples, RU=rushing, CH=choppy, PF=partly frozen, FZ=frozen solid.

Baseline

	16-Jan	16-Feb	15-Mar	16-Apr	17-May	15-Jun	17-Jul	15-Aug	14-Sep	17-Oct	15-Nov	17-Dec
AC-RT50					N	Y	Y	Y	Y	N	N	N
AC-SHEN					Y	Y	Y	Y	Y	N	N	N
TR-ADEL	Data not collected				Y	N	N	N	N	Y	N	Y
TR-MTH					Y	N	N	Y	N	N	N	Y
AC-JBP					Y	Y	Y	N	Y	N	N	Y

May 26

	17-May	26-May	26-May	26-May	26-May	27-May
	Baseline	15:30	17:30	19:30	21:30	17:00
AC-RT50		N	Y	Y	N	Y
AC-SHEN	Y	N	N	Y	N	N
TR-ADEL	Y	N	Y	N	N	N
TR-MTH	Y	N	N	N	N	N
AC-JBP	Y	N	Y	N	N	Y

June 27-29

	15-Jun	27-Jun	27-Jun	27-Jun	27-Jun	28-Jun	28-Jun	28-Jun	29-Jun
	Baseline	16:30	18:00	20:00	22:00	11:00	13:00	15:00	16:00
AC-RT50	Y	N	N	N	N	N	N	N	N
AC-SHEN	Y	N	N	N	N	N	N	N	N
TR-ADEL	N	N	N	N	N	N	N	N	N
TR-MTH	N	N	N	N	N	N	N	N	N
AC-JBP	Y	N	N	N	N	N	N	N	N

August 15

	15-Aug	15-Aug	15-Aug	15-Aug	15-Aug	16-Aug	17-Aug
	Baseline	15:00	17:00	19:00	21:30	15:00	11:00
AC-RT50	Y	N	N	N	Y	N	N
AC-SHEN	Y	N	N	N	N	N	Y
TR-ADEL	N	N	Y	N	N	N	N
TR-MTH	Y	Y	Y	N	N	Y	N
AC-JBP	N	N	Y	Y	N	N	N

Table G. Supplementary Data for Wildlife Observed at Time of Sample Collection, 2002. Codes indicate the following: Y=Wildlife was observed in or around sample site location at time of collection, N=Wildlife was not observed in or around sample site location at time of collection.

Appendix B. Rainfall Information

The rainfall information provided in this report was obtained from two sources: WINC FM Radio (located 1.8 miles N of the study site) and the Virginia Tech Agricultural Research and Extension Center (located 8.7 miles SW of the study site). As Figure A reveals, rainfall varied between the two locations. Totals from these two sources were averaged to generate the numbers reported in the body of this document.

In addition, average monthly rainfalls during the 2002 study year can be considered in light of historical rainfall information for the last 85 years. Figure B and Table H show that rainfall during 2002 exceeded Winchester's historic average four out of twelve months. Data Tables I and J depict precipitation amounts recorded at WINC FM Radio and at the Virginia Agricultural Research and Extension Center.

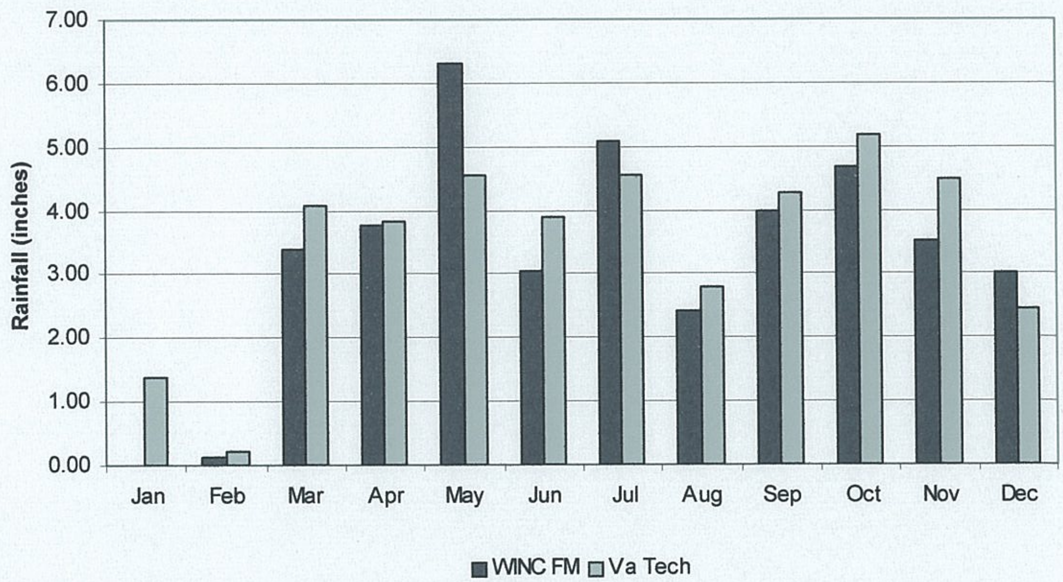

Figure A: Rainfall Amounts Recorded by WINC FM and the Virginia Tech Agricultural Research and Extension Center for 2002. This figure illustrates the range of rainfall amounts that can fall within a geographically small area. Frozen precipitation amounts were not included. January information was not available from WINC FM.

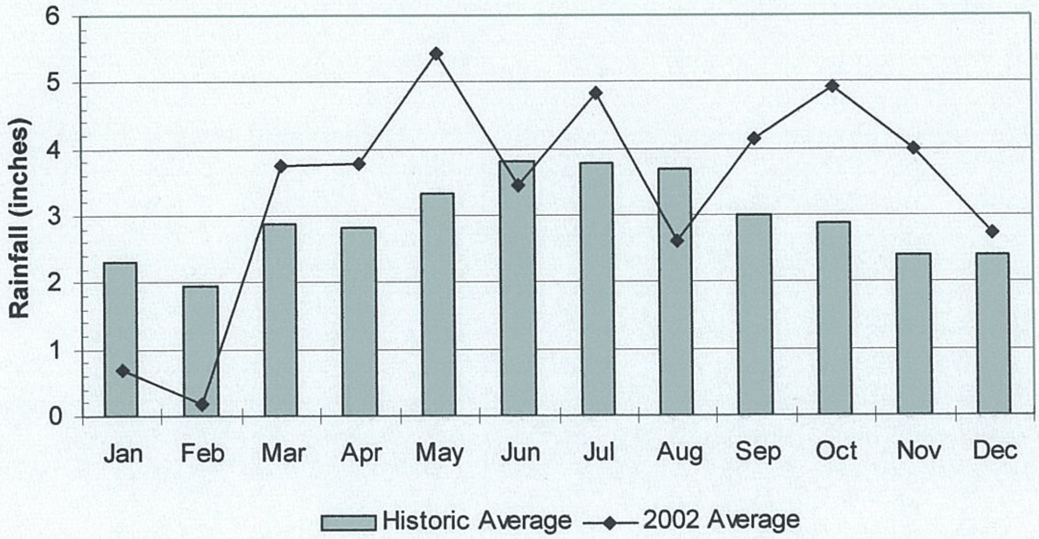

Figure B. Rainfall for Winchester, VA: the 85-year Historic Average and the 2002 Study Year Average.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Avg for both locations:	**0.69**	**0.18**	**3.74**	**3.80**	**5.43**	**3.47**	**4.83**	**2.60**	**4.14**	**4.93**	**4.00**	**2.73**
Historic avg (85 yr)	**2.31**	**1.94**	**2.89**	**2.82**	**3.34**	**3.81**	**3.79**	**3.7**	**2.99**	**2.88**	**2.39**	**2.41**

Table H. Monthly Rainfall Averages for Winchester, Virginia. This table displays rainfall totals (in inches) for the 2002 study year (generated from WINC FM and Virginia Tech information) and for the previous 85 years (provided by the *Winchester Star*).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1		0.01		0.42		0.02			0.12			0.01
2					0.76				0.26		T	
3			0.59		0.15				0.01			
4						0.12		0.31				
5					0.12	0.06	0.05			0.02		0.47
6						0.25		0.49			0.67	0.17
7		0.09			0.06	0.16						0.00
8					0.14							0.00
9					0.10							0.00
10				0.34	0.40		0.02			0.08		0.00
11		0.02	0.29				0.63			0.68	0.56	0.41
12			0.17				0.00			0.51	0.18	0.64
13				0.04	0.02					0.02	0.54	
14				0.19	0.73	1.10	2.21	0.03		0.06		0.61
15				0.48	0.73	0.67	0.09					0.01
16			0.40					0.61	0.22	0.98	0.01	
17			0.01		0.01			0.01	0.04	0.61	0.76	
18		0.02	1.05		0.94						0.14	
19			0.20		0.01	0.20	0.03	0.01		0.03		
20				0.12							0.03	0.20
21				0.04								
22				0.73					0.70		0.49	
23				0.01					0.63			
24							1.01	0.11	0.01			
25			0.57	0.03			0.04			0.04		0.29
26							0.31		1.78	0.54		0.19
27					1.70	0.08	0.30		0.20	0.02	0.14	
28				0.80	0.08	0.33	0.40	0.01				
29			0.12	0.55	0.34	0.05		0.83		0.03		
30				0.01	0.01			0.01	0.02	0.97		
31										0.09		

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Sum	**0.00**	**0.14**	**3.40**	**3.76**	**6.30**	**3.04**	**5.09**	**2.42**	**3.99**	**4.68**	**3.52**	**3.00**
Avg	**0.00**	**0.04**	**0.38**	**0.29**	**0.37**	**0.28**	**0.42**	**0.24**	**0.36**	**0.31**	**0.35**	**0.21**

Yr Sum 2002:	**39.34**
Avg/mo 2002:	**0.27**

Table I. Rainfall (inches) Recorded by WINC FM Radio Station for 2002. Frozen precipitation levels are not included in this table. "T" indicates trace (negligible) levels of rain; blank cells indicate no rainfall. Data not available for January 2002.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1									0.21			
2			0.63		0.77				0.03			
3			0.02					1.33				
4					0.16	0.53		0.02				
5						1.01	0.02	0.46			0.89	0.34
6	0.44				0.04	0.54					0.03	
7		0.14			0.25							
8					0.14							
9				0.17	0.56		0.05			0.01		
10		0.07					0.21			0.62		
11										0.84	0.58	0.74
12			0.09		0.17					0.01	0.90	0.14
13			0.42	0.26	0.56	0.53	0.17	0.06		0.03		0.65
14			0.02	0.18	0.02	0.61	1.96	0.01				0.22
15				0.21		0.06		0.16	0.24	0.21		
16									0.01	1.36	0.76	
17					0.03					0.01	0.41	
18			0.21		1.05	0.09	0.13	0.02				
19	0.25		0.29	0.32		0.01					0.05	
20			1.16	0.24								0.36
21				0.71					0.93		0.67	
22				0.34					0.53		0.01	
23							0.80					
24	0.19				0.02		0.04	0.12		0.01		
25				0.07	0.44		0.06			0.53		0.50
26			0.65		0.21	0.08	1.04		1.97	0.14		
27				0.17	0.06	0.09	0.08		0.36		0.11	
28				1.16		0.34		0.40		0.04		
29								0.20		1.19		
30	0.36		0.09		0.07					0.18	0.07	0.01
31	0.14		0.50									

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Sum	**1.38**	**0.21**	**4.08**	**3.83**	**4.55**	**3.89**	**4.56**	**2.78**	**4.28**	**5.18**	**4.48**	**2.96**
Avg	**0.28**	**0.11**	**0.37**	**0.35**	**0.28**	**0.35**	**0.41**	**0.28**	**0.54**	**0.37**	**0.41**	**0.37**

Yr Sum 2002:	**42.18**
Avg/mo 2002:	**0.34**

Table J. Rainfall (Inches) Recorded by Virginia Tech Agricultural Research and Extension Center for 2002. Frozen precipitation (snow) levels are not included in this table. Blank cells indicate no rainfall.

Appendix C. Baseline Data

Tables K - M on the following pages display the complete set of baseline data obtained for nitrate and phosphate concentrations and turbidity levels during the course of this year-long study. In addition to these numbers, each table also shows the high, low, average, median and standard deviation for each set of figures by sample site and by sample run (i.e., all five sites combined).

	16-Jan 11:00	16-Feb 13:00	15-Mar 14:00	16-Apr 11:30	17-May 10:00	15-Jun 13:00	17-Jul 13:30	15-Aug 11:00	14-Sep 11:30	17-Oct 15:30	15-Nov 13:00	17-Dec 13:30	High	Low	Median	Average	Standard Deviation
AC-RT50	1.3	1.0	0.60	1.2	1.5	2.0	1.6	1.9	1.8	1.8	2.6	2.6	2.6	0.60	1.7	1.7	0.60
AC-SHEN	1.2	1.0	0.60	1.1	1.3	1.6	1.7	1.3	1.3	1.6	2.4	2.6	2.6	0.60	1.3	1.5	0.56
TR-ADEL	1.8	1.5	1.3	1.9	2.5	3.2	3.5	2.5	3.0	2.9	3.4	3.2	3.5	1.3	2.7	2.6	0.77
TR-MTH	1.4	1.0	1.0	1.6	2.0	2.4	2.5	2.0	2.0	2.2	2.6	2.7	2.7	1.0	2.0	2.0	0.59
AC-JBP	1.3	1.4	0.90	1.6	1.8	2.2	2.2	1.9	2.2	1.8	2.6	2.3	2.6	0.90	1.9	1.9	0.49
High	1.8	1.5	1.3	1.9	2.5	3.2	3.5	2.5	3.0	2.9	3.4	3.2					
Low	1.2	1.0	0.60	1.1	1.3	1.6	1.6	1.3	1.3	1.6	2.4	2.3					
Median	1.3	1.0	0.90	1.6	1.8	2.2	2.2	1.9	2.0	1.8	2.6	2.6	Grand Median			1.9	
Average	1.4	1.2	0.88	1.5	1.8	2.3	2.3	1.9	2.1	2.1	2.7	2.7	Grand Average			1.9	
Standard Deviation	0.23	0.25	0.29	0.33	0.47	0.59	0.76	0.43	0.62	0.52	0.39	0.33					

Table K. Baseline Nitrate Concentrations (ppm), 2002. Data in shaded cells were used to calculate statistics by sample site.

	16-Jan 11:00	16-Feb 13:00	15-Mar 14:00	16-Apr 11:30	17-May 10:00	15-Jun 13:00	17-Jul 13:30	15-Aug 11:00	14-Sep 11:30	17-Oct 15:30	15-Nov 13:00	17-Dec 13:30	High	Low	Median	Average	Standard Deviation
AC-RT50	0.02	0.02	0.05	0.03	0.09	0.09	0.06	0.03	0.04	0.07	0.10	0.03	0.10	0.02	0.05	0.05	0.03
AC-SHEN	0.03	0.04	0.03	0.03	0.01	0.06	0.08	0.04	0.05	0.04	0.03	0.04	0.08	0.01	0.04	0.04	0.02
TR-ADEL	0.03	0.08	0.05	0.06	0.05	0.13	0.11	0.04	0.06	0.08	0.14	0.04	0.14	0.03	0.06	0.07	0.04
TR-MTH	0.01	0.04	0.01	0.02	0.05	0.07	0.11	0.03	0.04	0.03	0.05	0.04	0.11	0.01	0.04	0.04	0.03
AC-JBP	0.01	0.05	0.02	0.02	0.02	0.09	0.05	0.06	0.07	0.06		0.07	0.09	0.01	0.05	0.05	0.03
High	0.03	0.08	0.05	0.06	0.09	0.13	0.11	0.06	0.07	0.08	0.14	0.07					
Low	0.01	0.02	0.01	0.02	0.01	0.06	0.05	0.03	0.04	0.03	0.03	0.03					
Median	0.02	0.04	0.03	0.03	0.05	0.09	0.08	0.04	0.05	0.06	0.08	0.04		Grand Median:		0.05	
Average	0.02	0.05	0.03	0.03	0.04	0.09	0.08	0.04	0.05	0.06	0.08	0.04		Grand Average:		0.05	
Standard Deviation	0.01	0.02	0.02	0.02	0.03	0.03	0.03	0.01	0.01	0.02	0.05	0.02					

Table L. Baseline Phosphate Concentrations (ppm), 2002. Data in shaded cells were used to calculate statistics by sample site. An anomalous datum (from Site AC-JBP, 15-Nov 13:00) was omitted from the study.

	16-Jan 11:00	16-Feb 13:00	15-Mar 14:00	16-Apr 11:30	17-May 10:00	15-Jun 13:00	17-Jul 13:30	15-Aug 11:00	14-Sep 11:30	17-Oct 15:30	15-Nov 13:00	17-Dec 13:30	High	Low	Median	Average	Standard Deviation
AC-RT50	0.635	1.89	0.820	1.82	1.08	3.23	2.56	0.760	1.17	2.76	1.67	6.60	6.60	0.635	1.75	2.08	1.65
AC-SHEN	1.20	1.99	2.71	3.55	2.07	6.12	3.47	8.23	3.36	4.92	2.86	5.29	8.23	1.20	3.42	3.81	2.00
TR-ADEL	3.31	2.94	1.73	1.38	1.02	1.91	2.50	2.71	3.57	4.91	2.38	7.50	7.50	1.02	2.61	2.99	1.77
TR-MTH	1.65	1.74	1.64	2.44	1.42	3.16	2.35	2.29	2.27	3.02	1.90	3.39	3.39	1.42	2.28	2.27	0.644
AC-JBP	1.36	1.59	1.85	2.53	3.73	3.80	5.19	2.60	1.95	2.87	2.00	3.97	5.19	1.36	2.57	2.79	1.16
High	3.31	2.94	2.71	3.55	3.73	6.12	5.19	8.23	3.57	4.92	2.86	7.50					
Low	0.635	1.59	0.820	1.38	1.02	1.91	2.35	0.760	1.17	2.76	1.67	3.39					
Median	1.36	1.89	1.73	2.44	1.42	3.23	2.56	2.60	2.27	3.02	2.00	5.29		Grand Median		2.44	
Average	1.63	2.03	1.75	2.34	1.86	3.64	3.21	3.32	2.46	3.70	2.16	5.35		Grand Average		2.79	
Standard Deviation	1.01	0.531	0.672	0.822	1.12	1.55	1.19	2.86	1.00	1.12	0.467	1.73					

Table M. Baseline Turbidity Levels (NTU), 2002. Data in shaded cells were used to calculate statistics by sample site.

Appendix D. Storm Data

The tables on the following pages show the complete set of storm data obtained for the three water quality parameters studied over the course of this project. Tables for nitrate, phosphate and turbidity data are grouped by storm. In addition to the data gained from direct laboratory analysis, each table also shows the high, low, average, median and standard deviation by sample site and by sample run (i.e., all five sites combined).

	15-Mar Baseline	20-Mar 8:00	20-Mar 11:00	20-Mar 13:30	20-Mar 16:00	20-Mar 18:00	20-Mar 20:00	21-Mar 8:00	22-Mar 9:00	High	Low	Median	Average	Standard Deviation
AC-RT50	0.6	1.2	1.3	1.5	1.6	1.6	1.7	1.8	1.8	1.8	1.2	1.6	1.6	0.22
AC-SHEN	0.6	1.0	1.2	1.4	1.5	1.6	1.6	1.7	1.7	1.7	1.0	1.6	1.5	0.25
TR-ADEL	1.3	0.60	1.4	1.6	1.9	2.1	2.1	2.4	2.6	2.6	0.60	2.00	1.8	0.63
TR-MTH	1.0	0.90	1.5	1.6	1.7	1.9	1.8	1.9	1.5	1.9	0.90	1.7	1.6	0.33
AC-JBP	0.9	0.70	1.5	1.6	1.8	1.6	1.8	1.9	1.9	1.9	0.70	1.7	1.6	0.39
High	1.3	1.2	1.5	1.6	1.9	2.1	2.1	2.4	2.6					
Low	0.60	0.60	1.2	1.4	1.5	1.6	1.6	1.7	1.5					
Median	0.90	0.90	1.4	1.6	1.7	1.6	1.8	1.9	1.8		Grand Median		1.7	
Average	0.88	0.88	1.4	1.5	1.7	1.8	1.8	1.9	1.9		Grand Average		1.6	
Standard Deviation	0.29	0.24	0.13	0.09	0.16	0.23	0.19	0.27	0.42					

Table N-a. Nitrate Data (ppm) for March 20, 2002 Storm. Data in shaded cells were used to calculate statistics by sample site.

	15-Mar Baseline	20-Mar 8:00	20-Mar 11:00	20-Mar 13:30	20-Mar 16:00	20-Mar 18:00	20-Mar 20:00	21-Mar 8:00	22-Mar 9:00	High	Low	Median	Average	Standard Deviation
AC-RT50	0.05	0.19	0.21	0.11	0.07	0.06	0.06	0.07	0.06	0.21	0.06	0.07	0.10	0.06
AC-SHEN	0.03	0.10	0.13	0.10	0.07	0.04	0.05	0.06	0.05	0.13	0.04	0.07	0.08	0.03
TR-ADEL	0.05	0.14	0.20	0.15	0.13	0.15	0.12	0.10	0.17	0.20	0.10	0.15	0.15	0.03
TR-MTH	0.01	0.34	0.17	0.07	0.09	0.09	0.06	0.04	0.05	0.34	0.04	0.08	0.11	0.10
AC-JBP	0.02	0.23	0.11	0.09	0.10	0.05	0.07	0.02	0.09	0.23	0.02	0.09	0.10	0.06
High	0.05	0.34	0.21	0.15	0.13	0.15	0.12	0.10	0.17					
Low	0.01	0.10	0.11	0.07	0.07	0.04	0.05	0.02	0.05					
Median	0.03	0.19	0.17	0.10	0.09	0.06	0.06	0.06	0.06		Grand Median		0.08	
Average	0.03	0.20	0.16	0.10	0.09	0.08	0.07	0.06	0.08		Grand Average		0.11	
Standard Deviation	0.02	0.09	0.04	0.03	0.02	0.04	0.03	0.03	0.05					

Table N-b. Phosphate Data (ppm) for March 20, 2002 Storm. Data in shaded cells were used to calculate statistics by sample site.

	15-Mar Baseline	20-Mar 8:00	20-Mar 11:00	20-Mar 13:30	20-Mar 16:00	20-Mar 18:00	20-Mar 20:00	21-Mar 8:00	22-Mar 9:00	High	Low	Median	Average	Standard Deviation
AC-RT50	0.820	196	30.4	17.6	8.36	5.43	4.00	2.53	2.73	196	2.53	6.90	33.4	66.4
AC-SHEN	2.71	191	41.0	21.0	14.5	12.1	9.11	4.83	2.84	191	2.84	13.3	37.0	63.4
TR-ADEL	1.73	221	89.9	41.1	12.9	8.48	5.48	3.30	2.32	221	2.32	10.7	48.1	76.0
TR-MTH	1.64	175	86.4	20.2	8.02	5.88	4.01	2.41	4.39	175	2.41	6.95	38.3	62.0
AC-JBP	1.85	250	76.7	22.1	12.6	4.95	5.61	3.64	3.56	250	3.56	9.11	47.4	85.5
High	2.71	250	89.9	41.1	14.5	12.1	9.11	4.83	4.39					
Low	0.820	175	30.4	17.6	8.02	4.95	4.00	2.41	2.32					
Median	0.672	196	76.7	21.0	12.6	5.88	5.48	3.30	2.84		Grand Median		9.11	
Average	1.73	207	64.9	24.4	11.3	7.37	5.64	3.34	3.17		Grand Average		40.8	
Standard Deviation	1.75	29.3	27.3	9.48	2.91	2.98	2.09	0.979	0.816					

Table N-c. Turbidity Data (NTU) for March 20, 2002 Storm. Data in shaded cells were used to calculate statistics by sample site.

	9-Apr 12:00	9-Apr 16:00	9-Apr 18:00	10-Apr 11:00	16-Apr Baseline	High	Low	Median	Average	Standard Deviation
AC-RT50	1.6	1.3	1.3	1.4	1.2	1.6	1.3	1.4	1.4	0.14
AC-SHEN	1.5	1.4	1.3	1.2	1.1	1.5	1.2	1.4	1.4	0.13
TR-ADEL	2.2	2.3	2.6	2.1	1.9	2.6	2.1	2.3	2.3	0.22
TR-MTH	1.9	1.9	1.9	1.8	1.6	1.9	1.8	1.9	1.9	0.050
AC-JBP	1.8	1.9	1.7	1.7	1.6	1.9	1.7	1.8	1.8	0.10
High	2.2	2.3	2.6	2.1	1.9					
Low	1.5	1.3	1.3	1.2	1.1					
Median	1.8	1.9	1.7	1.7	1.6		Grand Median		1.8	
Average	1.8	1.8	1.8	1.6	1.5		Grand Average		1.7	
Standard Deviation	0.27	0.41	0.54	0.35	0.33					

Table O-a. Nitrate Data (ppm) for April 9, 2002 Storm. Data in shaded cells were used to calculate statistics by sample site.

	9-Apr 12:00	9-Apr 16:00	9-Apr 18:00	10-Apr 11:00	16-Apr Baseline	High	Low	Median	Average	Standard Deviation
AC-RT50	0.03	0.06	0.02	0.06	0.03	0.06	0.02	0.05	0.04	0.02
AC-SHEN	0.03	0.05	0.03	0.06	0.03	0.06	0.03	0.04	0.04	0.02
TR-ADEL	0.03	0.48	0.24	0.09	0.06	0.48	0.03	0.17	0.21	0.20
TR-MTH	0.06	0.22	0.10	0.05	0.02	0.22	0.05	0.08	0.11	0.08
AC-JBP	0.09	0.17	0.11	0.10	0.02	0.17	0.09	0.11	0.12	0.04
High	0.09	0.48	0.24	0.10	0.06					
Low	0.03	0.05	0.02	0.05	0.02					
Median	0.03	0.17	0.10	0.06	0.03		Grand Median		0.08	
Average	0.05	0.20	0.10	0.07	0.03		Grand Average		0.10	
Standard Deviation	0.03	0.17	0.09	0.02	0.02					

Table O-b. Phosphate Data (ppm) for April 9, 2002 Storm. Data in shaded cells were used to calculate statistics by sample site.

	9-Apr 12:00	9-Apr 16:00	9-Apr 18:00	10-Apr 11:00	16-Apr Baseline	High	Low	Median	Average	Standard Deviation
AC-RT50	1.70	39.8	18.1	1.83	1.82	39.8	1.70	10.0	15.4	18.0
AC-SHEN	2.50	25.0	14.8	3.18	3.55	25.0	2.50	8.99	11.4	10.7
TR-ADEL	1.88	71.7	27.7	2.28	1.38	71.7	1.88	15.0	25.9	32.8
TR-MTH	1.97	33.2	10.9	1.84	2.44	33.2	1.84	6.44	12.0	14.8
AC-JBP	2.19	25.5	13.9	2.37	2.53	25.5	2.19	8.14	11.0	11.1
High	2.50	71.7	27.7	3.18	3.55					
Low	1.70	25.0	10.9	1.83	1.38					
Median	1.97	33.2	14.8	2.28	2.44		Grand Median		8.99	
Average	2.05	39.0	17.1	2.30	2.34		Grand Average		15.1	
Standard Deviation	0.308	19.2	6.47	0.550	0.822					

Table O-c. Turbidity Data (NTU) for April 9, 2002 Storm. Data in shaded cells were used to calculate statistics by sample site.

	17-May Baseline	26-May 15:30	26-May 17:30	26-May 19:30	26-May 21:30	27-May 17:00	High	Low	Median	Average	Standard Deviation
AC-RT50	1.5	2.2	2.0	1.6	1.7	1.9	2.2	1.6	1.9	1.9	0.24
AC-SHEN	1.3	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	0.00
TR-ADEL	2.5	1.6	3.0	2.3	2.3	2.7	3.0	1.6	2.3	2.4	0.53
TR-MTH	2.0	2.0	2.5	2.5	2.5	2.5	2.5	2.0	2.5	2.4	0.22
AC-JBP	1.8	1.1	2.0	1.7	2.3	2.1	2.3	1.1	2.0	1.8	0.47
High	2.5	2.2	3.0	2.5	2.5	2.7					
Low	1.3	1.1	1.7	1.6	1.7	1.7					
Median	1.8	1.7	2.0	1.7	2.3	2.1		Grand Median		2.0	
Average	1.8	1.7	2.2	2.0	2.1	2.2		Grand Average		2.0	
Standard Deviation	0.47	0.42	0.51	0.41	0.37	0.41					

Table P-a. Nitrate Data (ppm) for May 26, 2002 Storm. Data in shaded cells were used to calculate statistics by sample site.

	17-May Baseline	26-May 15:30	26-May 17:30	26-May 19:30	26-May 21:30	27-May 17:00	High	Low	Median	Average	Standard Deviation
AC-RT50	0.09	0.52	0.28	0.20	0.25	0.05	0.52	0.05	0.25	0.26	0.17
AC-SHEN	0.01	0.02	0.22	0.22	0.21	0.05	0.22	0.02	0.21	0.14	0.10
TR-ADEL	0.05	0.70	0.29	0.32	0.37	0.09	0.70	0.09	0.32	0.35	0.22
TR-MTH	0.05	0.37	0.23	0.25	0.21	0.07	0.37	0.07	0.23	0.23	0.11
AC-JBP	0.02	0.31	0.16	0.29	0.16	0.05	0.31	0.05	0.16	0.19	0.11
High	0.09	0.70	0.29	0.32	0.37	0.09					
Low	0.01	0.02	0.16	0.20	0.16	0.05					
Median	0.05	0.37	0.23	0.25	0.21	0.05		Grand Median		0.23	
Average	0.04	0.38	0.24	0.26	0.24	0.06		Grand Average		0.24	
Standard Deviation	0.03	0.25	0.05	0.05	0.08	0.02					

Table P-b. Phosphate Data (ppm) for May 26, 2002 Storm. Data in shaded cells were used to calculate statistics by sample site.

	17-May Baseline	26-May 15:30	26-May 17:30	26-May 19:30	26-May 21:30	27-May 17:00	High	Low	Median	Average	Standard Deviation
AC-RT50	1.08	135	157	171	80.3	6.63	171	6.63	135	110	67.3
AC-SHEN	2.07	5.94	111	136	65.4	6.40	136	5.94	65.4	64.9	59.3
TR-ADEL	1.02	194	183	346	265	1.89	346	1.89	194	198	128
TR-MTH	1.42	245	120	387	161	2.46	387	2.46	161	183	144
AC-JBP	3.73	186	126	205	156	3.82	205	3.82	156	135	79.4
High	3.73	245	183	387	265	6.63					
Low	1.02	5.94	111	136	65.4	1.89					
Median	1.42	186	126	205	156	3.82	Grand Median			156	
Average	1.86	153	139	249	146	4.24	Grand Average			138	
Standard Deviation	1.12	91.1	29.9	111	79.5	2.19					

Table P-c. Turbidity Data (NTU) for May 26, 2002 Storm. Data in shaded cells were used to calculate statistics by sample site.

	15-Jun Baseline	27-Jun 16:30	27-Jun 18:00	27-Jun 20:00	27-Jun 22:00	28-Jun 11:00	28-Jun 13:00	28-Jun 15:00	29-Jun 16:00	High	Low	Median	Average	Standard Deviation
AC-RT50	2.0	1.8	1.5	1.5	1.5	1.7	1.7	1.8	1.8	1.8	1.5	1.7	1.7	0.14
AC-SHEN	1.6	1.6	1.7	1.5	1.1	1.5	1.5	1.6	1.5	1.7	1.1	1.5	1.5	0.18
TR-ADEL	3.2	2.1	2.1	2.9	2.9	3.1	3.0	3.1	3.0	3.1	2.1	3.0	2.8	0.42
TR-MTH	2.4	2.4	2.3	2.4	2.5	2.0	2.4	2.4	2.2	2.5	2.0	2.4	2.3	0.16
AC-JBP	2.2	1.9	1.9	2.0	2.1	1.9	2.2	2.3	2.2	2.3	1.9	2.1	2.1	0.16
High	3.2	2.4	2.3	2.9	2.9	3.1	3.0	3.1	3.0					
Low	1.6	1.6	1.5	1.5	1.1	1.5	1.5	1.6	1.5					
Median	2.2	1.9	1.9	2.0	2.1	1.9	2.2	2.3	2.2		Grand Median		2.1	
Average	2.3	2.0	1.9	2.1	2.0	2.0	2.2	2.2	2.1		Grand Average		2.1	
Standard Deviation	0.59	0.30	0.32	0.60	0.73	0.62	0.59	0.59	0.56					

Table Q-a. Nitrate Data (ppm) for June 27-29, 2002 Storm. Data in shaded cells were used to calculate statistics by sample site.

	15-Jun Baseline	27-Jun 16:30	27-Jun 18:00	27-Jun 20:00	27-Jun 22:00	28-Jun 11:00	28-Jun 13:00	28-Jun 15:00	29-Jun 16:00	High	Low	Median	Average	Standard Deviation
AC-RT50	0.09	0.32	0.16	0.11	0.06	0.05	0.08	0.03	0.03	0.32	0.03	0.07	0.11	0.10
AC-SHEN	0.06	0.08	0.12	0.09	0.06	0.05	0.06	0.06	0.05	0.12	0.05	0.06	0.07	0.02
TR-ADEL	0.13	0.10	0.01	0.09	0.16	0.07	0.10	0.07	0.06	0.16	0.01	0.08	0.08	0.04
TR-MTH	0.07	0.04	0.03	0.11	0.02	0.08	0.03	0.03	0.06	0.11	0.02	0.04	0.05	0.03
AC-JBP	0.09	0.08	0.05	0.05	0.05	0.06	0.04	0.05	0.03	0.08	0.03	0.05	0.05	0.01
High	0.13	0.32	0.16	0.11	0.16	0.08	0.10	0.07	0.06					
Low	0.06	0.04	0.01	0.05	0.02	0.05	0.03	0.03	0.03					
Median	0.09	0.08	0.05	0.09	0.06	0.06	0.06	0.05	0.05		Grand Median		0.06	
Average	0.09	0.12	0.07	0.09	0.07	0.06	0.06	0.05	0.05		Grand Average		0.07	
Standard Deviation	0.03	0.11	0.06	0.02	0.05	0.01	0.03	0.02	0.02					

Table Q-b. Phosphate Data (ppm) for June 27-29, 2002 Storm. Data in shaded cells were used to calculate statistics by sample site.

	15-Jun Baseline	27-Jun 16:30	27-Jun 18:00	27-Jun 20:00	27-Jun 22:00	28-Jun 11:00	28-Jun 13:00	28-Jun 15:00	29-Jun 16:00	High	Low	Median	Average	Standard Deviation
AC-RT50	3.23	80.2	69.9	11.0	6.03	2.74	1.60	1.64	1.42	80.2	1.42	4.39	21.8	33.1
AC-SHEN	6.12	20.5	77.7	13.9	9.04	10.4	4.61	9.49	4.05	77.7	4.05	9.95	18.7	24.4
TR-ADEL	1.91	32.6	62.1	5.97	2.50	1.45	1.48	1.15	1.43	62.1	1.15	1.99	13.6	22.3
TR-MTH	3.16	23.0	57.8	4.38	2.36	2.36	1.86	1.86	1.89	57.8	1.86	2.36	11.9	19.9
AC-JBP	3.80	280	56.2	7.00	4.97	3.28	1.97	2.42	2.26	280	1.97	4.13	44.8	96.8
High	6.12	280	77.7	13.9	9.04	10.4	4.61	9.49	4.05					
Low	1.91	20.5	56.2	4.38	2.36	1.45	1.48	1.15	1.42					
Median	3.23	32.6	62.1	7.00	4.97	2.74	1.86	1.86	1.89		Grand Median		4.13	
Average	3.64	87.3	64.7	8.45	4.98	4.05	2.30	3.31	2.21		Grand Average		22.2	
Standard Deviation	1.55	110	8.98	3.91	2.77	3.61	1.30	3.48	1.09					

Table Q-c. Turbidity Data (NTU) for June 27-29, 2002 Storm. Data in shaded cells were used to calculate statistics by sample site.

	15-Aug Baseline	15-Aug 15:00	15-Aug 17:00	15-Aug 19:00	15-Aug 21:30	16-Aug 15:00	17-Aug 11:00	High	Low	Median	Average	Standard Deviation
AC-RT50	1.9	1.8	1.7	1.6	1.5	1.4	1.6	1.8	1.4	1.6	1.6	0.14
AC-SHEN	1.3	1.3	1.6	1.5	1.3	1.4	1.3	1.6	1.3	1.4	1.4	0.13
TR-ADEL	2.5	2.3	3.4	2.2	2.4	2.8	3.1	3.4	2.2	2.6	2.7	0.48
TR-MTH	2.0	2.1	2.9	2.0	2.2	2.2	2.2	2.9	2.0	2.2	2.3	0.32
AC-JBP	1.9	1.4	2.5	1.8	1.9	2.1	2.0	2.5	1.4	2.0	2.0	0.36
High	2.5	2.3	3.4	2.2	2.4	2.8	3.1					
Low	1.3	1.3	1.6	1.5	1.3	1.4	1.3					
Median	1.9	1.8	2.5	1.8	1.9	2.1	2.0		Grand Median		2.0	
Average	1.9	1.8	2.4	1.8	1.9	2.0	2.0		Grand Average		2.0	
Standard Deviation	0.43	0.43	0.77	0.29	0.46	0.59	0.69					

Table R-a. Nitrate Data (ppm) for August 15, 2002 Storm. Data in shaded cells were used to calculate statistics by sample site.

	15-Aug Baseline	15-Aug 15:00	15-Aug 17:00	15-Aug 19:00	15-Aug 17:00	16-Aug 15:00	17-Aug 11:00	High	Low	Median	Average	Standard Deviation
AC-RT50	0.03	0.02	0.16	0.06	0.10	0.07	0.02	0.16	0.02	0.07	0.07	0.05
AC-SHEN	0.04	0.05	0.12	0.06	0.04	0.08	0.05	0.12	0.04	0.06	0.07	0.03
TR-ADEL	0.04	0.47	0.28	0.18	0.17	0.16	0.08	0.47	0.08	0.18	0.22	0.14
TR-MTH	0.03	0.04	0.19	0.08	0.15	0.04	0.06	0.19	0.04	0.07	0.09	0.06
AC-JBP	0.06	0.39	0.14	0.08	0.06	0.13	0.08	0.39	0.06	0.11	0.15	0.12
High	0.06	0.47	0.28	0.18	0.17	0.16	0.08					
Low	0.03	0.02	0.12	0.06	0.04	0.04	0.02					
Median	0.04	0.05	0.16	0.08	0.10	0.08	0.06		Grand Median		0.08	
Average	0.04	0.19	0.18	0.09	0.10	0.10	0.06		Grand Average		0.12	
Standard Deviation	0.01	0.22	0.06	0.05	0.06	0.05	0.02					

Table R-b. Phosphate Data (ppm) for August 15, 2002 Storm. Data in shaded cells were used to calculate statistics by sample site.