The Status of Water Quality in the Rivers and Tributaries of the Shenandoah River Watershed

Final Report
(Third Edition)

August, 2007

A paper prepared by Charles Vandervoort of the Friends of the Shenandoah River with the cooperation of the Volunteer Monitors of the Shenandoah River Watershed.

Table of Contents

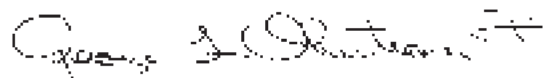
Foreword

In this era of concern over the effects of human population growth and its' concurrent land-use changes, economic development, and even the possibility of global warming, timely information is critical. Everything is changing so fast, people need to know the exact status of where things might have stood at any particular point-in-time. Charles Vandervoort's report, "The State of the Shenandoah River", does just that. It spells out exactly where the Shenandoah River stands in terms of pollution and impairment in the year 2007. It is a compilation of data collected by citizen volunteer water quality monitors. The volunteers have to collect these samples in all kinds of weather and for their efforts we owe them a large debt of gratitude. The samples they collect are analyzed on a bi-monthly basis at The Friends of the Shenandoah River laboratory at the Shenandoah University in Winchester, Virginia. The University has been very helpful in providing lab space to The Friends of the Shenandoah River. The picture that emerges from Charles' hard work is not necessarily a pretty one, but it is a very important one.

Every person wants to feel that they are leaving a "real service" as a legacy and Charles has done just that. He first started these reports as a county-by-county description of the Shenandoah River and its' tributaries as it meanders through each county. This report is the final chapter describing the whole watershed as the river flows north from Waynesboro, Virginia through the Shenandoah Valley to the West Virginia border. It is a true legacy because from now on whenever anybody needs to know exactly what the water quality levels were at this point in time; all they have to do is read Charles' report.

I can't emphasize enough how much I appreciate the effort Charles put in to this report, and I hope everyone who read it will not only realize its' value but also appreciate the work that went into it. I can't thank him enough and I don't think the rest of Virginia can either, but I will try.

THANK YOU CHARLES.



George L. Ohrstrom, II
President
The Friends of the Shenandoah River

Executive Summary

The Shenandoah River is endangered. This has been reported widely in the local press, national newspapers, and by environmental organizations such as American Rivers and the Chesapeake Bay Journal. The causes are high runoff of pollution from farms and urban areas, as well as over-burdened sewage treatment plants. Fish-kills are an immediate and severe problem.

The purpose of this report is to explore the extent and nature of the problems, where they are occurring, the causes of the pollution, what can be done to alleviate the deterioration, and to list the factors that help or hinder progress.

Important tools in this research are the database on water quality of the Shenandoah River compiled over more than ten years by the Friends of the Shenandoah River (FOSR) and its cooperating partners, and the availability of highly qualified and scientifically trained members of private watershed organizations.

With support from the Robbins Foundation, the FOSR since 2002 has prepared a number of reports on the health of the river for each county in the Shenandoah River Watershed. This report updates those reports and addresses the water quality in the entire Shenandoah Valley.

One of the first tasks in the preparation of this report was that of defining appropriate standards or criteria for objectively evaluating water quality for the six water quality parameters analyzed in this report. These parameters include nitrate-nitrogen (referred to as nitrogen), ortho-phosphate (referred to as phosphorus), total ammonia consisting of NH_3 and ammonium ion NH_4^+ (an analytically distinct form of nitrogen referred to as ammonia), pH, turbidity, and dissolved oxygen..

For the purpose of this report criteria were developed to provide a quantitative and thoughtfully derived measure of the impact of a particular concentration of each parameter such as, for example, nitrogen on (1) eutrophication, and (2) the health of fish and other aquatic life. These criteria enabled classification of water in the rivers, tributaries, and effluent of STPs into three categories: unimpaired, impaired, and severely impaired. The task of developing these criteria from basic principles, of course, was far beyond the resources of the FOSR and supporting organizations. Instead, the criteria were based on an extensive review of existing criteria developed by authorities such as the EPA, VA DEQ, state and county water control organizations, academic institutions, and other organizations involved in water quality research and regulating water quality.

It was found that many sections of the rivers and their tributaries were highly polluted. Nitrogen concentration increased from 1.0 PPM (impaired) in 1997 to 1.5 PPM (borderline severely impaired) in 2006. Turbidity increased from 4.4 NTU (impaired) to 20.8 NTU (very severely impaired) over that same time period. This finding supports the statement that the Shenandoah River is endangered, and that if these trends continue unchecked, the Shenandoah River could become even more polluted.. With the overall river already heavily polluted for more than ten years, phenomena such as the fish kills and eutrophication of the Chesapeake Bay come as no surprise.

We looked at specific locations and found nitrogen concentration highest in the North Fork and North River. Turbidity is highest in the Middle River.

The pollution levels described above are average levels, and parts of the River, of course, have pollution levels above and below the average. We found that the nitrogen concentration in 2006 covered a wide range from the unimpaired (see definition in Appendix C) 0.2 PPM (on the North River in its upper reaches where it originates in the highlands) to the highly impaired 3.0 PPM (at a site in Rockingham County that has a high density of poultry and dairy farms as well as a major regional wastewater treatment facility). The average nitrogen pollution in the five River sites with the highest nitrate concentrations was 2.6 PPM (severely impaired). The average nitrogen pollution in tributaries was 4.6 PPM, also severely impaired. The tributaries are more polluted with nitrogen than the main branches of the Shenandoah River consisting of the North River, South River, Middle River, North Fork, South Fork, and Main Stem.

During 2006, the turbidity levels in the rivers ranged from 1.0 to 60.1 NTU. At the five sites with the lowest turbidity, the average turbidity was 5.8 NTU (impaired), and ranged from 1.0 to 8.5 NTU. The five sites with the highest turbidity the average was 46.0 NTU (severely impaired), and ranged from 28.0 to 60.1 NTU. These turbidities are extremely high. Furthermore, the average levels may be underestimated because most of the turbidity occurs during and shortly after rain storms that can occur at times where there is no scheduled monitoring. High turbidity is correlated with processes that reduce the amount of dissolved oxygen in water, and could impose severe stress on fish and other oxygen dependent forms of water life.

A major source of pollution is the runoff from urban and agricultural areas during periods of heavy precipitation. The runoff contains nutrients, sediment, and noxious substances that are harmful to fish that, unless the streams are protected by vegetated or forested buffer zones that absorb the runoff, will flow directly into the river and their tributaries.

In addition to the runoff caused by precipitation, pollution – especially sediment – can also come from poorly engineered development projects that disturb land without adhering to best management practices (BMPs) aimed at preventing exposed soils from washing away. And cattle often contribute to stream bank erosion and grind up stream beds when securing drinking water or seeking shade.

Point source pollution, as the name implies, is pollution that comes from specific points along the River and its tributaries. A typical point source is a permitted effluent pipe from a municipal sewage treatment plant (STP). Another important point source is an effluent pipe that discharges permitted but only partly treated factory waste into the water. The location of most of these point sources is well known, and waste water from sewage treatment facilities and industrial polluters was reduced substantially under the terms of the Federal Clean Water Act of 1972. Although this act had a beneficial effect by reducing pollutant loads in waste water, the cost of improving the cleanliness of water is high, and will be substantially higher as tougher standards prove necessary.

An uncertain number of point sources, especially in rural areas, are straight discharge pipes of raw sewage from toilets, kitchens, and other sources of household waste that lead directly from the house or farm to the river. These are illegal but, partly because of lack of county and state personnel to find them and enforce requirements, are hard to control.

We will summarize here some of the areas where progress is being made, and areas where progress is slow.

Factors helping progress in improving water quality.

1. As part of the multi-state agreement of 2000 related to cleanup of the Chesapeake Bay, Virginia now requires all wastewater treatment plants of 500,000 gallons or more daily capacity to upgrade their discharges to achieve average discharges of no more than 4 mg/l of total nitrogen and 0.2 mg/l of phosphorus under a nutrient "cap" which is designed to result in satisfactory conditions in the Bay by 12/31/2010. Smaller treatment facilities also have tougher standards to meet and come under the "cap."
2. Virginia is providing substantial funding to Soil and Water Conservation Districts in the Chesapeake Bay watershed (of which the Shenandoah River is an important part) to help in reducing non-point sources of pollution from agriculture. At the same time, State Government is proceeding with what is called a TMDL. This program was established under the Federal Clean Water Act of 1972 and is designed to reduce pollutants reaching all rivers and tributaries in the State to levels which are acceptable for the health of aquatic life and human body contact recreation.
3. Conversion of forest land to agricultural and urban development use is slowing down: Deforestation to create new agricultural land seems to be at an end. Communities are putting tighter regulations on the amount of deforestation that can take place by both limiting development in mountainous areas, stipulating the minimum lot size in wooded zones, and by stepping up public education efforts to teach people about the value of trees and shrubs.
4. Public Appreciation of the Shenandoah River is growing: Greater attention by the media to the problems of the Shenandoah River may motivate private citizens to urge their public representatives to spend more time on developing plans to reverse the adverse trends. Partly due to the severe problem with the fish kills, media in the local area and as far away as Washington DC are devoting significant newspaper space to informing the public on the status of the river. And the appointment of a full-time "river keeper" (Jeff Kelble) who stays informed and implements action on issues such as excessive sedimentation and nutrients, fish-kill and other issues, is doing a great job informing the public on the status of the river, and on how they could volunteer some of their time to help.
5. Movement towards collaborative partnerships among watershed organizations is increasing. There are dozens of organizations such as the FOSR, the Friends of the North Fork of the Shenandoah River, the Shenandoah Valley Pure Water Forum, the Valley Conservation Council, to mention just a few, that are collaborating with state and federal government in controlling point and non-point pollution. Addressing these problems is putting a severe strain on the financial, volunteer, and staff resources of the numerous federal, state, local government agencies, quasi-government agencies, and nonprofit watershed organizations that are collaborating, or want to collaborate. To make these resources more effective, part of the solution is to pool resources and expand collaboration among these organizations.
6. Advances in Regional Water Resources Water Planning: In 2002 a (RWRPC) committee was created for the Shenandoah Valley in response to a 2003 state mandate requiring either local or regional water supply plans by 2011. This RWRPC is led by local elected officials, but is a stakeholder inclusive group including the FOSR and other nonprofit watershed organizations. The RWRPC employs a total watershed approach to their task by assessing and including social, economic, political, and ecological factors in an attempt to comprehensively address the water quantity and quality issues facing the Shenandoah Valley. Through an extensive process involving numerous stakeholder meetings throughout the Shenandoah Valley, as well as a Valley wide stakeholder survey, RWRPC has now identified six primary goals and supporting strategies, which have been combined into an action plan for water quality and quantity conservation in the Shenandoah. This development of the plan and the success in achieving collaboration among the numerous stakeholders involved can be considered a successful attempt at addressing the valley's water quality and quantity problems.

Areas hindering progress

Growing urbanization and slow adoption of measures for environmentally friendly development: As reported in American Rivers, the population of the Shenandoah Valley is soaring and agricultural land is being replaced by urban and suburban development. This rapid growth leads to more roads, parking lots, and roofs and other impervious surfaces preventing rain from soaking into the ground. The resulting runoff water carries with it lawn fertilizer and other pollutants that feed into tributaries and rivers.

Inadequate enforcement of environmental laws controlling erosion: Almost all communities in the Shenandoah Valley have adequate laws to control soil erosion. Plans must be approved and during construction the project is subject to inspection to ensure that the plan is properly implemented. Unfortunately, frequent inspection is very difficult because of too few trained inspectors that are knowledgeable on what soil erosion is, and how it is controlled. This, as we probably all know, is symptomatic in law enforcement.

Lack of public and private sector understanding of what the environment is worth: There are many ecosystems such as forests, rivers, grass lands, that provide real services but that are not measured in traditional markets. Forests, for instance, provide climate regulation, control erosion, absorb carbon dioxide, generate oxygen, provide recreational opportunities, etc. But the private owners cannot directly capture that value, so why should they invest in the environment? For example, a farmer who invests in installing a riparian buffer and thereby reduces the amount of nutrient spilling from his land into the river does not capture this benefit. Of course, he benefits indirectly from the improvement in environment, although he probably does not perceive it, and it does not mean more money in his pocket. There are scientific techniques that can make the economic benefits of improving or the disbenefits of degrading the environment explicit to farmers, developers, or households, but such measures are not easy to make operational.

Action Priorities

Cleaning up the waters and reversing the increasing trends in pollution in the whole Shenandoah River Watershed will require a large amount of time, money, and effort. Over the short term, however, one cannot go wrong in concentrating on focusing on the worst problems. Judging from their high levels of pollution and increasing trends of deterioration, suggested short term action priorities would include:

1. Clean up the two most impaired rivers: North River and the North Fork.
2. Clean up the seven most impaired tributaries at: Muddy Creek – North River (JR01), Pleasant Run – North River (JR10), Long Glade Creek – North River (JR06), Cooks Creek – North River (JR07) , Mill Creek – Page County (FP13), Christians Creek – Augusta County (GA290, and Wheat Spring Branch – Clarke County (FC32).
3. Review permits to achieve possible reductions for nitrogen and turbidity for the effluents of the STPs: Boyce STP – Clarke County (FC31), Toms Brook – Shenandoah County (NS05), Edinburgh STP – Shenandoah County (NS28), and Berryville STP – Clarke County (FC07).

Acknowledgments

Water quality assessments in this report were made possible by volunteer work, non-cash contributions, and funding from:

- Robbins Foundation
- Ohrstrom Foundation
- The volunteer monitors Clarke, Shenandoah, Warren, Page, Rockingham, Frederick, and Augusta counties.
- Friends of the North Fork of the Shenandoah River.
- River Network, Canaan Valley Institute, and Izaac Walton League
- Governments of Clarke, Shenandoah, Warren, Page, Rockingham and Augusta counties
- Virginia Environmental Endowment (VEE)
- Virginia Department of Environmental Quality (DEQ)
- National Fish and Wildlife Foundation (NFWF)
- Chesapeake Bay Small Watershed Grant
- Chesapeake Bay License fund
- Pure Water Forum
- Environmental Protection Agency (EPA)
- Virginia General Assembly
- James Madison University
- Shenandoah University
- Members of the Friends of the Shenandoah River (FOSR)

I would like to extend special thanks to the many members of the FOSR and other watershed organizations who contributed to this report. Dick Marzolf of the FOSR read an early draft, provided comments on the organization of the report, and made valuable contributions to the content of the report. Bob Luce and Meryl Christiansen of the FOSR prepared the sections of the report on fish kill and mercury pollution. Gary Lauben, the FOSR webmaster prepared the overview map of the Shenandoah River Watershed showing the monitoring locations. Bud Nagelvoort of the FOSR and chairman of the Lord Fairfax Soil and Water Conservation District, provided valuable insights on the impact of the Federal Clean Water Act of 1972 on point source pollution. And Leslie Watson of the Friends of the North Fork of the Shenandoah River provided constructive and far-sighted insights on the need and opportunities for building collaborative partnerships among the many community watershed organizations in the Shenandoah River Watershed. Finally, I would like to thank the Ohrstrom and Robbins Foundation for funding the costs of printing and publishing this and earlier FOSR reports.

1

Introduction

Purpose

The American Rivers organization reported last year that the Shenandoah River is the 5th most endangered river in the Unites States. Although many of us already knew that the Shenandoah River had problems with excessive nutrients, and that there is now an even larger problem of big fish kills, this news still came as a shock. There is a dearth of quantitative data however, enabling pinpointing where the problems are occurring, and developing estimates of the magnitude and trends of the problems. Therefore, the purpose of this report is to:

- Assess and provide quantitative information on the health, with regards to nutrient and chemical pollution, of the Shenandoah River and its tributaries in the Shenandoah River Watershed by:
  - Identifying the levels and trends in six water quality parameters consisting of nitrogen, phosphorus, ammonia, pH, turbidity, and dissolved oxygen, over the past ten years.
  - Developing and suggesting criteria for evaluating those levels of the parameters of nitrogen, phosphorus, ammonia, pH, turbidity, and dissolved oxygen that could cause eutrophication and harm to aquatic life.
  - Identifying and ranking the rivers, tributaries, and STPs in accordance with the above criteria.
- Discuss qualitatively the possible causes of excessive levels of nutrient and chemical pollution.
- Discuss the types of actions that are currently being taken to address problems with the river, the areas where progress is being made, and areas where progress is slow.

Background

The Friends of the Shenandoah River is a citizen organization engaged in applying scientific principles in researching and monitoring water quality by collecting water samples in the rivers, tributaries, and STPs in the Shenandoah River Watershed, analyzing these samples in a certified laboratory, maintaining the results in a comprehensive database accessible to the public, and reporting and analyzing the results.

The FOSR and supporting organizations monitor the whole Shenandoah River Watershed as outlined on Map 1-1.

In 2006 the monitoring program included a total of 102 sites shown as small purple rectangles on Map 1-2. Of these, 27 sites sampled river water, 67 sampled water from tributaries, and 8 sampled the effluent of Sewage Treatment Plants (STPs).

What we hope to accomplish in this report is to quantify to what extent and where the rivers and tributaries are polluted, to suggest what the causes might be, and to outline the actions that need to be taken to alleviate the degradation of the river. The FOSR are well positioned to address these tasks because, with their own volunteer monitors and the collaboration of the many other volunteer monitoring groups in the watershed, it has established a comprehensive data base for water quality that goes back to 1997.

The first chapters look at the overall levels of pollution in the rivers and tributaries of the Shenandoah River. Then the probable reasons for the pollution are discussed, and some of the measures that can and should be taken to alleviate the degradation of the water are described. Finally, prospects are analyzed for halting or reversing the degradation of the river. The report also includes a special section on the fish kills, and on mercury contamination in the South River.

Map 1-1
Outline of Shenandoah Watershed within the Potomac Watershed

Map 1-2
The Shenandoah River Watershed and Monitoring Sites

Methodology

The methodology section described in more detail in the appendix discusses the following:

1. How the sampling sites were selected. The challenge of this task was to ensure, to the extent possible, that the measurement of the water quality parameters provided an unbiased estimate of the health of the surface waters in the Shenandoah River Watershed.
2. Description of the six water quality parameters monitored by the FOSR and supporting organizations, and the process for selecting the criteria for quantitatively indicating their impact on water quality. Of primary importance was the impact on stimulating eutrophication, and on adversely affecting the health of fish and other aquatic life. The criteria were developed from a comprehensive survey of the literature published by organizations engaged in protecting and improving surface water quality, and involved in assessing and regulating surface water quality. These included Federal, State and local governments; universities, foundations, and community watershed organizations.
3. Discussion of the FOSR laboratory located in the Shenandoah University, and the methods for controlling the quality of the data collected by the monitors, and the laboratory analysis of the data.

Water Quality Criteria

One of the first tasks in the preparation of this report was that of specifying criteria for objectively evaluating water quality for the six water quality parameters analyzed in this report. These parameters include nitrate-nitrogen (referred to as nitrogen) and measured as parts per million (PPM) or, what is the same, milligrams per liter; ortho-phosphate (referred to as phosphorus) and also measured in PPM; total ammonia consisting of NH3 and ammonium ion $NH4^{+}$ (referred to as ammonia) and also measured in PPM; pH which measures acidity of the water and is measured in logarithmic units; turbidity which is measured in nephelometric turbidity units; and dissolved oxygen measured in PPM and referred to as oxygen.

For the purpose of this report, the emphasis in developing these criteria was to provide a quantitative and thoughtfully derived measure of the impact of a particular concentration of each parameter such as, for example, nitrogen on (1) eutrophication, and (2) the health of fish and other aquatic life. We developed water quality criteria, for each water quality parameter, for identifying unimpaired, impaired, and severely impaired water.

The task of developing these criteria starting from basic principles, was, of course far beyond the resources of the FOSR and supporting organizations. Instead, the criteria (see Table 1-1) were based on an extensive review and adaptation of existing criteria developed by authorities such as the EPA, VA DEQ, state and county water control organizations, academic institutions, and other organizations involved in water quality research and regulating water quality.

Table 1-1: Suggested Criteria for Water Quality

	Nitrogen, ppm	Phosphorus, ppm	Ammonia, ppm	pH	Turbidity, ntu	Oxygen, ppm
Not Impaired	< =0.75	<=0.05	<=1.0	6.5 to 8.0	0 to 4.0	> 5
Impaired	0.75 to 1.5,	0.05 to 0.1,	1.0 to 10.0,	5.0 to 6.5	4.0 to 7.0	2 to 5
Severely Impaired	> 1.5	>0.1	>10.0,	>8.0 or <5,	>7	< 2

Findings

In the year 2006, the rivers were severely impaired by turbidity in all the counties in the Shenandoah Valley. For example, and as shown in the next chapter, the average turbidity in the rivers for each of the counties ranged from 7.7 NTU (Clarke County) to 32.6 NTU (Rockingham County). It is not surprising that the Shenandoah River was classified by the American Rivers organization as the 5th most endangered river.

The rivers were also severely impaired by high nitrogen in 2006 in Rockingham County and Shenandoah County. The rivers in Augusta, Clarke, and Warren Counties scored a little better because the pollution levels of their rivers were one notch lower, but still at the impaired level.

Average levels of the other four parameters of phosphorus, ammonia, pH, and dissolved oxygen in the rivers were slightly better: they were only somewhat impaired for a few counties, but never severely impaired.

The tributaries were also highly polluted, but not to the same extent as the rivers. Rivers in Warren, Clarke, and Rockingham Counties were severely impaired with nitrogen, with rivers in Page and Shenandoah Counties less impaired, and the Warren County tributaries were not polluted with nitrogen. Turbidity was at the severely impaired level for Augusta, Clarke, and Rockingham Counties. Turbidity in the remaining three counties was at the impaired level. Average levels of phosphorus, pH, dissolved oxygen, and NH_4 were generally at the unimpaired levels for tributaries.

Overall Trend: The previous section discussed water quality at a specific point of time, the year 2006. This section looks at an equally or perhaps more important measurement of water quality, and that is how water quality varies over time, i.e., the trend.

It was found that the trend in nitrogen and turbidity pollution in the rivers is increasing at levels that exceed population growth and economic growth in the valley. In 1997 the nitrogen levels in about half of the river samples taken that year were unimpaired. By 2006 only 13 percent of the rivers had unimpaired levels of nitrogen. Thus, pollution increased significantly between 1997 and 2006. Statistical analysis indicates that the average concentration of nitrogen in the rivers gradually increased at a rate of about 3.4% percent per year.

The increase in nitrogen concentration in the tributaries from 1997 to 2006 follows a similar pattern. In 1997, 58% of the total number of samples taken that year was unimpaired. By the year 2006, however, the number of unimpaired samples had dropped by half to 31%. The trend for nitrogen concentration in the tributaries is more than 4% per year.

For turbidity, 67% of the total number of river samples taken in 1997 were unimpaired. By 2006 the turbidity had increased substantially, and the number of unimpaired samples had dropped to 38%. The average annual increase over the 1997 – 2006 time period for average turbidity in the rivers was 8%. This is very high and far exceeds the rate of population and economic growth in the valley.

Much of the increase in turbidity took place during the last three years from 2004 - 2006. The trend for turbidity in the tributaries at 8.4% was also very high, and was also caused mostly by the sharp jump in turbidity over the last three years. This is something to worry about and at this time there is no simple answer why turbidity is so high and has started increasing.

The average nitrogen concentrations reported at monitoring sites vary widely, and depend on a large number of factors including, we believe, most importantly the type of landuse of the terrain through which the stream flows. For example, and as shown in Figure 4-1 on page 23 there is a wide variability of the results for average nitrogen concentration reported at each of the monitoring sites in 2006. In that figure the nitrogen concentrations are ranked in order of increasing concentration. The site with the lowest concentration of 0.2 PPM is GA37 (a site on a the North River in Augusta County located on a forest road in the unperturbed highlands), and the site with highest concentration of 3 PPM is JR09 (a site also on the North River but in Rockingham County, and flowing through agricultural land). Chapter 5 of this report illustrates a few of the relationships between landuse (such as forest, agricultural, urban) and concentration of the water quality parameters through which a stream flows

2

Overview of Water Quality in Rivers, Tributaries, and STPs in the Counties of the Shenandoah River Watershed

This chapter presents an overview, by county, of the current status and the trends in water quality in the Shenandoah River Watershed. Later chapters go into considerably more detail by analyzing the average water quality for each of the five major river section in the Shenandoah River system, and consisting of the Main Stem, North Fork, South Fork, North River,, South River, and Middle River)

A: Water Quality by County in 2006

Table 2-1 shows the average water quality in the rivers, the tributaries, and the outfalls of sewage treatment plants (STP) for each of the six counties during 2006. The average[1] was calculated for 27 sampling sites on the rivers, 67 sampling sites on the tributaries, and 8 sites where samples are taken from the effluent of the STPs.

The table shows that the major problems in the rivers and tributaries are high concentrations of nitrogen and turbidity. For many of the counties, these concentrations are often severely impaired for the year 2006.

Table 2-1: Current water quality in the rivers, by county, year 2006

	Average Concentration in Rivers, Year 2006						
Averages	Augusta	Clarke	Page	Rockingham	Shenandoah	Warren	Grand Average
Nitrate PPM	1.26	1.12	1.51	2.48	1.93	1.20	1.51
Ortho Phos PPM	0.05	0.03	0.05	0.08	0.08	0.04	0.06
Amm PPM	0.05	0.03	0.07	0.05	0.04	0.04	0.05
pH	8.07	8.67	8.30	7.84	8.37	8.25	8.18
Turbidity	18.60	7.71	31.75	32.63	16.22	29.39	20.61
DO mg/L	9.11	9.71	9.92	9.24	9.70	9.39	9.37

	Average Concentration in Tributaries, Year 2006						
Average	Augusta	Clarke	Page	Rockingham	Shenandoah	Warren	Grand Average
Nitrate PPM	1.70	2.13	1.23	2.99	1.10	0.33	1.68
Ortho Phos PPM	0.05	0.02	0.04	0.10	0.01	0.02	0.05
Amm PPM	0.06	0.02	0.05	0.07	0.04	0.02	0.05
pH	8.15	8.46	7.90	8.31	8.02	7.77	8.10
Turbidity	29.15	12.00	4.89	30.72	5.14	4.80	17.19
DO mg/L	9.42	9.64	10.05	9.01	9.69	10.21	9.63

	Average Concentration in STPs, Year 2006				
Average	Clarke	Page	Shenandoah	Warren	Grand Average
Nitrate PPM	26.16	5.77	12.06	1.19	11.85
Ortho Phos PPM	6.90	1.50	3.16	0.04	3.08
Amm PPM	3.60	0.35	1.23	0.05	1.32
pH	8.18	7.60	7.71	8.26	7.82
Turbidity	6.43	3.46	7.05	24.66	8.03
DO mg/L	7.91	5.08	6.88	9.30	6.88

Legend	
Unimpaired	(green)
Impaired	(yellow)
Severely Impaired	(red)

1. Note that this "simple" average gives equal weight to samples taken from all tributaries, rivers, or STPs, whether the flow is large or small. This will tend to provide a different estimate of the "true" average that would resulted from calculating a weighted average. Further details are discussed in the methodology section of the report.

Unlike the concentrations for nitrogen and turbidity, however, the concentrations of phosphorus, ammonia, pH, and dissolved oxygen, although sometimes impaired, are never severely impaired. Therefore, although we analyze all of these water quality parameters in this report, we place stronger focus on nitrogen and turbidity because of the severely impaired levels they can reach. And as is well known nitrogen and turbidity are major causes of eutrophication

Rivers in half of the counties – Page, Rockingham, and Shenandoah – had average nitrogen levels that indicated severe impairment (red). Rivers in the other three counties had nitrogen levels indicating they were impaired (yellow) – none of the rivers had average nitrogen concentrations that were unimpaired.

Average turbidity in the rivers was at the severely impaired level for all six counties. Since, by definition, actual values will exceed the average about 50% of the time, nutrient levels at times can be at the high end of severe impairment.

For the tributaries, both the average nitrogen and turbidity concentrations in Augusta, Clarke, and Rockingham counties were severely impaired. But, as for the rivers, the average concentrations of phosphorus, ammonia, pH, and dissolved oxygen were generally unimpaired,

Regarding the effluent from sewage treatment plants (STPs), the impairment levels for some of the water quality parameters were high. Except for pH and dissolved oxygen which were at unimpaired or at very low levels of impairment for the STPs of all six counties, the other parameters were all impaired or highly impaired, and at concentrations that are far above those found in the rivers and tributaries. This is because STPs must purify, to the extent possible, highly polluted wastewater – a costly process. The permitting process therefore allows high concentrations in the effluent of STPs as long as the contamination of the river or tributary water does not exceed certain concentrations calculated under the Total Maximum Daily Load (TMDL) process.

Nevertheless, although these pollutants are diluted many thousands of times by the rivers and tributaries into which their outfall flows, the TMDL process is not perfect, and effluents of STPs can contribute significantly to river and tributary water pollution.

In general, the high concentrations of nitrogen and turbidity in the rivers during 2006 are worrisome. Averaging over all the counties (the grand average column in the table), nitrogen pollution for the year 2006 in the rivers was severely impaired for nitrogen (1.51 PPM), and even more severely impaired in the tributaries (1.68 PPM). The reason for this 11% difference is not known, but it could be caused by the fact that river water is diluted by "clean" groundwater whereas tributaries perhaps contain mostly surface runoff.

The grand average for turbidity for the year 2006 in the rivers was 20.62 NTU. This compares to 17.19 NTU for the tributaries, a 17% decrease.

B: Water Quality in 1997 compared with 2006

The earlier table we studied shows a snapshot of water quality for each county and for the year 2006. An indication of the deterioration in water quality between 1997 and 2006 for nitrogen pollution is shown in the two pie charts in Figure 2-1.

In 1997, only 7% of the monitoring sites taking samples from the rivers recorded severely impaired levels of nitrogen pollution, 39% reported the nitrogen pollution was fair, and more than

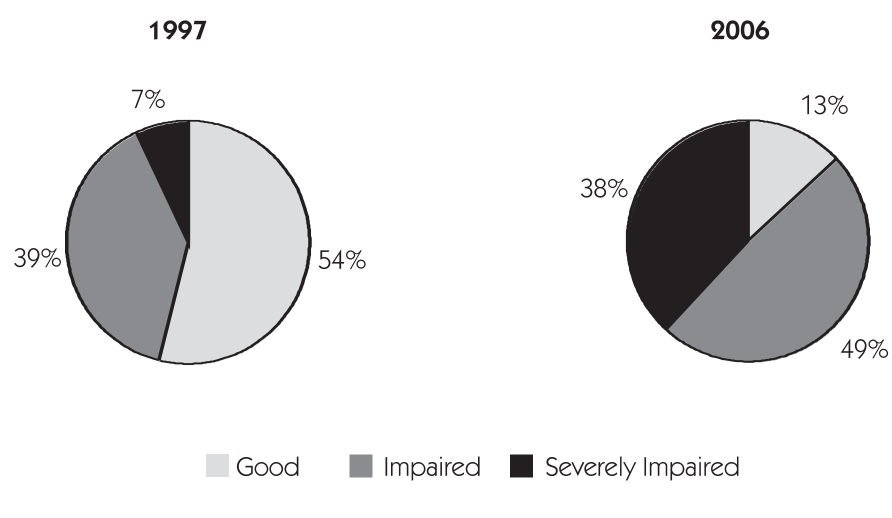


Figure 2-1
Change in Nitrate - Nitrogen Concentration in Rivers, 1997 and 2006

half the sites (54%) reported the water was unimpaired. The grand average over all the counties for nitrogen in 1997 was 1.04 ppm.

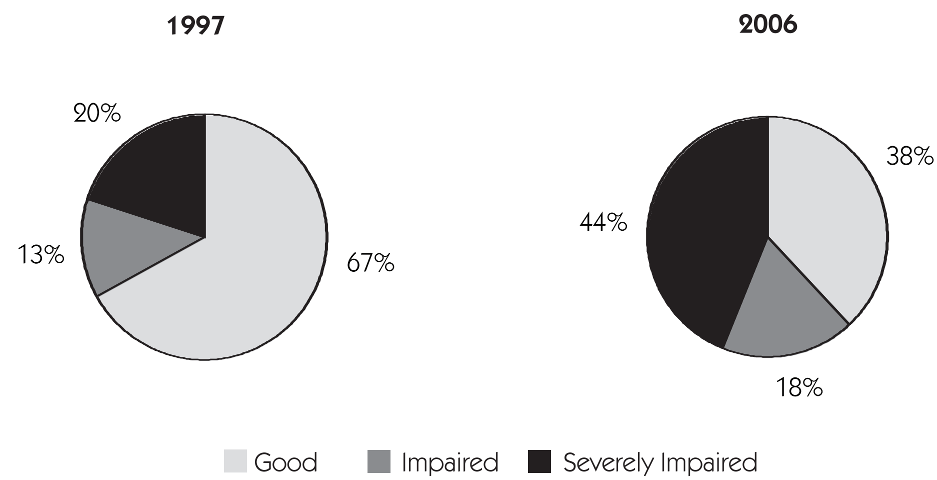
By the year 2006 the situation had changed drastically; the samples recording severely impaired nitrogen pollution had increased from the 7% in 1997 to 39% by 2006. Similarly, the percentage of sites that reported the river water was in impaired condition had increased a little from 39% to 49%, and the sites reporting unimpaired river water had dropped from 54% to only 13%, a considerable drop.

The increase in nitrogen concentration in the tributaries from 1997 to 2006 follows a similar pattern. In 1997, 58% of the total number of samples taken that year were unimpaired (i.e., concentrations lower than the EPA standard), 30% were impaired (concentrations higher than the EPA standard), and only 12% were severely impaired. By the year 2006, however, the number of unimpaired samples had dropped by half to 31%, the number of impaired samples had dropped somewhat to 22%, but the percentage of severely impaired samples had quadrupled 48%; almost half of all the tributaries that were sampled.

For turbidity, (see Figure 2-2) 67% of the total number of river samples taken in 1997 were unimpaired, 13 % were impaired, and 20 % were severely impaired. By 2006 the turbidity had increased substantially. The number of unimpaired river samples had dropped to 38%, the impaired samples stayed almost the same at 18%, and the severely impaired samples had more than doubled to 45%.

In summary, from 1997 to 2006, there was a significant deterioration in water quality. In the next chapter we will we will take a much more detailed look at this adverse trend by including all the years between 1997 and 2006. We will see that there has been a steady and statistically significant rise in nitrogen concentrations and turbidity since 1997.

Figure 2-2
Change in Turbidity in Rivers, 1997 and 2006



3 The Trends in Water Quality

In this chapter we will estimate the trend of pollution in rivers, river sections, and tributaries by including all the data available between 1997 and 2006 – not just the first and last year of record. (We will also include some data from the VA DEQ) These calculations will also include the statistical significance of the trend, an important calculation because of the large amount of "scatter" in the data. The statistical significance calculation will tell us whether or not the trend is real (was it statistically significant), or whether the trend was not significant and could not be isolated from the random scatter of points (the variation due to chance).

Trends at the aggregate level where it is calculated for all the rivers combined, and all the tributaries combined were significant for nitrogen and turbidity. Trends at the aggregate level could not be clearly established for phosphorus, ammonia, pH, and dissolved oxygen.

After establishing the overall trends in water quality and their validity, we then in Chapter 4 move away from grand averages, and start focusing on individual sites. As we shall see, the quality of water changes significantly depending on which site is selected. Finally, we will investigate what could be causing the differences in water quality among sites.

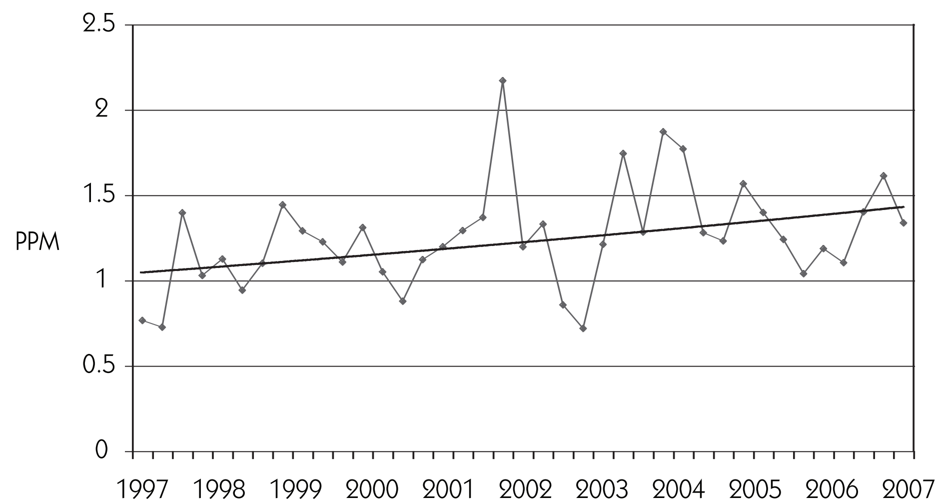
A: Trend for Nitrogen in Rivers and in Tributaries

Trend for Nitrogen in Rivers

Figure 3-1 shows the average nitrogen concentration averaged by year and quarter for the combined total average for all the river sections of the Shenandoah River Watershed, and for all the years between 1997 to 2007. Averaging the data by year and quarter provides a "smooth" line, and this makes it easier to see the trend (if any) and also provides some insight on seasonality. For the case of nitrogen there seems to be some seasonality in that nitrogen levels often peak in the summer. A linear trend line[2] is estimated and shown on the graph.

The trend line shows that, ten years ago, in 1997, the average nitrogen concentration in the rivers in the Shenandoah River Watershed already was above 0.75 ppm; the level where it starts to contribute

Figure 3-1 Smooth Plot of Nitrogen Trend in the Rivers, 1997 - 2006



2. An exponential growth trend line gives slightly higher correlation, but requires more computational effort. In addition, the growth projections from exponential projections are rather wild, and we decided to stick to the more conservative linear growth projections.

to high algae growth, and to eutrophication in the waters downstream. The latter is especially important because of its impact on the Chesapeake Bay (see below).

As the trend line shows, the concentration increased at an annual growth rate of about 3.4% and by 2000 was above the impaired level. By 2007 the average concentration of nitrogen was at about 1.5 ppm – just above the severely impaired level.

The rate at which overall nitrogen pollution in the rivers is growing is surprising and serious. The implication of this trend is that, if urbanization and industrial development continues as in the past, and if efforts to control nutrients in the river are not intensified and made more effective, we can expect a doubling of nitrogen pollution every 20 years. If urbanization and development of the Shenandoah Valley grows at rates higher than expected, as they seem to be doing, nitrogen pollution could double even faster.

Unless reduced or at least stopped, the consequences especially with regard to the Chesapeake Bay with its problems with "dead zones" (the Chesapeake Bay Foundation defines a dead zone as one where oxygen levels are less than 1.0 ppm) have been very serious for some time. As stated by the Chesapeake Bay Foundation in their May 19, 2005 newsletter:

> *"In 2004, the Bay's dead zone covered more that 35% of the volume of the Chesapeake's main stem, rivaling last year's near record "dead zone" and harming and killing fish, crabs, and other living organisms. Pollution from sewage and agriculture is the major culprit."*

Although Figure 3-1 provides a good estimate of the trend for nitrogen pollution averaged over all the rivers.[3] We can get a more precise estimate of the trend by applying the statistical analysis to all the data collected between 1997 and 2006. The results are shown in Figure 3-2.

Each point on the graph gives the nitrogen concentration in PPM for a given site on a given day between 1/1/1997 and 1/5/2007. For example, the highest concentration of 9.2 PPM occurred on 6/5/1999; this sample was taken from the North River at site JR11 in Rockingham County (see Table 9-1: List of Site Names (abbreviated) and Coordinates,) The second highest concentration of 8.0 PPM occurred on 7/28/2001, again at the JR11 site. The point of drawing attention to these "outliers" is to show that they exist, and to draw attention not to be misled by "averages." High outliers, such as for ammonia, are stressful and can kill fish. And low outliers, such as for oxygen, can do the same

The result of plotting all these observations is a complicated graph containing about 4,500 points, and shows the large amount of scatter that is so characteristic of environmental phenomena where influencing factors can not be controlled. The "scatter" or "noise" is caused by the large number of factors, many of which are sometimes totally, and often somewhat beyond our control (weather, human

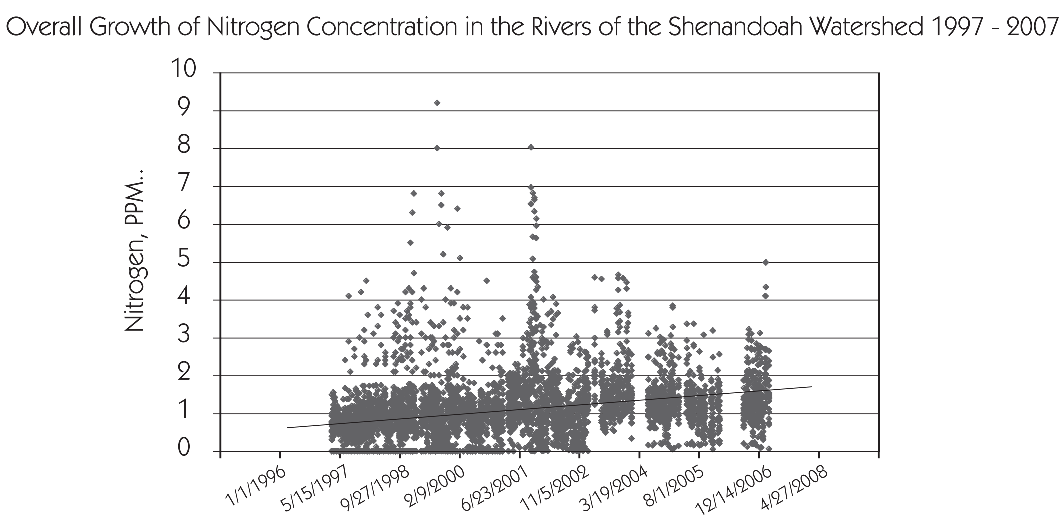


Figure 3-2
Scatter Diagram of Nitrogen (PPM) in the Rivers, 1997 - 2007

3. The rivers include the Main Stem of the Shenandoah, North Fork of the Shenandoah, South Fork of the Shenandoah, the North River, and the South River, and the Middle River.

activities, farming practices, etc.) that all vary randomly,[4] and that influence water quality. This scatter or noise in the data is a common problem in environmental analysis. Fortunately, advances in computer technology and development of powerful statistical analysis packages have made possible the detection of the true signals among all the accompanying noise. This enables us to isolate the trend from all the scatter and to be able to make definitive statements about the significance of the trend, the reliability of the trend parameters, and most importantly to provide reasonably accurate estimates of the rate of increase of nitrogen and other pollution over the past ten years.

At first glance the figure does not seem to show much information, although it is quite evident the average nitrogen concentration seems to be well above 1.0 ppm for the whole 10-year period, and that there seems to be a slightly increasing trend in nitrogen pollution.

The statistical techniques[5] show that:

- There is a statistically significant trend in the growth of nitrogen.
- Each year we can expect that, with a 95% level of confidence and assuming the environmental variables (population growth, urbanization change, weather, level of effort and effectiveness of environmental programs, etc.) stay the same, the overall annual average of nitrogen in the rivers could increase by between 0.052 and 0.061 PPM, with an average of about 0.056 PPM.
- In 2006 the overall average for nitrogen was 1.50 PPM. In 2007 it will be 1.56 PPM. By 2016 and if environmental factors do not change, the average nitrogen concentration in the rivers could be as high as 2.06 PPM.

Long Term Trend for Nitrogen

From 1970 to early 2004 the VA DEQ has collected water quality data in the whole state of Virginia for a number of parameters. In some cases they used the same sampling sites as the FOSR, and this provides an opportunity to go back almost 40 years to view the levels of pollution at that time.

Since the VA DEQ covers such a large area and samples so many parameters in addition to the nutrients, their coverage of the Shenandoah River Watershed is rather sparse compared to that of the FOSR. Whereas the FOSR covers more than 140 sampling sites, the VA DEQ can cover only a fraction of these. And whereas the FOSR can afford to (since they use volunteers) sample twice a month and at regular intervals, the VA DEQ limits sampling to once a month, and often skips a month or two. And for some sites, such as FC01 (the Route 50 bridge over the Shenandoah River in Clarke County) the VA DEQ sampling spanned only a few years, from mid-2001 to mid-2003. Nevertheless, the VA DEQ and FOSR data nicely complement each other with the former providing information on pollution levels more than 40 years ago and before FOSR sampling started, and with the FOSR data providing the frequency of collection that enables the calculation of trend lines over the past ten years.

Figure 3-3 shows the long term history for nitrogen at FC08, the sampling site under the Route 7 bridge over the Shenandoah River in Clarke County. The graph, with the time scale in years and quarters, shows that in 1970 the average concentration of nitrogen in the Shenandoah River was unimpaired. However, soon thereafter it reached impaired levels for many quarters and seemed to be rising slowly (statistical tests confirm this rising trend). From 1997 to 2003 the FOSR and VA DEQ data for FC08 overlap, and this provides an opportunity to compare the results from these two organizations. The agreement is close, and statistical tests confirm that there is no difference between the results obtained by these two organizations. The same is true for FC01 where the VA DEQ and FOSR data overlap for the mid-2001 to mid-2003 time period. Statistical analysis reveals a small (about 3% increase per year) but significant increasing trend (not shown in the graph) for the data collected by both the FOSR and VA DEQ.

---

4. A variable can vary randomly but still reveal a pattern. For example, throwing a die will yield random values between 1 and 6. But the average value, if the die is true and depending on the number of throws, will be close to 3.5.

5. Although statistics provide a powerful tool for identifying problem areas and trends, and for testing hypotheses or assumptions to provide tentative explanations of phenomenon, they are limited as methods of showing causes and effects or of revealing the processes that underlie the variations. The next step, that of identifying the underlying processes requires analysis integrating the facts revealed by statistical analysis of the water quality data base with another database, such as a geographic information system on land use and topography that quantifies the factors that can explain the reasons for high or low pollution levels.

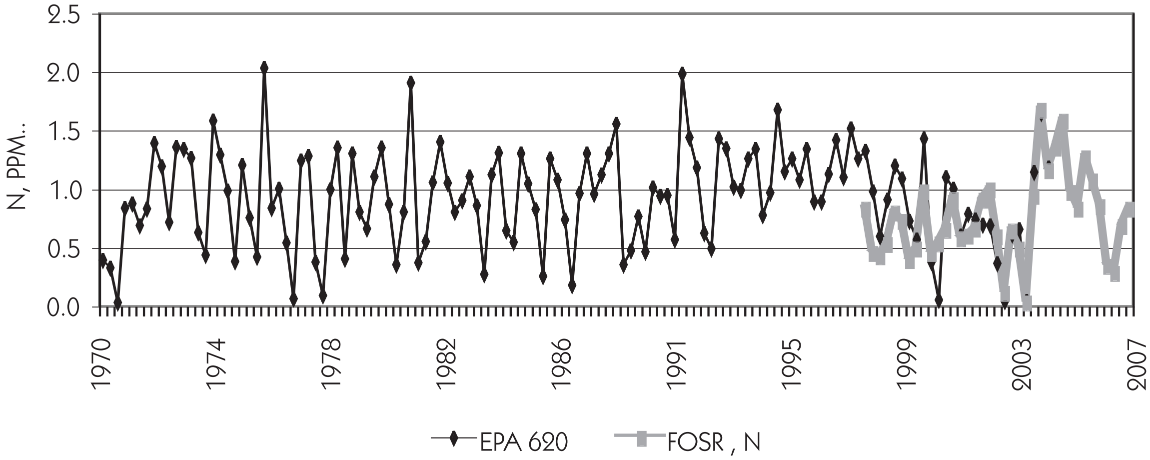


Figure 3-3
VA DEQ and FOSR Data for Nitrogen at FC08, 1994 - 2007

Trend for Nitrogen in Tributaries

Figure 3-4 shows the same analysis as for the rivers, but for the tributaries in the Shenandoah River Watershed. There are many more sampling sites located on tributaries than there are on the rivers, and the figure therefore contains almost double the number of points, 8851 to be exact. As is the case for the rivers, there is a considerable amount of scatter. Nevertheless, because the data are so plentiful, we can calculate a significant increasing trend of more than 4% per year. If the trend continues at this rate, from an average level of 1.83 PPM in 2006, the nitrogen concentration would increase to 1.90 in 2007 and to 2.60 PPM by the year 2016.

B: Trend for Turbidity in Rivers and in Tributaries

Trend for Turbidity in Rivers

Figure 3-5 shows a "smooth" line graph of the growth of turbidity combined for all the rivers in the Shenandoah River Watershed. There appears to be an upward trend, and the trend may be showing some exponential growth for the past four years. And it is obvious that there were high peaks in turbidity in 1998 and 2006. The scatter diagram for turbidity shown later tells us that the highest reading in 1998 was 400 NTU; in 2006 it was 430 NTU.

The linear trend line shows that ten years ago, the average turbidity in the rivers was about 2.0 NTU. The water was unimpaired according to the turbidity criterion. Except for the large spike in early 1998 to more than 20.0 NTU that was probably produced by heavy rainfall during the winter that coincided with the taking of a samples, the average turbidity stayed below 5.0 NTU until the year 2001. After that year, the average turbidity started increasing and by early 2007 had increased to 10.0 NTU, a level that is high and indicates concentrations well above the severely impaired level of 7.0 NTU.

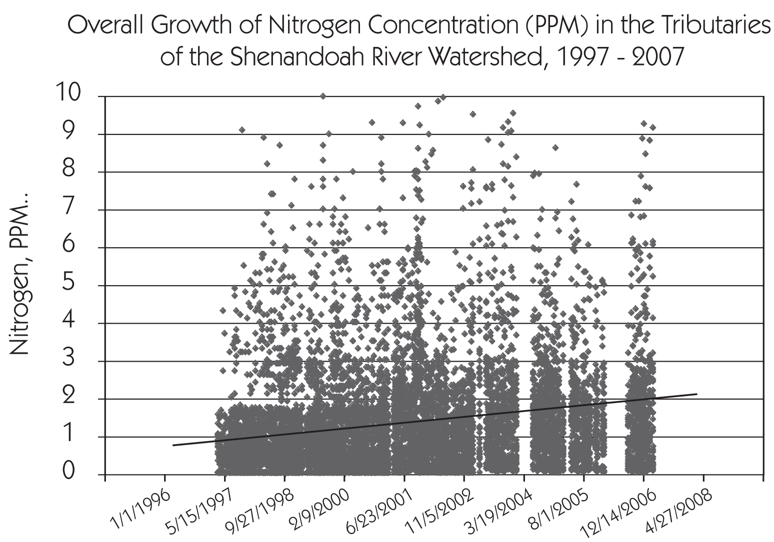


Figure 3-4
Scatter Diagram Nitrogen (PPM) in the Tributaries, 1997 - 2007

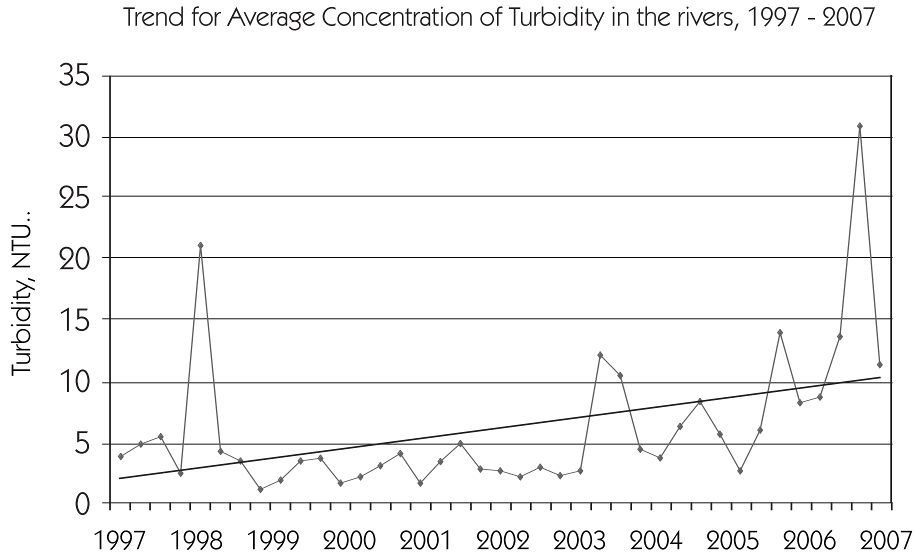


Figure 3-5
Smooth Plot of Turbidity (NTU) in the Rivers, 1997 - 2007

As given by the trend line, the average turbidity in the overall river system is increasing at about 8% per year.

The scatter diagram in Figure 3-6 below uses the same data as for the previous figure, but the data points are not smoothed. The figure shows a generally increasing trend in the basic (if we exclude the outliers in 1998 and 2006) turbidity level. Statistical analysis[6] shows the growth rate is 8.4% per year, and that the trend is statistically significant. The average for the rivers over the 1997 - 2007 time period was 5.48 NTU.

Trend of Turbidity in Tributaries

Figure 3-7 shows the smooth graph for turbidity in tributaries. As for nitrogen, there are high peaks in the years 1998 and 2006.

Figure 3-8 shows the scatter diagram for turbidity in the tributaries of the Shenandoah River Watershed. The high peaks in turbidity occurred on 1/10/1998 and 1/24/1998 when more than 15 sampling sites reported turbidity readings of more than 50 NTU, and with the highest reading being about 400 NTU. And on 10/6/2006 and 11/17/2006 more than 20 sampling sites reported turbidity readings of more than 50 NTU. The highest reading was more than 600 NTU.

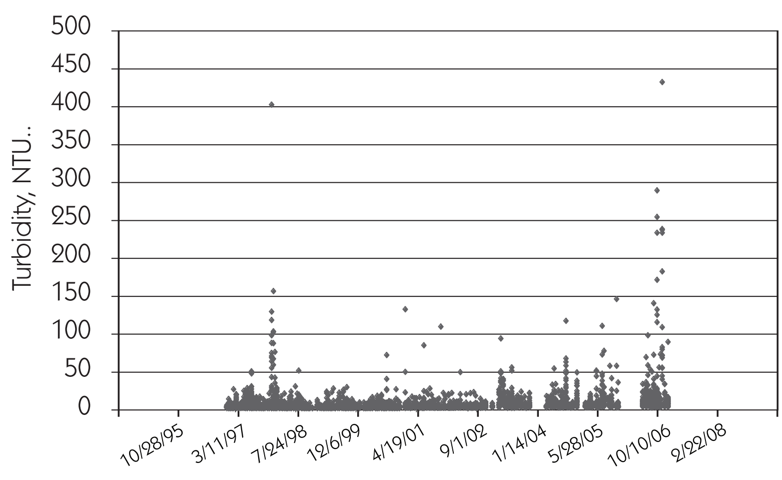


Figure 3-6
Scatter Diagram of Turbidity in the Rivers, 1997 - 2007

6. It may be surprising that data containing such a large scattering of points and therefore a very low correlation coefficient can still have a valid trend. But this is a common situation in many scientific applications, and statistical techniques have been developed that can deal with this problem. For example, a typical problem is that of detecting the trend in global warming from a time-series of widely scattered temperature readings. In this report we apply such statistical techniques to calculate the trend.

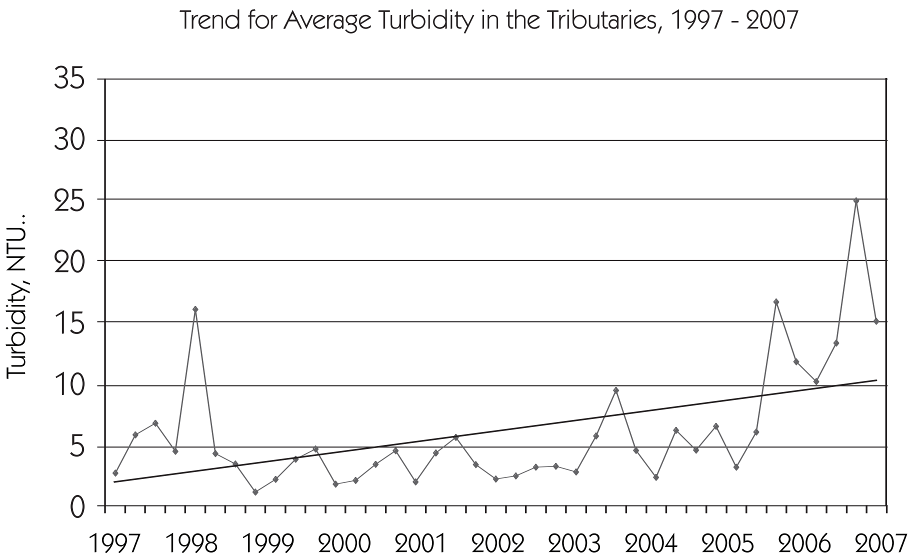


Figure 3-7
Smooth Plot of Turbidity in Tributaries, 1997 - 2007

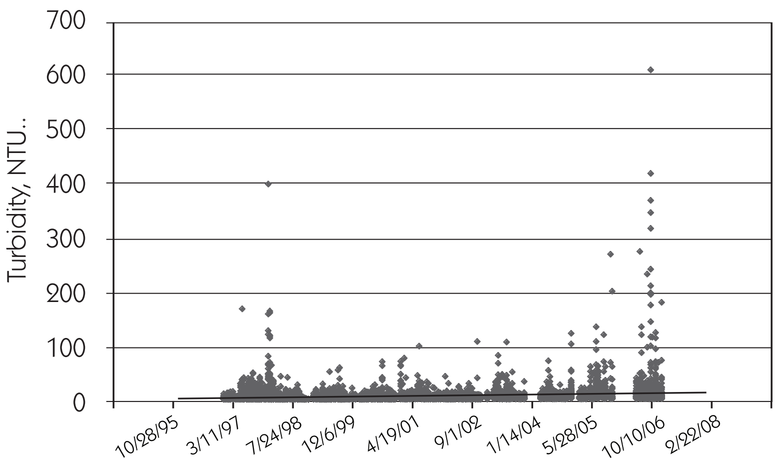


Figure 3-8
Turbidity in Tributaries, scatter plot

The trend calculated for the tributaries shows an annual growth rate of 8.4%, and the average turbidity over the 1997 - 2007 time period was 5.6 NTU. Thus both the growth rate of turbidity and the average level where slightly higher for the tributaries than for the rivers.[7]

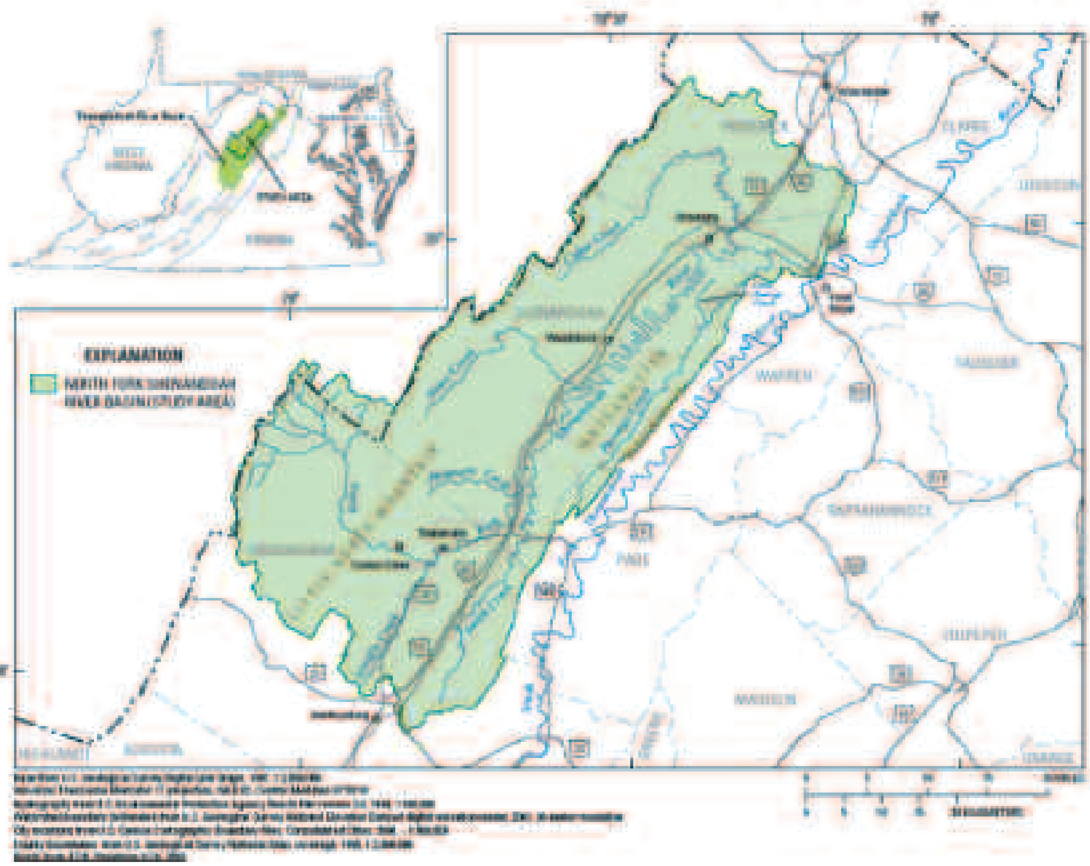
C: Water Quality in Each Section of the River, and by Year

The previous section presented graphs for the average nitrogen concentrations and turbidity measurements averaged over all the counties in the Shenandoah River Watershed. The overall trends were generally increasing.

In this section we look more closely at the data to determine in which parts of the river the trends are increasing and by how much, where the trends are flat, and where the trends are going down. We do this by separating the overall Shenandoah River system into its five major river components: the South Fork, South River, North Fork, North River, Middle River, and the Main Stem. We shall examine all the parameters – not just nitrogen and turbidity.

The five river sections (see Map 3-1) are organized as follows: Starting in the southern part of the watershed we have the three tributaries to the South Fork. The South River flowing along the West slope of the Blue ridge in Augusta County through Waynesboro is joined by the North River created in the high Alleghany mountains northwest of Staunton, and the Middle River coming in from southwest of Staunton. All three join in Port Republic where they create the South fork of the Shenandoah River. The North Fork flows in from the mountainous area in the northwestern part of Rockingham County, and joins the South Fork at Front Royal to form the Main Stem. The Main Stem then flows almost due north for about 60 miles to join the Potomac River at Harpers Ferry.

7. The explanation probably lies in the fact that, per unit of water flowing, the narrow tributaries have greater exposure to runoff than the wider rivers.



Map 3-1
Map of the Rivers Krstolic and Hayes, USGS

The counties share several of the river sections:
North Fork – Except for one sample site in Warren County, all the other sample sites are in Shenandoah County,
South Fork – Five sampling sites are in Augusta County, three are in Page County, and one is in Warren County.
North River – Three sampling sites are in Augusta County and three are in Rockingham County.
Middle River – All seven sampling sites are in Augusta County.
Main Stem – Four sampling sites are in Clarke County, and four are in Jefferson County West Virginia.

Average Nitrogen Levels by River Section

Table 3-1 shows the average levels of nitrogen for the five river sections taken over the whole 1997 – 2006 time span.

To be unimpaired, the river's nitrogen concentration should be below 0.75 PPM. In 1997, the Main Stem, Middle River, South Fork, and South River all had average nitrogen concentrations that were close to unimpaired, but during successive years the nitrogen concentrations increased and by the year 2006 these four river sections were impaired by higher levels of nitrogen. The North Fork and North River, however, were already above the impaired level in 1997, and by 2006 had ended up well above the severely impaired level. A later section will report the trends of river pollution in more detail.

Table 3-1: Average Levels (PPM) of Nitrogen by River section

Year	Main Stem	Middle River	North Fork	North River	South Fork	South River	Grand Total
1997	0.60	0.77	0.95	3.24	0.77	0.74	1.06
1998	0.73	1.02	1.39	2.08	1.03	1.07	1.15
1999	0.70	0.98	1.72	2.13	1.07	0.96	1.20
2000	0.80	1.01	1.23	1.39	0.95	0.92	1.05
2001	0.88	1.49	2.61	2.16	1.19	1.60	1.55
2002	0.61	0.98	1.75	1.19	0.80	1.16	1.04
2003	1.52	1.46	2.17	2.70	1.86	1.07	1.68
2004	1.15	1.30	1.70	1.68	1.23	1.03	1.33
2005	0.86	1.22	1.51	1.54	1.08	1.02	1.20
2006	1.12	1.38	1.92	2.20	1.44	1.05	1.48
Grand Total	0.82	1.14	1.64	2.00	1.10	1.06	1.25

The Figure 3-9 takes the values from Table 3-1 and shows these as a bar graph. The average concentration of nitrogen for almost all of the sections was above the impaired level for the all the years in the time period. The North River had the highest concentrations of nitrogen.

Figure 3-9 is useful in that it shows the trend of nitrogen for the river sections over the 1997 - 2006 time period.

Figure 3-10, called a "box and whiskers" diagram, shows details of actual distribution of the data collected for each river section. The box contains 50% of the data points. The minus sign roughly in the middle of the box gives the median value of the data; its position indicates the skewness (lack of symmetry) of the data. The "plus" signs show the maximum and minimum values recorded, and the "whiskers" show the top 95 percentile and bottom 5 percentile points. For example, for the North River, and starting from the top, the maximum value is 5.0 PPM, the 95% point (top of the whisker) is 4.6 PPM, the 75% point (top of the box) is 2.8 PPM, the median value is 2.4 PPM, the 25% point (bottom of the box) is at 1.3 PPM, the 5% point (bottom of the whisker) is at 0.113 PPM, and the minimum value is 0.09 PPM. And since the median value is slightly above the center of the box we can see that the distribution is slightly skewed.

Average Turbidity Levels by River Section

Table 3-2 shows the same information as for nitrogen, but for turbidity. As explained earlier, turbidity in the waters of the Shenandoah River Watershed is a serious problem. Turbidity should be between 0.0 and 4.0 for the water to be called clear and unimpaired, but if larger than 4.0 and less than 7.0 it can be called impaired. If the turbidity is above 7.0 the water can be called cloudy, and is severely impaired.

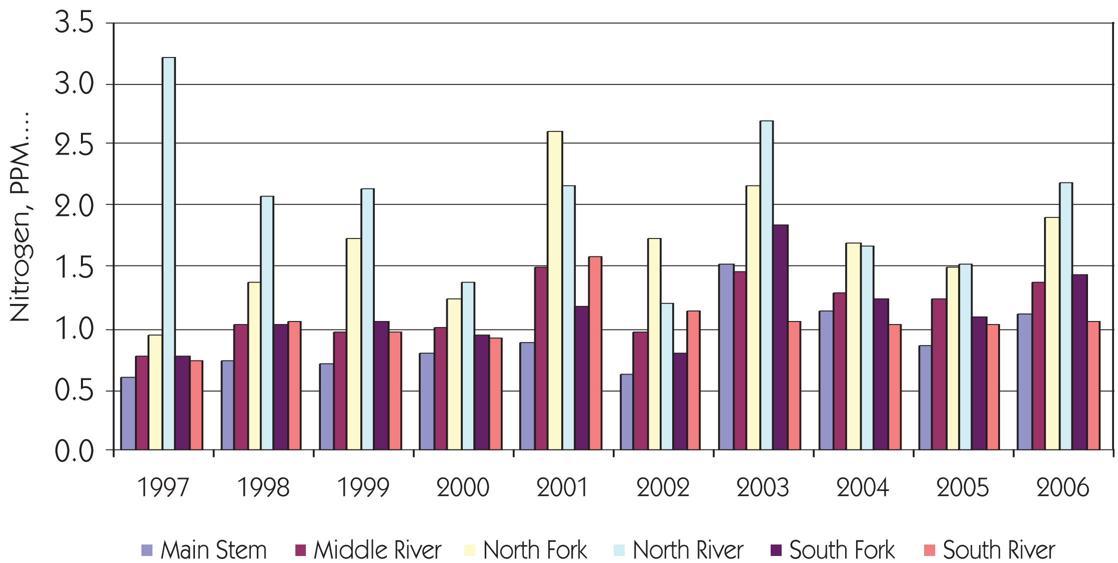


Figure 3-9
Average Nitrogen by River Section, 1997 - 2006

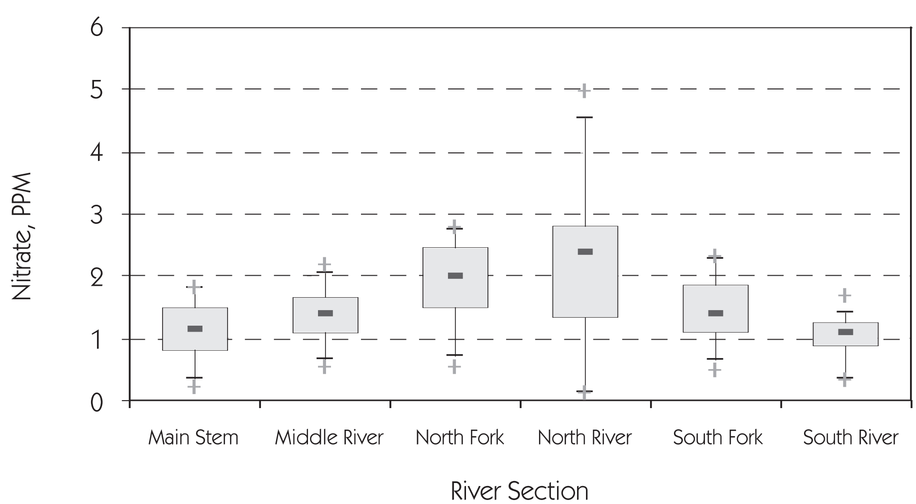


Figure 3-10
Variation of Nitrogen, by River Section

Table 3-2: Average Turbidity (NTUs) by River Section

Year	Main Stem	Middle River	North Fork	North River	South Fork	South River	Grand Avg.
1997	3.86	5.89	2.92	5.11	3.19	3.20	4.10
1998	4.55	14.63	4.96	4.94	5.79	11.57	8.17
1999	1.77	5.08	1.61	2.03	1.29	2.69	2.60
2000	2.26	4.60	1.40	2.19	1.48	3.28	2.62
2001	2.74	6.98	3.13	1.59	1.38	2.63	3.24
2002	2.19	4.71	1.76	1.64	1.27	1.80	2.29
2003	10.34	8.85	10.20	4.11	7.79	5.38	7.56
2004	10.57	9.76	5.53	3.95	6.65	4.41	6.80
2005	5.29	12.61	3.52	9.31	4.53	7.06	7.79
2006	7.71	26.97	13.82	22.18	29.25	16.54	20.85
Grand Avg.	4.28	9.54	4.01	5.01	5.36	5.39	5.84

The table shows that the average levels of turbidity for each year fluctuate more than those for nitrogen. This is because much of the turbidity is caused by runoff from agricultural and urban areas during rain storms.[8] And turbidity is short-lived since the sediment deposited in the water soon sinks to the bottom.

Figure 3-11
Average Turbidity by River Section, 1997 - 2006

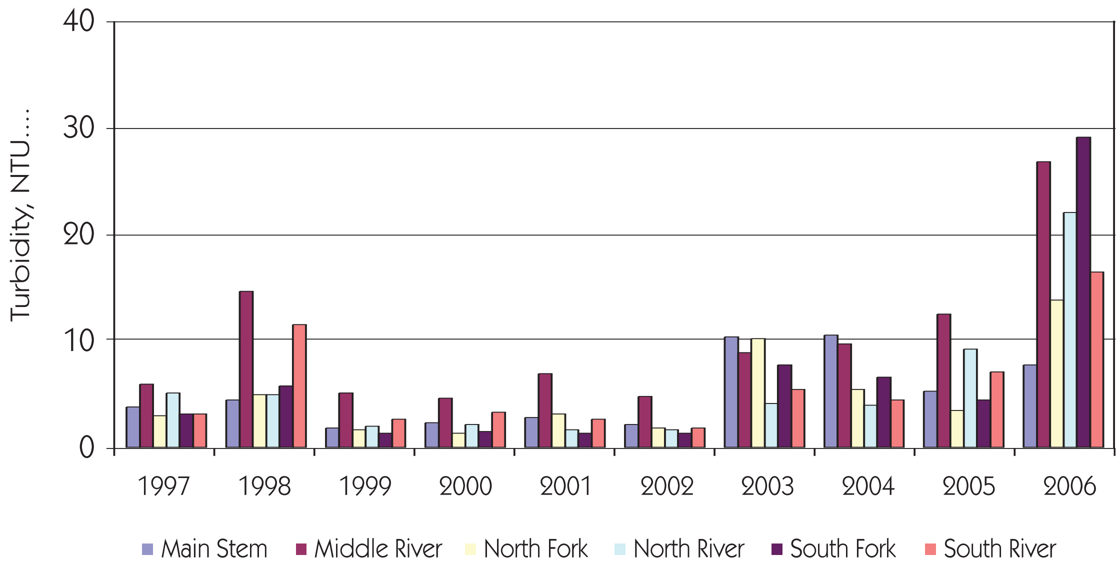
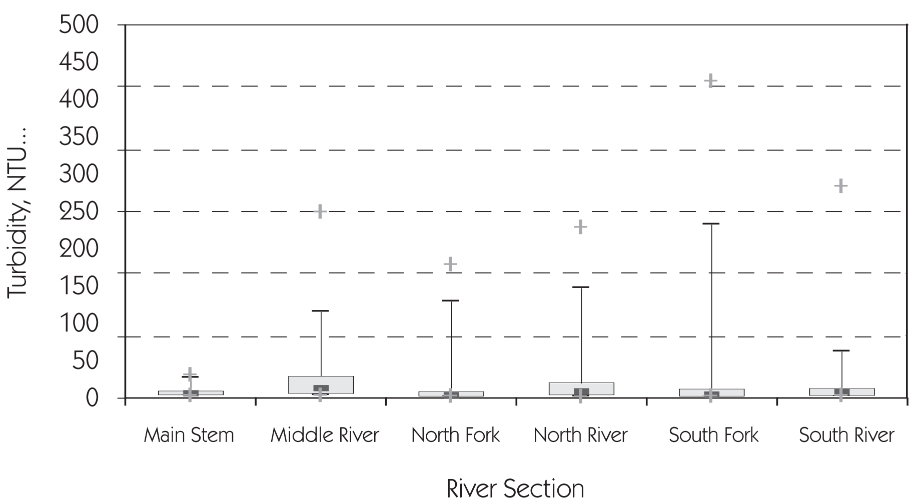


Figure 3-12
Variation of Turbidity by River Section, 2006



8. Elizabeth A. Johnston and Woodward S. Bousquet, October 3, 2004. *What happens when it rains; A study of water quality in Abrams Creek and Town Run, Winchester and Frederick County, Virginia* .Environmental Studies Program, Shenandoah University, Virginia.

In 1997, only two river sections – the Middle River and North River – were impaired by turbidity and at that time were already cloudy with average turbidity between 4 and 7 NTU. In 2006 none of the river sections were unimpaired by turbidity, although the North Fork came very close to being unimpaired.

Turbidity levels during the 2006 seem to have been unusually high: there were 14 samples (not shown on the graph) that recorded NTU larger than 100, and that ranged between 107 and 430 NTU. It is probable that these high values could have been caused by rainstorm/runoff events that occurred at the same time or shortly before the samples were taken.

The year 2004 recorded two measurements (not shown on the graph) of 108 NTU and 144 NTU. The years 1999, 2000, and 2002 yielded low turbidity measurements. This could be attributed to the severe droughts that limited runoff, and that occurred in the Shenandoah River Watershed in those years.

It is difficult to see the values on this graph because the scale is expanded to capture the high measurements – from 0.0 where the water is perfectly clear, to 500 NTU where the water is opaque. It can be seen, however, that the median values of turbidity are low in the Main Stem and North fork, but are elevated for the other river sections. And as we have seen earlier, the upward excursions for turbidity are high.

Average Ammonia Levels by River Section

Ammonia is a reduced form of nitrogen. As shown in Table 3-3, and except for one year (in 1998 the ammonia level in the North Fork was slightly above the impaired level of 1.0 PPM) ammonia levels do not seem to be a problem in the river sections. In fact, in 2006 all the river sections had average ammonia levels well below the impaired level.

Table 3-3: Table of Average Ammonia by River Section, 1997 - 2006

Year	Main Stem	Middle River	North Fork	North River	South Fork	South River	Grand Avg.
1997	0.46	0.62	0.50	0.41	0.36	0.49	0.48
1998	0.27	0.51	1.09	0.27	0.43	0.41	0.47
1999	0.29	0.43	0.33	0.28	0.34	0.28	0.33
2000	0.32	0.37	0.33	0.28	0.36	0.35	0.33
2001	0.03	0.08	0.03	0.07	0.07	0.06	0.06
2002	0.04	0.08	0.02	0.18	0.04	0.05	0.07
2003	0.04	0.05	0.05	0.05	0.09	0.07	0.06
2004	0.06	0.06	0.04	0.06	0.08	0.08	0.07
2005	0.04	0.04	0.03	0.05	0.06	0.04	0.04
2006	0.03	0.05	0.04	0.07	0.06	0.04	0.05
Grand Avg.	0.20	0.26	0.32	0.18	0.20	0.20	0.22

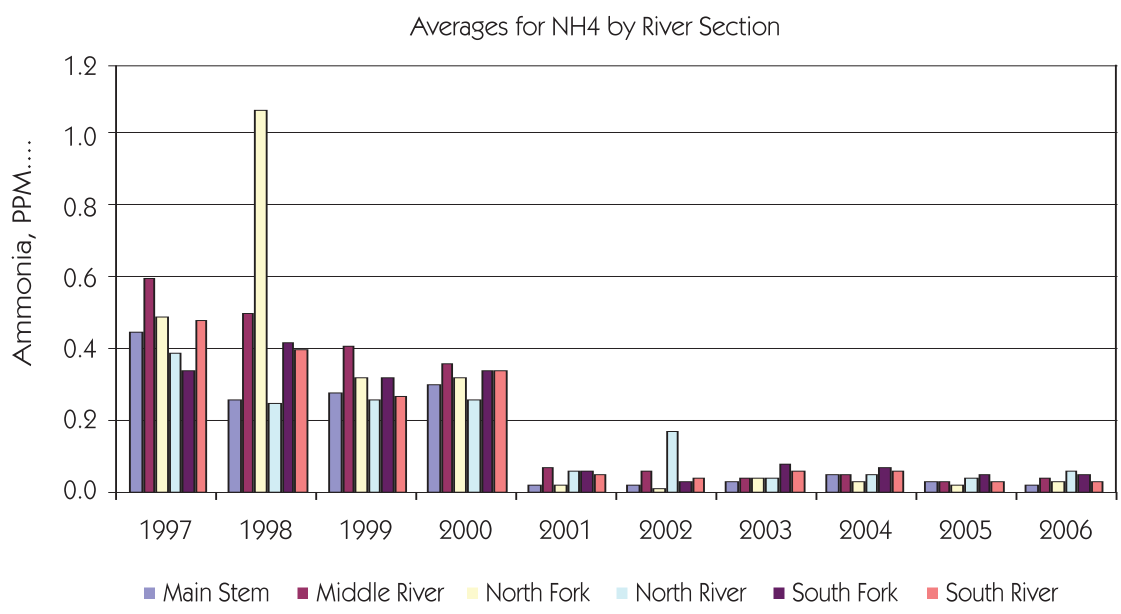
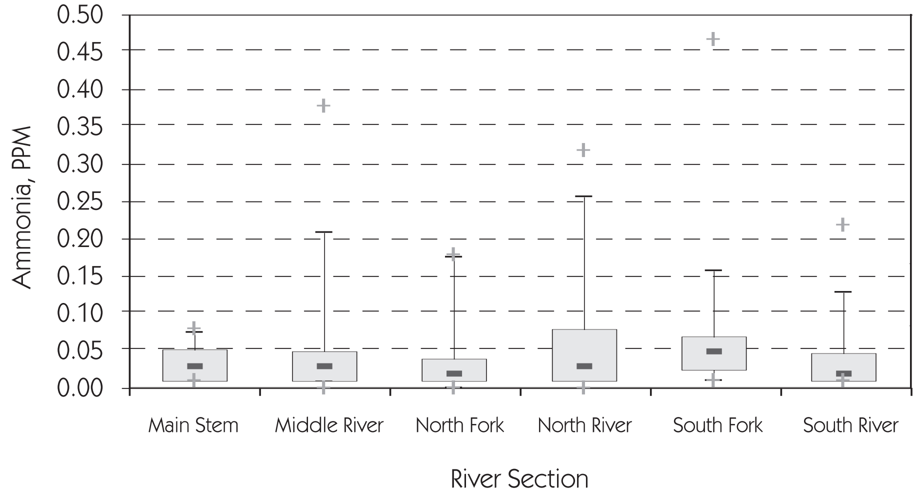


Figure 3-13
Variation of Ammonia concentration, by River Section, 2006



Average pH Levels by River Section

To be unimpaired, the pH of the stream should be between 6.5 and 8, and the North River and South River generally fall in the unimpaired category. The other river sections have pH in some years that are slightly above 8.0.

Table 3-4: Average of pH by River Section, 1997 - 2006

Year	Main Stem	Middle River	North Fork	North River	South Fork	South River	Grand Avg.
1997	7.97	7.86	8.05	7.89	8.08	7.73	7.92
1998	8.22	8.02	8.19	7.94	8.33	7.90	8.10
1999	8.33	8.05	8.40	7.75	8.32	8.00	8.13
2000	8.08	7.99	8.36	7.64	8.15	7.81	7.98
2001	8.04	7.67	8.01	7.41	8.09	7.52	7.77
2002	8.49	8.11	8.57	7.80	8.50	8.01	8.21
2003	7.96	7.94	8.04	7.72	7.95	7.76	7.88
2004	8.03	8.03	8.22	7.76	8.10	7.87	7.97
2005	8.14	8.03	8.00	7.76	8.10	7.84	7.96
2006	8.67	8.17	8.57	7.97	8.35	7.94	8.21
Grand Avg.	8.17	7.97	8.25	7.75	8.21	7.83	8.01

It should be noted that the averages calculated in this report are "arithmetic" averages. This is appropriate for all parameters except pH. The "statistical methods" in the appendix discusses that, since pH concentration is logarithmic, the average pH is derived by calculating the average value of the hydrogen ions (moles per liter) and converting that into average pH by taking the anti-log.

The median level for pH hovers slightly below 8.0 most of the time. This is the unimpaired level for pH. But the graph also shows that the pH exceeds a pH 10, the severely impaired level, once for the Middle River and once for the South River. It is known that such high pH levels affect the health of fish, and the graph thus indicates a possible problem that must be addressed. And we must take into account the diurnal variation in pH. As explained in the Methodology section, the pH varies during the day, starting off low in the morning and peaking at dusk. Peaks in the pH may not be captured in the monitoring schedule.

Average Phosphorus Levels by River Section

During the years 1997 - 2002 the phosphorus levels in the river sections were all at the highly impaired levels. (larger than 0.1 PPM). By 2003, however, phosphorus levels dropped sharply, much of it due to legislation that was passed and private initiatives to limit phosphorus in household detergents. And by the year 2006 the average phosphorus concentrations in almost all the river sections were at the unimpaired level (less than 0.05 PPM). Only the North Fork, North River, and South River were above the unimpaired level.

The median level for phosphorus is elevated in some of the river sections – North Fork, South Fork, and South River, but still well below the 0.1 level where severe impairment starts. And except

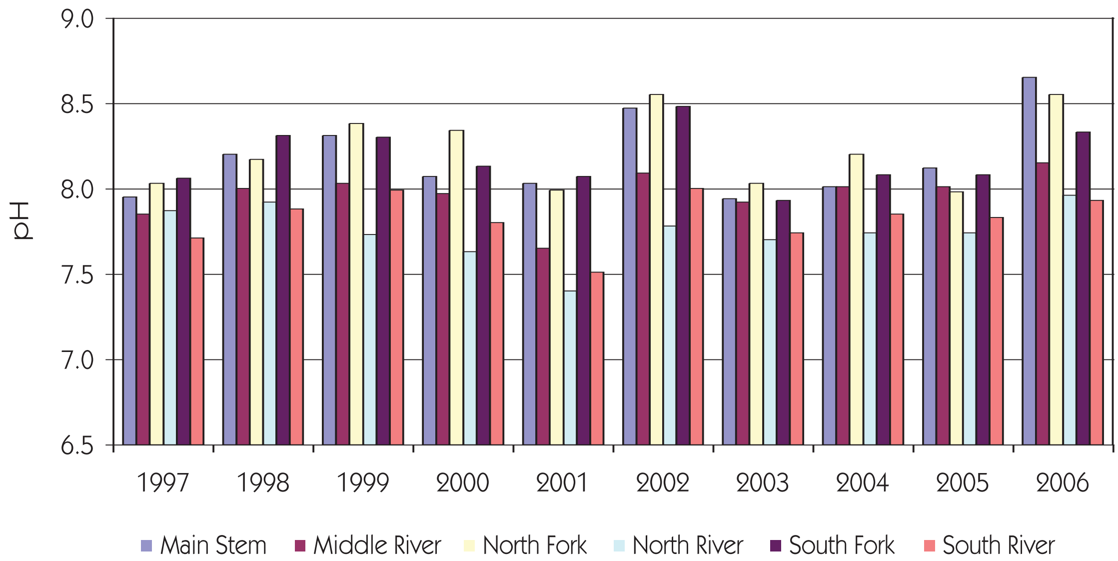


Figure 3-14
Averages of pH by River Section, 1997 - 2006

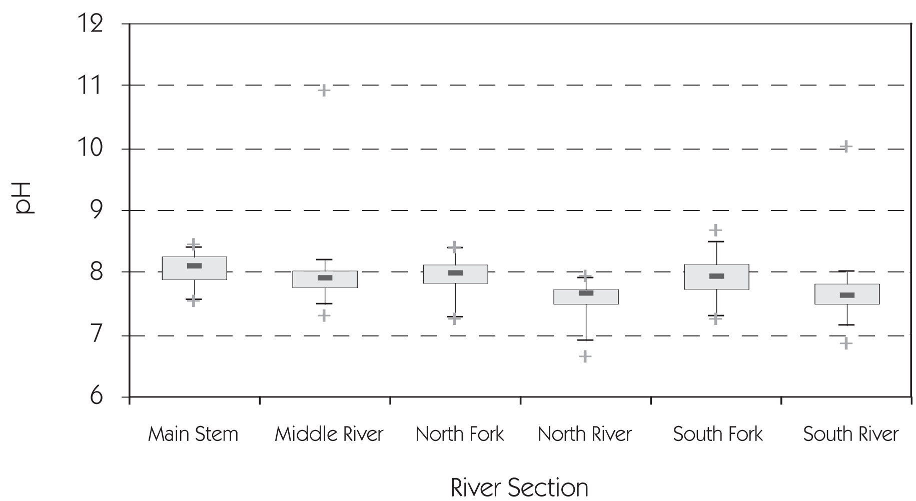


Figure 3-15
Variation of pH by River Section, 2006

Table 3-5: Average Phosphorus concentration (ppm) in River Sections, 1997 - 2006

Year	Main Stem	Middle River	North Fork	North River	South Fork	South River	Grand Avg.
1997	0.45	0.27	0.33	0.59	0.89	0.76	0.54
1998	0.42	0.36	0.64	0.70	0.71	0.75	0.56
1999	0.42	0.23	0.63	0.94	0.59	0.25	0.48
2000	0.39	0.22	0.41	0.43	0.51	0.25	0.36
2001	0.14	0.14	0.27	0.13	0.18	0.15	0.16
2002	0.15	0.07	0.33	0.12	0.22	0.13	0.15
2003	0.06	0.04	0.12	0.10	0.10	0.04	0.07
2004	0.04	0.04	0.11	0.04	0.06	0.04	0.05
2005	0.04	0.04	0.10	0.05	0.05	0.06	0.05
2006	0.03	0.04	0.08	0.06	0.05	0.06	0.05
Grand Avg.	0.27	0.16	0.35	0.34	0.36	0.26	0.28

Figure 3-16
Average of Phosphorus Concentration by River Section, 1997 - 2006

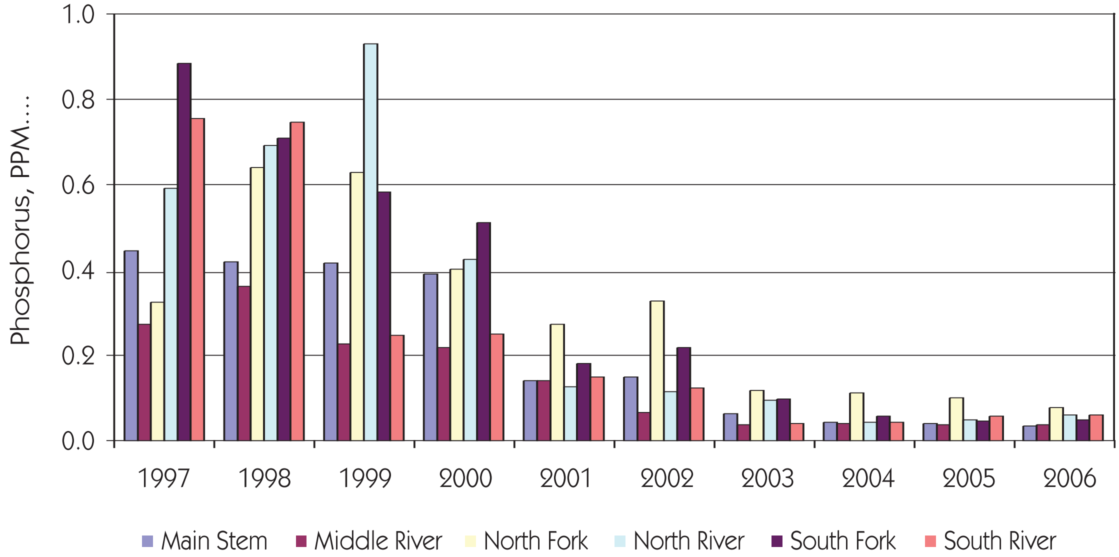
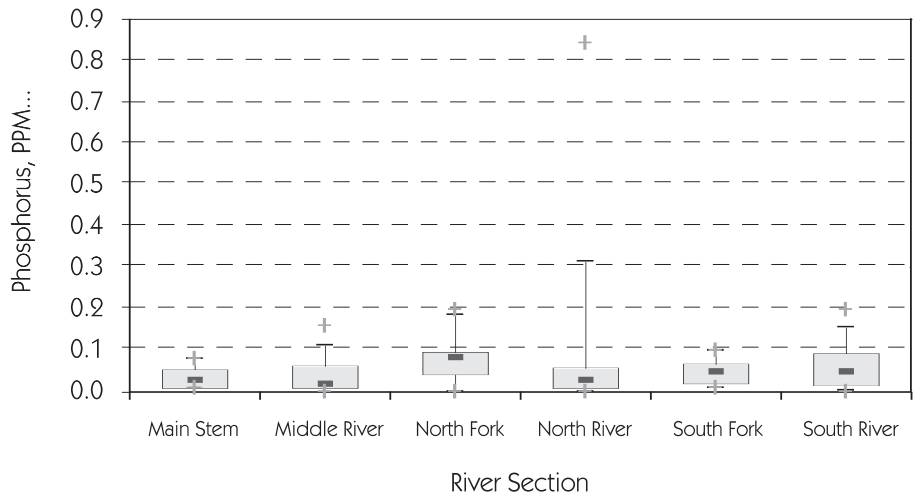


Figure 3-17
Variation of Phosphorus Concentration by River section, 2006



for the North River where a very high value of 0.85 PPM is reached, the upside excursions for the other river sections are not worrisome.

Average Dissolved Oxygen Levels by River Section

The concentrations of dissolved oxygen in the river sections were at the unimpaired level (>0 5 Mg/L) for all years. In fact, the levels were at about 9.0 Mg/L which is well above the 0.5 Mg/L necessary to support healthy aquatic life. Because of the high level of nitrogen in the river sections, it is surprising to find such levels of dissolved oxygen in the river sections. As discussed elsewhere in the report, nutrients, principally nitrogen, stimulate algae blooms, and when these algae die they sink to the bottom they decompose and the decomposition process removes oxygen from the water. These algae blooms also happen in the river sections, but because the water flows fast and there are many riffles where water and air are mixed, the water is continuously refreshed with oxygen from the air. In deeper and still water where there is no recirculation, such as in the Chesapeake Bay, the excessive nutrients can cause serious deficiencies in the levels of dissolved oxygen.

Dissolved oxygen concentrations seem to be acceptable in all river sections, and there was only one instance, for the Middle River, where the DO level dropped below 6.0 Mg/L. It is well known that there is a considerable diurnal variation in dissolved oxygen. Because of the contribution of oxygen from photosynthesis during the day and the removal of oxygen by microbial respiration at night, the minimum oxygen concentrations occurs just before dawn. Because none of the FOSR measurements are made at night or during the early dawn, the actual average dissolved oxygen concentrations could be lower than those presented in this report. Dissolved oxygen is critical for the health of fish, and the FOSR plans to examine measures to assure that future dissolved oxygen readings include the possible impact of the diurnal variation.

Table 3-6: Average dissolved oxygen concentration by River Section, 1997 - 2006

Year	Main Stem	Middle River	North Fork	North River	South Fork	South River	Grand Avg.
1997	9.46	8.68	9.05	7.64	8.84	9.12	8.88
1998	8.33	7.68	7.89	7.43	7.96	7.89	7.89
1999	9.34	8.12	10.20	8.56	9.51	9.36	9.07
2000	9.38	8.35	10.15	8.68	8.69	8.28	8.86
2001	9.66	8.38	9.92	8.54	8.79	8.25	8.86
2002	8.19	7.42	9.25	7.51	7.83	7.58	7.86
2003	9.72	9.33	10.53	9.57	9.49	9.34	9.55
2004	8.70	9.09	10.44	9.00	9.00	8.79	9.07
2005	9.84	9.71	9.80	9.55	9.89	9.53	9.69
2006	9.71	9.22	9.56	9.24	9.78	9.10	9.37
Grand Avg.	9.20	8.52	9.62	8.53	8.90	8.68	8.85

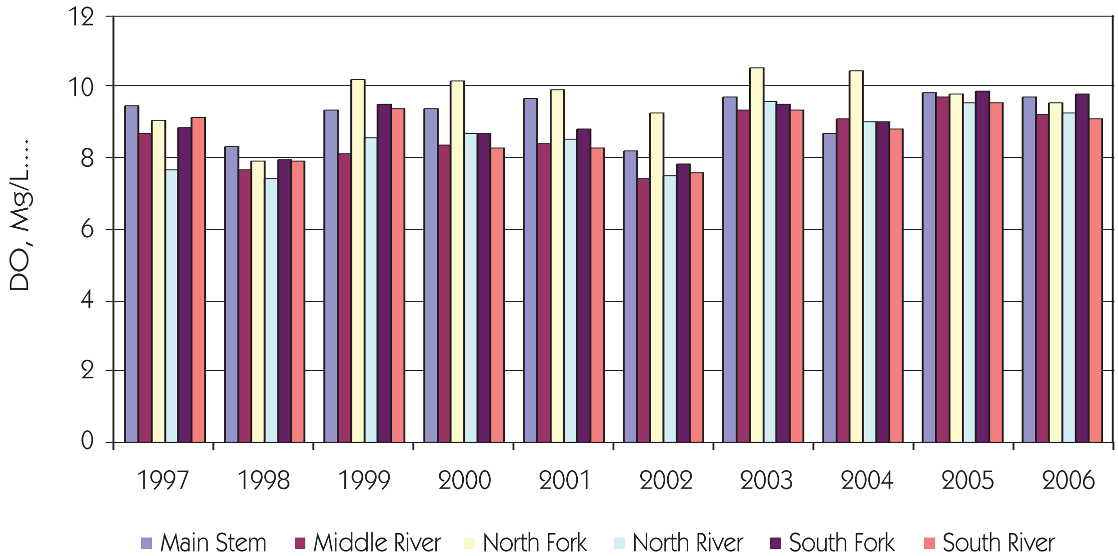


Figure 3-18
Average DO by River Section, 1997 - 2006

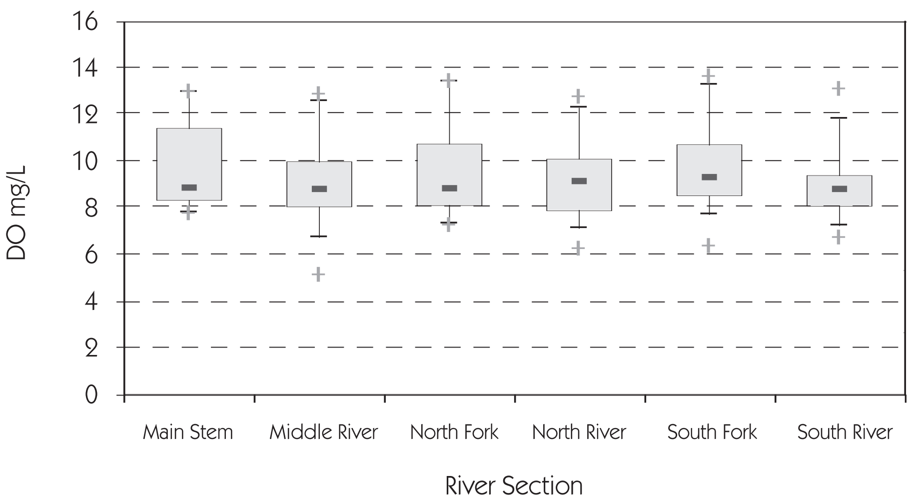


Figure 3-19
Variation in dissolved oxygen concentration by River Section, 2006

4 Most and Least Impaired Sites of the River and Tributaries, 2006

A: River Sites

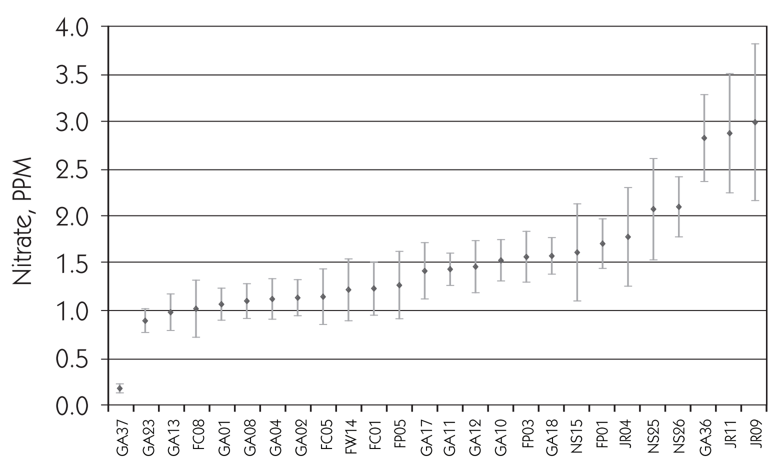
The 26 sampling sites on rivers that were active in 2006 reported a wide range of values for the parameters. In this section we will examine and rank the sites for nitrogen and turbidity. These two parameters are of most interest because of their relatively high degree of impairment, and their effect on eutrophication and health of aquatic life.

Figure 4-1 below provides detail for the year 2006 on the wide variation in nitrogen concentrations for the sites located on the various parts of the rivers. For each site the average concentration and the 95% confidence interval is presented. For example, GA37 has the lowest nitrogen concentration of 0.2 PPM. It is located on the North River near Elkton Lake in Rockingham County. The reason this site has such a low concentration of nitrogen may be that it flows down from the highlands through areas that are heavily forested and little disturbed by human activity. On the other hand, JR09 has an average nitrogen concentration in the year 2006 that was almost 3.0 ppm, and well above the severely impaired level. This site is located in an area in Rockingham County that has a high density of poultry rendering factories and dairy farms. The runoff from these activities could explain the reason for the high level of nitrogen pollution,

Except for GA37, the nitrogen concentrations for the river sites in the year 2006 were all above the impaired level of 0.75 PPM. And of the 26 river sites sampled in the years 2006, the overall average for nitrogen was about 1.50 ppm. Practically all the sites along the river in 2006 were impaired by high levels of nitrogen. The five most highly polluted sites were NS25, NS26, GA36, JR11, JR09 in Augusta, Rockingham, and Shenandoah counties. Each of these sites had nitrogen concentrations during that year of more than 2.0 ppm.

Table 4-1 below shows details of the concentrations of nitrogen at the five most impaired river sites for the year 2006, and compares the increase over the year 2005. We also show the same for turbidity since it is one of the major causes of impairment in the rivers. The increases from 2005 to 2006 for nitrogen are high, and range 14% for the North Fork at Lupton Bridge HRRSA[9] to 43% for the North River above the HRRSA. But the increases for turbidity are even higher, and range from 81% for the North River below HRRSA to a very high 863% for the North Fork at Lupton Bridge. As we

Figure 4-1
River Sites Ranked by Nitrogen Concentration, 2006



9. Harrisonburg-Rockingham Regional Sewer Authority.

Table 4-1: The Five Most Impaired River Sites, Year 2006

Site ID	Nitrate PPM, 2006	Change in Nitrogen, 2005 - 2006	Turbidity NTU, 2006	Change in Turbidity, 2005 - 2006	Site Name	County
NS25	2.05	14%	26	863%	North Fork at Lupton Bridge, Woodstock/Baseline data	Shenandoah
NS26	2.1	31%	12.3	215%	North Fork - Chapman Landing/Baseline data	Shenandoah
GA36	2.8	33%	8.5	240%	North R-Weyers	Augusta
JR11	2.8	33%	44.1	81%	North River below HRRSA	Rockingham
JR09	3	43%	46.6	215%	North River above HRRSA	Rockingham

shall see later, however, the 2005 to 2006 increase was unusually high; the annual increase in turbidity over the entire 1997 – 2004 time period was elevated, but not as high as during the final 2005 – 2006 time period.

If we go back as far as 1997, we can see that the concentrations of nitrogen and turbidity at the five most impaired river sites were already high. As shown in Figure 4-2, nitrogen levels at the five river sites were already above the impaired level, and trended upwards slightly towards the year 2006.

Turbidity (see Figure 4-3) started off at the impaired level in 1997 and 1998, then dropped a little below the impaired level, and reached highly impaired levels in 2006.

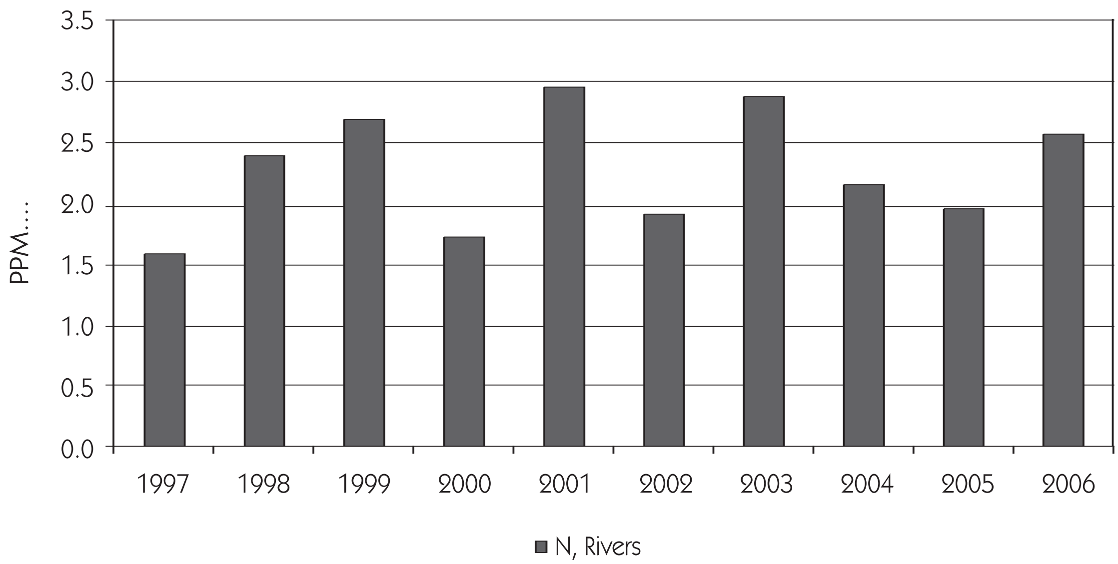


Figure 4-2
Nitrogen Trend at Five most impaired River Sites

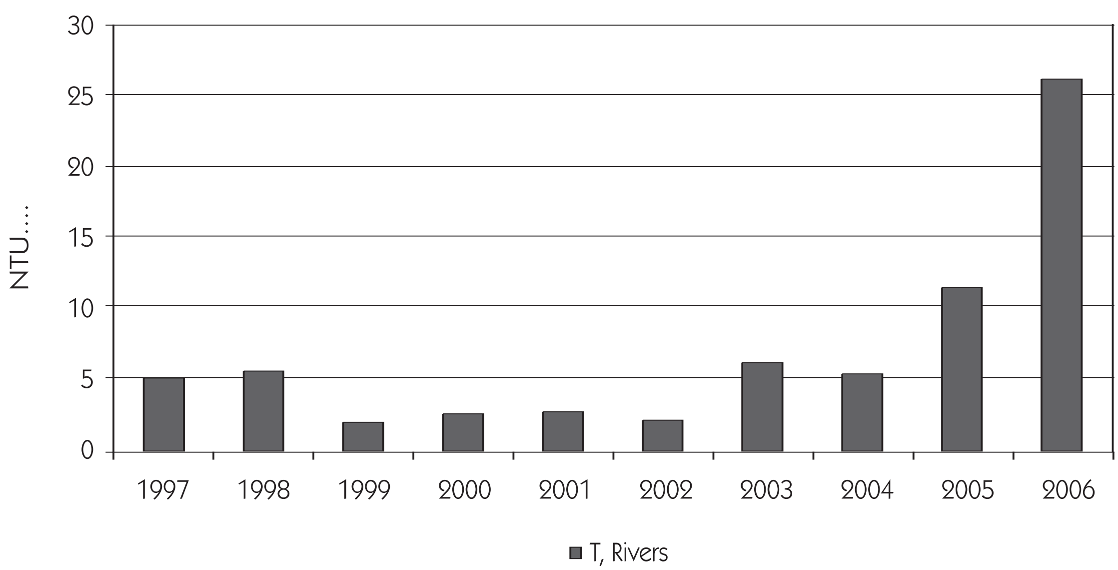


Figure 4-3
Turbidity Trend at most impaired Tributary and River Sites.

B: Tributary Sites

Figure 4-4 below shows information similar to what was discussed above, but for the tributaries. The sites are ranked in order of intensity of the nitrogen concentration, and it is clear that some tributaries have very low levels of sediment while others carry considerable sediment. The eleven sites on the left-hand section of the graph for example, have nitrogen concentrations well below 0.3 PPM; these tributaries[10] are located in areas relatively undisturbed by human development activities. On the other hand, there are ten sites with nitrogen levels exceeding 2.0 PPM, and three of these sites at the high end of the scale have average nitrogen levels exceeding 6.00 ppm.

The average nitrogen concentration in the tributaries is 1.74 ppm, and is somewhat higher than the average nitrogen concentration in the rivers of 1.48. However, the range of values for tributaries runs from 0.10 to 7.04 ppm and is considerably broader than that for the rivers which has a range from 0.16 to 2.97. The reason is probably that much of the water in the rivers is composed of groundwater, that sometimes depending on the season and amount of rainfall, reaches more that 50%. The tributaries, which are much smaller and do not have the depth of rivers, do not carry as much ground water. There was only one river site (located in the mountains) that was unimpaired, but there are about eleven tributary sites that were unimpaired.

The seven sites on the tributaries with the highest levels of nitrogen pollution are shown in Table 4-2 below. The table also includes, for each site, the corresponding values for turbidity.

The increase in nitrogen from 2005 to 2006 at the sites is high, and comparable to that for the rivers; and ranges from -5% (a slight decrease) to 48%, but not as high as for the rivers. The changes in turbidity for the tributaries range from 36% to 238%. Although high, the change in turbidity from 2005 to 2006 is not as extremely high as for the rivers.

Figure 4-4
Nitrogen Concentrations in Tributaries, Ranked by Site

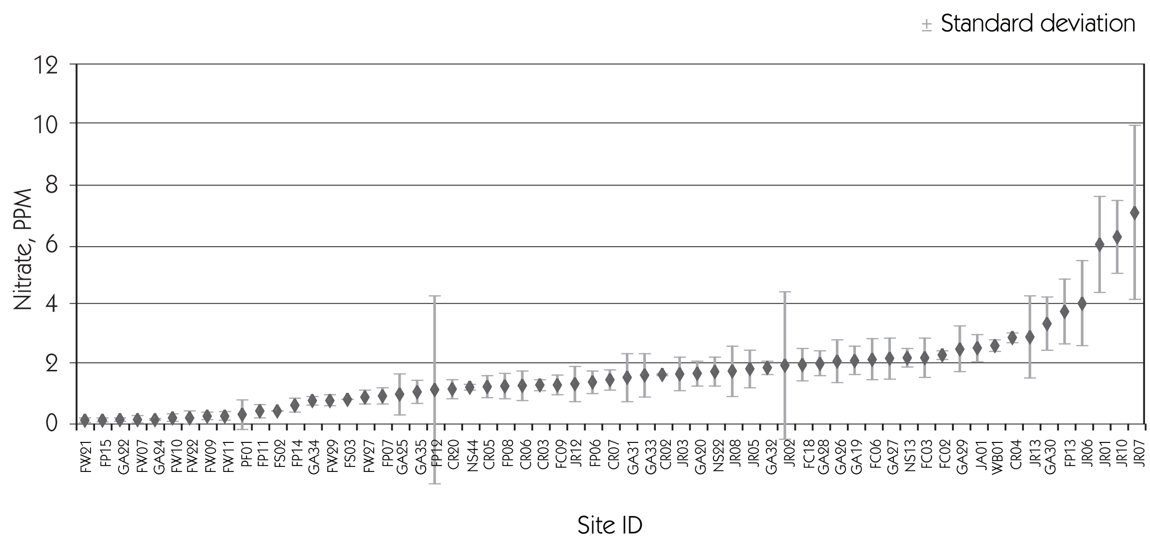


Table 4-2: Seven Tributary Sites with Highest Nitrogen Levels, 2006

Site ID	Nitrate PPM, 2006	Change in Nitrogen, 2005 - 2006	Turbidity NTU, 2006	Change in Turbidity, 2005 - 2006	Site Name	County
JR10	6.22	14%	55.6	92%	Pleasant Run-North River	Rockingham
JR01	6.0	40%	16.0	95%	Muddy Creek-North River	Rockingham
JR07	7.0	49%	100.1	47%	Cooks Creek-North River	Rockingham
JR06	4.0	48%	82.4	184%	Long Glade Creek-North River	Rockingham
FP13	3.73	20%	12.7	195%	Mill Creek	Page
GA29	2.48	3%	43.2	238%	Christians Creek, 907 bridge	Augusta
FC32	2.95	-5%	20.06	36%	Wheat Spring Branch	Clarke

10. The characteristics of some of these sites will be explored in more detail in the next chapter to see how characteristics of the watershed of a site could affect water quality.

C: Past History Of Nitrogen And Turbidity For Most Impaired Sites

Figure 4-5 below sheds light on the trends of turbidity for the five most impaired sites on the tributaries. There is no evidence that the trend for turbidity is leveling off. To the contrary, it started rising sharply after 2004, and in 2006 was moving through the severely impaired level of 25.0 PPM for the rivers and almost 50.0 PPM for the tributaries. This rapid rise in turbidity seems to apply to all the river and tributary sites, and deserves further investigation.

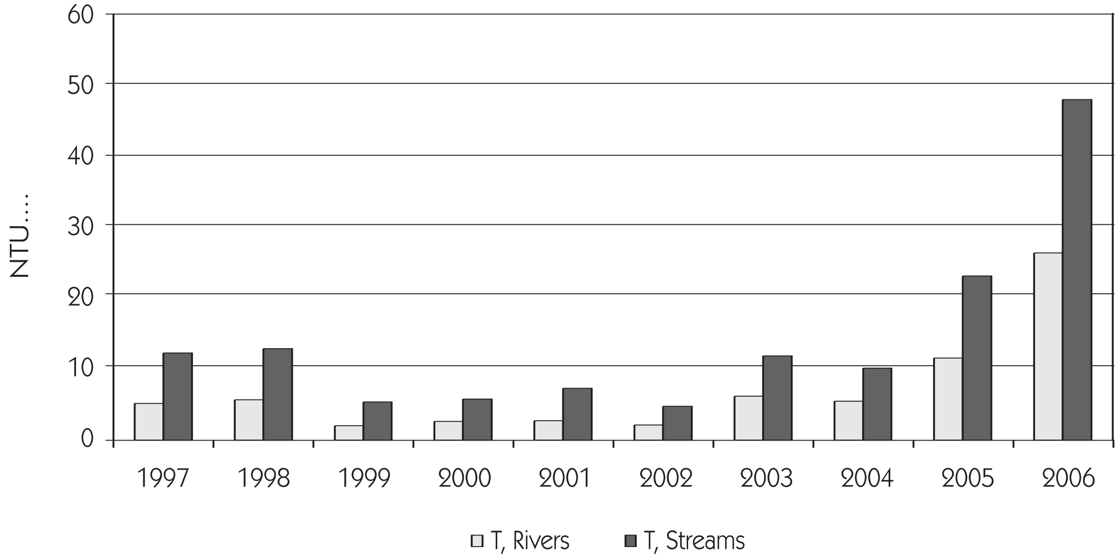


Figure 4-5
Trend for Turbidity at Most Impaired Sites

D: Sewage Treatment Plants (STPs)

The eight STPs active during 2006 had high impairment levels. STPs are a special case because they must purify, to the extent possible, highly polluted wastewater. Except for pH and dissolved oxygen which are at unimpaired levels for all six counties, the other parameters were all impaired or highly impaired at levels far above those found in the rivers and tributaries. Pollution control legislation, of which the Clean Water Act of 1972 is the earliest example, aims at controlling nutrients in the effluent through upgrading wastewater treatment plants. Since it would be extremely costly to upgrade sewage treatment plants to the level where the effluent of an STP would be that same as that found in rivers and tributaries, the wastewater treatment plants are issued permits that allow a certain amount of pollution. Nevertheless, although these pollutants are diluted many thousands of times by the rivers and tributaries into which their outfall flows, it is possible that they can still contribute significantly to river and tributary water pollution.

Figure 4-6 compares the concentrations of each of the six parameters of nitrogen, phosphorus, NH4, pH, turbidity, and dissolved oxygen for each of the seven STPs, and for the year 2006.

It is evident that nitrogen for FC31 and NS05 is well above the average level, and that phosphorus is also high for these two sites. Although permits have been granted by the VA DEQ to allow these high levels at FC31 and NS05, one can wonder why these two STPs are allowed to discharge more nitrogen than is allowed for the other STPs. The answer may be very simple, for example, the flow volume of the effluent may be very small relative to the flow volume of the receiving body of water.

Turbidity for NS28 and FC07 are somewhat above average. Ammonia seems to be a real problem for FC07 – and one wonders again why this STP cannot operate under the same standards as for the rest of the STPs. The Shenandoah River Riverkeeper, identifies the issue of the permitting process as an important one, and is engaged with the VA DEQ to promote reductions in these pollutants.

Figure 4-7: Variability of Nitrogen Concentrations in Effluent of STPs presents a more detailed view of the large variability of nitrogen concentrations in the effluent emitted by the seven STPs during 2006. The figure clearly shows the much higher concentration of nitrogen for NS05 and FC31 compared to those of the other five STPs.

Figure 4-6
Average Concentration of Water Quality Parameters in the Effluent of the STPs, 2006

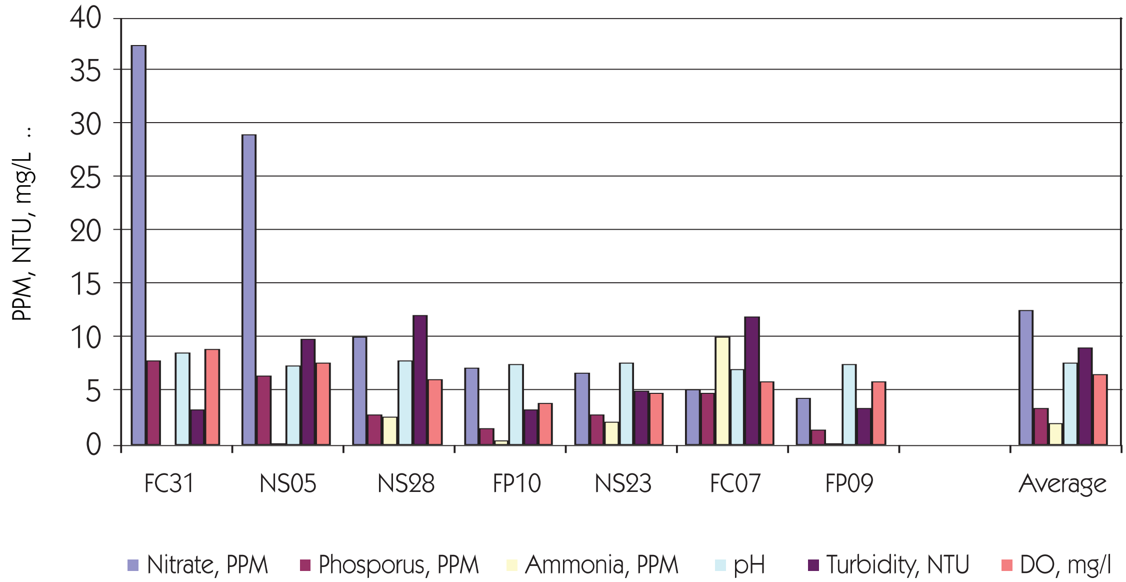
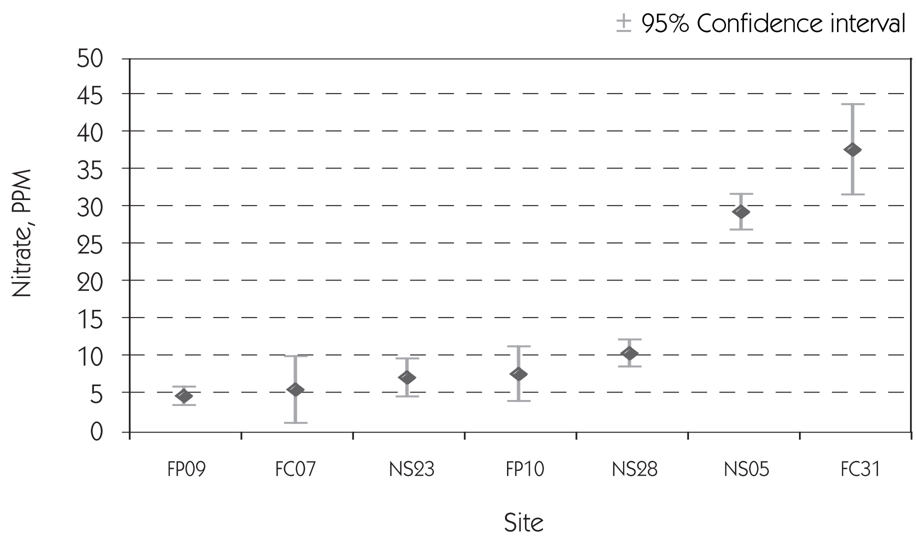


Figure 4-7
Variability of Nitrogen Concentrations in Effluent of STPs



5 Reasons for the High Pollution and the Growing Trend in Pollution

The purpose of this section is to discuss point source and non-point pollution. As stated in the American Rivers report, these sources of pollution are the two major reason for the deterioration of the Shenandoah River and its tributaries. We will also amplify on the statement in the American Rivers Report that the increasing trend in pollution is a consequence of the rapid population growth in the Shenandoah Valley, accompanied by deforestation and spreading of impervious surfaces. The chapter contains aerial photographs[11] illustrating how human activities can adversely impact on the River, and some of the remediation efforts that are being undertaken.

A: Non-point source pollution

One of the most important reasons for pollution is the runoff from urban and agricultural areas during periods of heavy precipitation.[12] The runoff contains nutrient, sediment, and noxious substances that, unless the tributaries are protected by vegetated or forested buffer zones that absorb the runoff, will flow directly into the river tributaries. In addition to this runoff from precipitation, pollution – especially sediment – can also come from poorly engineered development projects that disturb land without adhering to the best management practices (BMP) that prevent exposed soils from washing away. Cattle cooling off in tributaries and stirring up mud can cause considerable sedimentation. Finally, it is now conjectured that runoff rich in nutrients and possible growth hormones and other chemicals harmful to fish can come from litter waste from poultry processing plants.

B: Point-source pollution

Point source pollution, as the name implies, is pollution that comes from specific points along the river and tributaries. A typical point source is the effluent pipe from a sewage treatment plants (STP). Another important point source is effluent pipe that discharges factory waste into the water. The location of most of these point sources are well known, and waste water from wastewater treatment facilities and industrial polluters were substantially reduced by the Clean Water Act of 1972. Although this act had had a beneficial effect by reducing pollutant loads in waste water, the cost of improving the cleanliness of water is high, and operators exert considerable pressure to obtain permission to exceed the limitations imposed by the act. An uncertain but probably large number of point sources, especially in rural areas, are the straight discharge pipes of raw sewage from toilets, kitchens, and other sources of household waste that lead directly from the house or farm to the river. These are illegal but, partly because of lack of county and state personnel to find them and enforce requirements, are hard to control.

C: Land use changes and population growth

Most of the land in the Shenandoah River Watershed used for agricultural purposes has by now been cleared. But very significant stands of forests, such as for the development around Lake Frederick, are still being cleared to provide land for housing and industrial development. These forests provide tremendous benefits filtering out pollutants that might otherwise flow into the rivers and tributaries,

---

11. Bud Nagelvoort took photos during a helicopter survey of the Shenandoah Valley funded by the Chesapeake Bay Restoration Fund. Charles Vandervoort took photos from a small private plane.

12. David K. Mueller and Dennis R. Helsel, 1996, *Nutrients in the water: too much of a good thing*, U.S. Geological Survey circular 1136; and the National Water Quality Inventory – 1992 Report to Congress – U.S. Environmental Protection Agency.

but we have no estimates on how much. However, we do know what it is for air pollution. Virginia Department of Forestry estimates that forests provide over $900 million of air pollution abatement each year, based on conservative estimates of what it would cost to remove the same quantities of five major pollutants through alternative means.

Some photos illustrating the issues above

The aerial photo below shows the lack of a stream buffer on the right side of the stream, and the inadequate stream buffer of the left side of the stream. Also noteworthy is the runoff from the large muddy area near the cattle barn. The technical annex shows more of these photos taken from both the air and the ground of some of the causes of erosion.

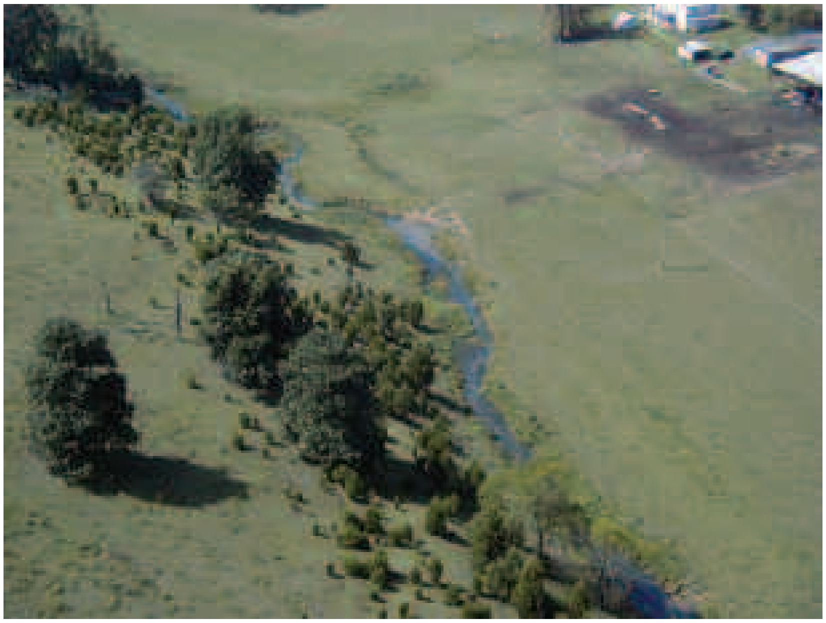


Photo 5-1
Aerial photo showing erosion along Pleasant Run

Turbidity is becoming a heightened concern for many researchers doing testing out in the field these days. Why? Mainly because high and persistent turbidity is the number one pollutant in the Shenandoah Valley. In addition, turbidity is a sensitive erosion indicator that warns of the impact that poorly planned and executed land, water run-off, and other causes of pollution are having on aquatic environments. Finally, in addition to being a good indicator to work with, it is relatively easy and inexpensive to measure in the laboratory. However, collecting the samples is hard work. Since turbidity is a rather fleeting event – it shoots up after a rain shower but then rapidly declines and the monitor must, for best results, collect the sample shortly after a storm. Unfortunately, the time of day the monitor collects the sample is at the whim of the weather. Therefore, we are quite sure that many of the spikes of turbidity are missed, and our monitoring results will tend to produce averages for turbidity that are low. But even though the effort to collect accurate turbidity data is high, it is well worth while. Our data, even though imperfect, indicates that high and persistent turbidity in the Shenandoah River watershed is becoming a serious problem.

Some of the reasons

Deforestation is frequently mentioned as a cause of pollution in tributaries and rivers, and as shown in Figure 5-1 and Figure 5-2, there seems indeed to be a pronounced relationship between forest cover and pollution. The Water Window developed under the direction of Professor Tom Benzing of the James Madison University provided an excellent tool for constructing this graph because it gives landuse in the watershed (or hinterland) for each of the sites monitored by the FOSR. The graph shows that strength of the correlation is only moderate for N – the R squared is 0.29 implying that about 30% of the variation in is explained by the degree of deforestation, and this suggests that replacing forests with agricultural or urban land will increase pollution. But much of this pollution, of course, can be significantly reduced by improving agricultural practices and by taking measures such as controlling stormwater in urban areas. (See Figure 5-5 and Figure 5-6 for an illustration of the much stronger relationship between forest coverage and turbidity).

Figure 5-1
Nitrogen vs. forestation, Rockingham County

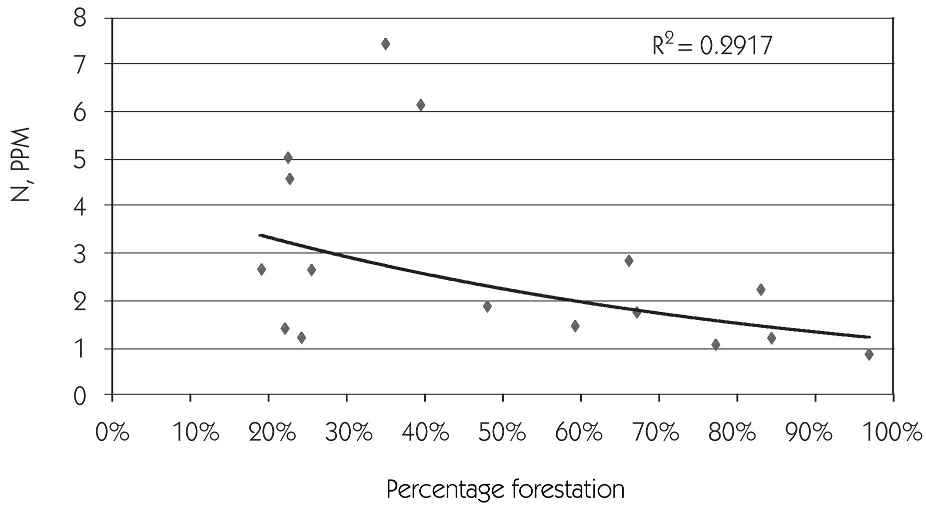
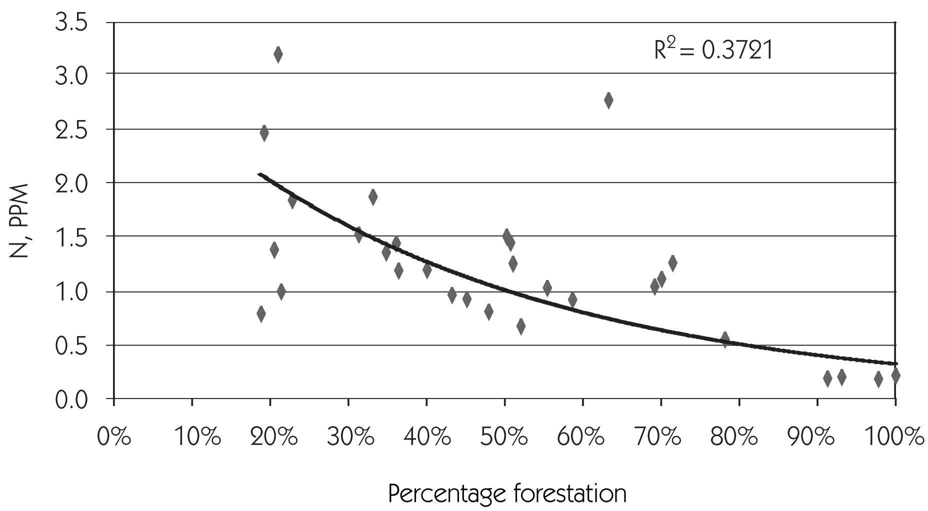


Figure 5-2
Nitrogen vs. forestation, Augusta County



The relationship for Augusta County is higher, about 37% of the variation in N is explained by the percentage of forest land. And since there are more samples for Augusta, our confidence in the significance of the correlation is higher.

In an attempt to find other variables that can explain possible relationships between the intensity and type of animal industry, and nitrogen levels, data available by county were examined. Data by sampling site were not available. All the various types of animal industry including cattle, hogs, and poultry affect pollution levels were examined, but the relation for poultry is the strongest. Figure 5-3 shows the results. For example, Rockingham poultry operations sold more than 10 million chickens in 2002, and its nitrogen pollution level is slightly over 4.0 PPM. It is clear that, as the number of chickens sold in a county goes up, the nitrogen levels tend to increase. And Rockingham County has by far the highest level of poultry industry, and explains to a large degree why this county is so much worse as far as pollution is concerned than Augusta County.

Stream Restoration – it works!

FOSR monitoring of Chapel Run in Clarke County shows the possible beneficial impact of stream restoration on water quality. Chapel Run, a six-mile long spring-fed tributary runs through soil that is a mixture of sand, silt, and clay, and is easily eroded. Cattle walking along the tributary banks to get water and to cool off have severely eroded the tributary banks.

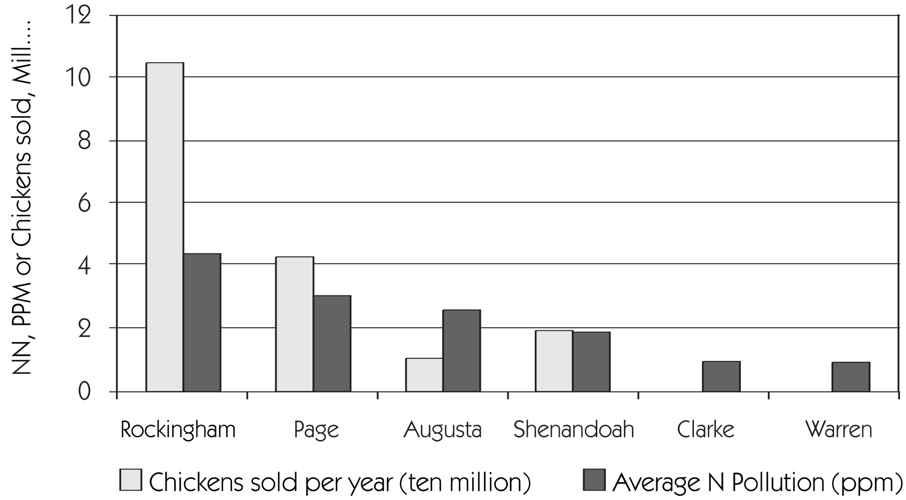


Figure 5-3
How the poultry industry is related to N-concentration in the streams

About five years ago, Bud Nagelvoort, one of the Clarke County monitors of FOSR and also the Chair the Lord Fairfax Soil and Water Conservation District became concerned about the deterioration of what used to be a good trout stream.

He worked with one of the farmers whose 600 acre cattle farm is along one mile of the six-mile long Chapel Run, and together with the LFSWCD and the Natural Resources Conservation Service of the U.S. Department of Agriculture they developed a plan for tributary restoration.

The plan involved adding about one mile of fence with much of it parallel to the tributary to keep the cattle out of the stream. This also required installing new wells and waterlines for drinking water for the cattle.

The total cost of the fencing and watering facilities was about $76,000, of which 75% was provided by cost-sharing funds through the Soil and Water Conservation District. The remaining 25% was paid by the landowners.

Also helping with the restoration were members of Trout Unlimited who volunteered their time to install tree trunks in the stream to prevent silt buildup and provide shelter for fish.

Figure 5-4 shows the nitrogen concentration in Chapel run before and after the restoration started. Before the start, the nitrogen levels trended upward from about 1 ppm in 1997 to about 2 ppm in early 2000. But by early January 2001 the nitrogen levels had leveled off to 2 ppm, and after the restoration was completed, in May 2004, the nitrogen levels seem to be declining. And the water

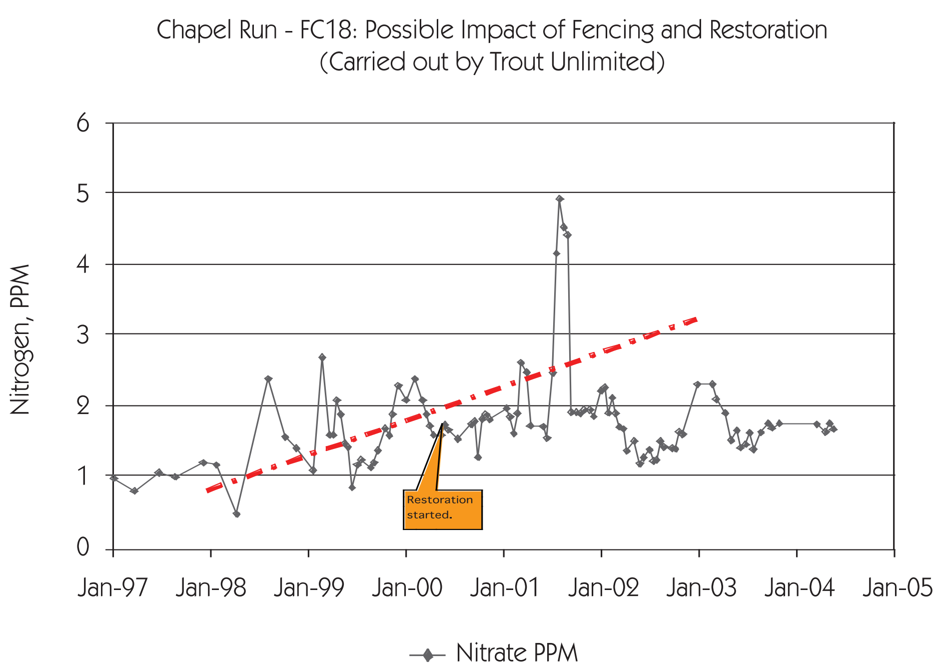


Figure 5-4
Impact of restoration on water quality

quality was judged good enough to warrant restocking the stream with trout.

What is impressive is that beneficial effects are already being seen from restoration involving only one-sixth of the total length of the stream.

Another example of stream restoration is that for the Willow Brook (WB) watershed. This watershed is included in the "Crooked Run/Willow Brook Initiative (WB/CR). Monitoring of this watershed indicated extremely high counts of E.Coli, and based on these findings the special initiative was funded in 2002 by the National Fish and Wildlife Foundation with matching funds from Lord Fairfax Soil and Water Conservation Service and Warren County. Two BMP's were installed on Willow Brook with promising initial results – E.coli measurement dropped from too many colonies to count to readings of 400/100 ml. A third BMP has been approved.

As made clear in Figure 5-5 and Figure 5-6, there is a strong relationship between percentage forest cover in the catchments area of a sampling site, and the turbidity measured at that site. For example, and as shown for Rockingham County below, the turbidity for low percentages of forest cover such as between 10% and 30%, the turbidity ranges between 5 NTU (fairly clear)and 12 NTU (extremely cloudy). But for sample sites with high forest coverage such as between 80% and 100 %, the turbidity falls around 2 NTU which indicates very "clear" water.

Figure 5-5
Turbidity vs. Forest Cover, Augusta County

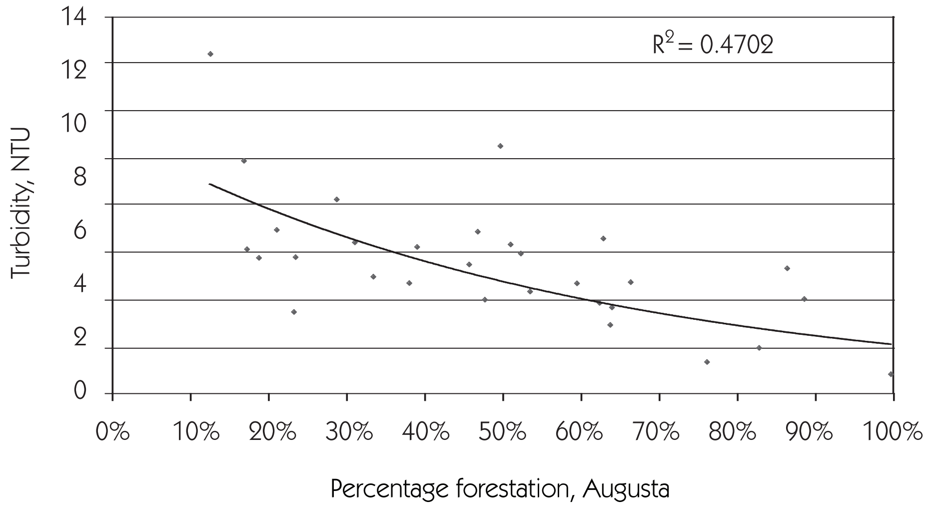
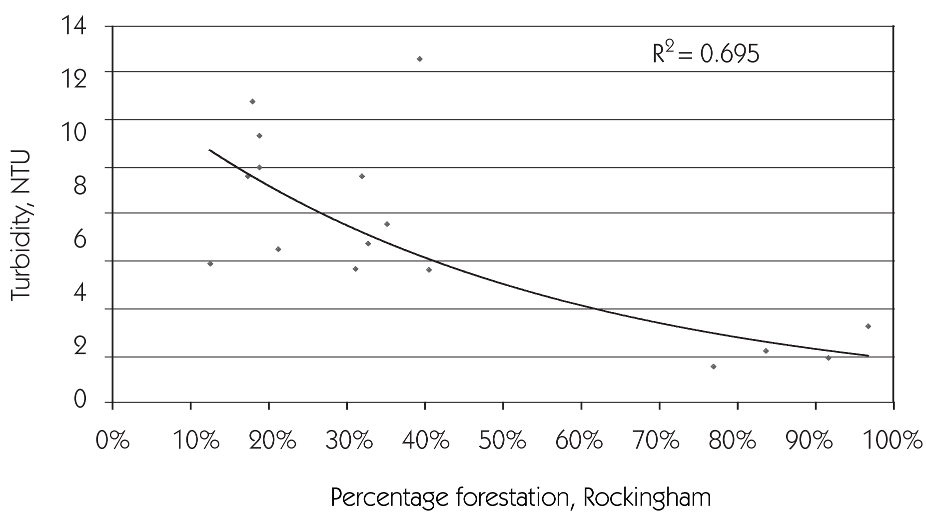


Figure 5-6
Turbidity vs. Forest Cover, Rockingham County



Photos taken during aerial surveys in 2004 and 2007

Photographs taken during an aerial surveys illustrating the impact on stream quality caused by insufficient stream protection.

Photo 5-2
Erosion caused by cows, near Smith Creek

The photo above shows the type of erosion caused from cow pastures, and that, unless there are adequate buffers, can cause considerable sedimentation and fecal matter to flow into a tributary creek.

Photo 5-3
Muddy water from cow pasture flowing into Smith Creek

The photo above shows how muddy water from an unprotected small run can pollute a larger stream, in this case Smith Creek in Shenandoah County.

Photo 5-4
Cows around and in stream, no buffer, Middle River

An example of a stream without protection of a fence or vegetation buffer, and vulnerable to the impact of cattle.

Photo 5-5
Erosion, Middle River

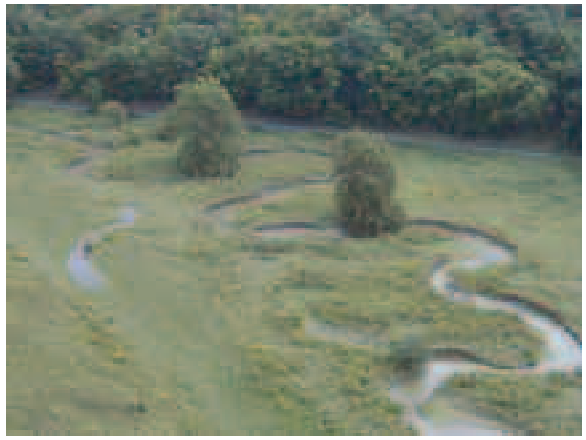


Photo 5-6
Poultry Farm, Holman's Creek, Shenandoah County

Rockingham County has over three hundred poultry rendering plants. According to the Chesapeake Bay Foundation, large-scale poultry operations produce more waste than hog, cattle, or dairy farms and up to 150 percent more of the nutrient pollution generated by human waste in the same area. In addition, poultry waste creates four times more nitrogen and 24 times more phosphorous than hog waste in Virginia

Photo 5-7
Trees and vegetation buffers, North Fork

Example of a good stream buffer.

Photo 5-8
Erosion with and without fencing, Willow Brook

The fencing seems to control erosion.

Photo 5-9
Earth moving, Pleasant Run

Muddy water can be seen to flow into one of the tributaries of Pleasant Run

Photo 5-10
Hinterland of FW21, Gooney Run, west of Rte. 340 in Warren County

Gooney Run is probably the most pristine stream in the Shenandoah River Watershed. It has an average nitrogen concentration in 2006 of only 0.2 PPM. One of the reasons, as shown in the photograph, is that the stream comes down from the forested highland shown in the hazy distance, and through country with little disturbance by human activities and with a high percentage of forest coverage.

Photo 5-11 shows a close-up of Gooney Run after it has come down from the highlands, and near the probable location where samples are taken. The stream is well protected with a forested buffer zone and is therefore hard to hard to see from the air.

Photo 5-11
Close-Up of FW21, Gooney Run, west of Rte. 340

Photo 5-12
Wheat Spring Branch, FC32

Photo 5-12 shows a small stream named Wheat Spring Branch that has one of the highest concentrations of nitrogen and sediment. It is located in Clarke County, originates in relatively flat country and, as shown in the picture, flows through large agricultural areas with little stream bank protection against runoff.

Photo 5-13
Deforestation caused by a development project.

Photo 5-13 illustrates a development project where almost no tree is left standing, and the cleared terrain will be replaced by impervious surfaces.

6

Prospects for Stopping and Reversing Degradation of the River

We summarize here the areas where progress is being made, and areas where progress is slow.

A: Areas where progress is being made

1. Conversion of forest land to agricultural and urban development use is slowing down: Deforestation to create new agricultural land seems to be at an end. According to the VCC,[13] reversion of farmland to forest is mostly complete, and urbanization is now the major converter of forest land. And according to the VCC there is a shift in ownership away from farmers who, in 1957 owned close 70% of forest land, and that by 1992 had declined to 30%.The VCC believes that less and less forestland is now owned by private citizens who view forests as a source of income. This is true, in part, but a significant fraction of these non-farmer private citizens are developers who don't see forestland as source of income, but see the forest land as a site for their houses. Communities therefore are putting tighter regulations on the amount of deforestation that can take place by both limiting development in mountainous areas, such as in the Clarke County Mountain Plan, and public education efforts to teach people about the value of trees and shrubs have been stepped up.
2. Public Appreciation of Shenandoah River is growing: Greater attention by the media to the problems of the Shenandoah River may motivate private citizens to urge their public representatives to spend more time on developing plans to reverse the adverse trends. It used to be, not so long ago, that one could ask a random person living in the Shenandoah River Watershed what he thought of the condition of the river. Chances are that he would not know anything, nor would he have much of an idea about how the health of the river would affect him and his family. And he would not be familiar with any of the many organizations that he could join to help with monitoring water quality, and to reverse the decline in water quality. But now, partly due to the severe problem with the fish kills, the media in the local area and as far away as Washington DC are devoting significant newspaper space to informing the public on the status of the river. And the appointment of a full-time "river keeper" (Jeff Kelble) who stays informed and designs and implements citizen actions on issues such as excessive sedimentation and nutrients, fish-kill and other issues, is doing a great job to informing the public on the status of the river, and on how they could volunteer some of their time to help.
3. Increased movement towards collaborative partnerships among watershed organizations. There are dozens of organizations (see the list in the Appendix) such as the FOSR, the Friends of the North Fork of the Shenandoah River, the Shenandoah Valley Pure Water Forum, the Valley Conservation Council, to mention just a few, that are collaborating with state and federal government in controlling point and non-point pollution. But, as most environmental issues, water quality problems are complex since they run across jurisdictional boundaries at the county, state, and federal level, and involve multiple stakeholders. Addressing these problems is putting a severe strain on the financial, volunteer, and staff resources of the numerous federal, state, local government agencies, quasi-government agencies, and nonprofit watershed organizations that are collaborating, or want to collaborate. To make these resources more effective, part of the solution is to pool resources and expand collaboration among these organizations. A recent report by a member of the Friends of the

13. Valley Conservation Council, *State of the Valley Report*, Staunton, Virginia, August 2003.

North Fork of the Shenandoah River[14] outlines the current status of collaboration, and suggests workable strategies for enhancing such collaboration. A typical move forward in this area is the important RWRPC discussed below.

4. Advances in Regional Water Resources Water Planning: In 2002 a Regional Water Resource Planning Committee (RWRPC) was created for the Shenandoah Valley in response to a 2003 state mandate requiring either local or regional water supply plans by 2011. This RWRPC is led by local elected officials, but is a stakeholder inclusive group including the FOSR and the FNFSR, and is facilitated by the Northern Shenandoah Valley Regional Commission (NSVRC). The RWRPC employs a total watershed approach to their task by assessing and including social, economic, political, and ecological factors in an attempt to comprehensively address the water quantity and quality issues facing the Shenandoah Valley. Through an extensive process involving stakeholder meetings throughout the Shenandoah Valley, as well as a Valley wide stakeholder survey, RWRPC has now identified six primary goals and supporting strategies, which have been combined into an action plan for water quality and quantity conservation in the Shenandoah Valley The main goal of the RWRPC is to reach regional consensus and state approval of this regional water quality and supply plan for the Shenandoah River by 2011. Although funding for implementation of the plan, as usual, may present problems even thought the benefits of successful implementation will far outweigh the costs. The development of the plan and the success in achieving collaboration among the numerous stakeholders involved can be considered a successful attempt at addressing the valley's water quality and quantity problems.

B: Areas where progress is slow

5. Growing urbanization and slow adaptation of measures for environmentally friendly development: As reported in American Rivers,[15] the population of the Shenandoah Valley is soaring and agricultural land is replaced by urban and suburban development. This rapid growth leads to more roads, parking lots, and roofs covering houses and large commercial establishments. Such hard surfaces prevent rain from soaking into the ground, and the rain water is forced to flow at sufficient velocity to carry with it lawn fertilizer and other pollutants that feed into the tributaries and rivers. Although there are perfectly feasible alternatives to asphalt-paved parking lots, these alternatives such as porous bricks are more expensive to install, and there are no market-based incentives for the developer to use such porous materials. As mentioned again below, although the benefit/cost ratio of using porous pavement materials is very high, and although this therefore looks good from the overall economic point of view, the private developers cannot directly capture that value, so they are reluctant to invest in the environment. Solving this problem can be done either through a collaborative process that, if successful, is probably the best way. Or it can be done through centralized regulations, but has proven difficult to enforce. Probably a combination of these two approaches is needed.
6. Inadequate enforcement of environmental laws controlling erosion: Almost all communities in the Shenandoah Valley have adequate laws to control soil erosion. As a typical example, Clarke County has an ordinance that addresses erosion problems on construction sites, and that requires anyone who causes land disturbance that exceeds 2500 square feet, such as for clearing land for a house, to submit an erosion and sediment control plan. Such a plan must be approved and during construction the project is subject to inspection to ensure that the plan is properly implemented. Unfortunately, frequent inspection is very difficult because of too few inspectors that are trained on what soil erosion is, and how it is controlled. This, as we probably all know, is symptomatic in law enforcement.
7. Lack of public and private sector understanding of what the environment is worth: There are many ecosystems such as forests, rivers, grass lands, that provide real services but that are not measured in traditional markets. Forests, for instance, provide climate regulation, control erosion, absorb carbon dioxide, generate oxygen, provide recreational opportunities, etc. But how much are these services (and they are provided free) worth? This is a good question,

---

14. Leslie D. Mitchell-Watson, *The Making and Keeping of Friends: Building and Sustaining the Capacity of a Community Watershed Organization in the Shenandoah Valley of Virginia*, Masters Thesis, Virginia Polytechnic Institute and State University, December 2006.

15. America's Most Endangered Rivers of 2006.

and it is now being increasingly addressed in a number of studies. For example, an article[16] published by the Izaak Walton League of America says that *"the environment is providing valuable economic services that are taken for granted. In fact, they are abused and degraded regularly. Sutton, Costanza, and their colleagues from Stanford University found that the environment is a large, unsupervised factory that pumps an estimated $2.084 trillion dollars worth of goods and services into the economy each year. That is 22 percent of the entire value of the U.S. economy."* The problem is that, although this looks good from the overall economic point of view, the private owners cannot directly capture that value, so why should they invest in the environment? For example, a farmer who invests in installing a riparian buffer and thereby reduces the amount of nutrient spilling from his land into the river does not capture this benefit directly by increasing his income. Of course, he benefits indirectly from the improvement in environment, although he probably does not perceive it, since it does not mean more money in his pocket.

16. Izaak Walton League of America, Breaking the Bank - America's Conservation Deficit , Spring 2007, page 23.

7

Mercury Contamination in the South River and South Fork of the Shenandoah River

Overview

Mercury contamination of the South River was discovered some 30 years ago below DuPont's textile plant in Waynesboro. It is generally accepted that the mercury originated with DuPont's operations and that airborne mercury contributions from elsewhere are trivial in comparison. Concentrations of mercury in the South River and the South Fork of the Shenandoah River, into which it flows, are well below the permissible limits for mercury in drinking water. Problems arise because bacteria can react with mercury to form methyl mercury. Methyl mercury can and does bioaccumulate as it is passed up the food chain, thereby reaching levels in the flesh of fish that are toxic to humans who eat the fish.

In 1977, a year after the discovery of mercury contamination, DuPont notified state and federal authorities, and the Virginia Department of Health (VDH) issued a fish consumption ban on 130 miles of the South River and the South Fork of the Shenandoah River. Based on monitoring results, VDH has changed the ban to a fish eating advisory when and where conditions warranted. As of this writing, all fish species in the South River (except trout) are banned for consumption from the footbridge at the DuPont plant in Waynesboro to the confluence with the North River at Port Republic. On the South Fork of the Shenandoah River from Port Republic to the confluence with the North Fork of the Shenandoah River and up the North Fork to Riverton Dam, then on the Shenandoah River from the confluence of the South and North Forks to Warren Power Dam just north of Front Royal there is an advisory not to eat more than two meals a month of fish taken from those waters. Stocked trout are exempt because they do not remain in the named rivers long enough to accumulate requisite levels of methyl mercury.

There was not a lot of activity for several years after the authorities were notified. However, in 1982 a consultant chosen by DuPont and the State Water Control Board recommended that natural attenuation was the best course to pursue regarding the mercury contamination. And in 1984 DuPont funded a 100-year monitoring program for mercury in fish, water, and sediments in the affected rivers that was carried out by various state agencies. But by 1999 it was evident that mercury levels in fish tissue were not decreasing as expected.

History/chronology of significant events

DuPont Co. used mercuric sulfate as a catalyst in the production of acetate fiber from acetylene and acetic acid in its plant at Waynesboro between 1929 and 1950. Sludge from the process was distilled to recover metallic mercury, which then was reacted with sulfuric acid to remake the catalyst.

On September 9, 1976, workers repairing a water line discovered metallic mercury in soil at the DuPont plant. On September 29, 1976, aquatic biologists collected the first samples. On April 13, 1977 DuPont notified the State Water Control Board, USEPA, and Virginia Department of Health (VDH) of the mercury contamination.

Also in 1977, VDH closed 130 miles of the South River and South Fork of the Shenandoah River to fishing. The ban reached from Waynesboro to Front Royal. In 1980 after data review, VDH replaced a consumption ban with consumption advisories on 90 river miles. The advisories have been changed from time to time. They are posted along the river and, until recently, have been printed in the Virginia freshwater fishing regulations. Now, up-to-date fish consumption advisories can be found at the Health Department's Web site, www.vdh.virginia.gov/hhcontrol.

In 1982 an engineering report that evaluated the mercury cleanup options and recommended natural recovery and monitoring was approved by state agencies.

In 1984 DuPont settled with the State Water Control Board by establishing a trust fund to support a 100-year monitoring program for mercury. The 100-year plan to monitor fish, water, sediments, and floodplain soils was initiated in 1990 by VADEQ and Department of Game and Inland Fisheries (DGIF). Fish tissue monitoring has been carried out six times from 1990 through 2005. The next round of sampling will be in 2007 and every five years thereafter for the next 85 years.

In September 1998, EPA issued to DuPont's Waynesboro site the Corrective Action portion of their Resource Conservation and Recovery Act (RCRA) permit to conduct investigations and determine what, if any, corrective measures of on-site SWMUs (solid waste management units) are necessary. The RCRA Facility Investigation (RFI) evaluated soil and groundwater quality beneath/near twenty SWMUs at the 177-acre facility. Further on-site investigation and possible corrective action are scheduled for the retort area (SMU 1), waste incineration area (SMU 4), the sludge pond (SMU 6/7) and the storm sewer system.

From the late 1980's to 1999, VADEQ lead the fish tissue monitoring efforts with VADGIF and VDH. It became apparent, however, that the mercury levels in fish tissue were not decreasing as predicted.

In November 2000, DuPont and VADEQ established the South River Science Team (SRST) to serve as a focal point for technical issues concerning mercury in the South River and downstream waterways. It is a cooperative effort between VADEQ, VADH, Department of Game and Inland Fisheries (VADGIF), and representatives from DuPont, USEPA Region III, academic institutions, and citizen groups. An FOSR has attended almost every meeting since the Team's inception.

SRST provides technical direction for the fish tissue mercury monitoring program and has planned and is carrying out research programs to determine specifically from where, and in what quantities, mercury is entering the river system, where and how it is being methylated, how it is being transported, and what effects it is having on a variety of potential receptors. This research is essential for the development of a practical, effective cleanup plan. It is a slow, painstaking endeavor because the mercury is highly dispersed and is present in invisible, minute concentrations. For example, concentrations of mercury in floodplain soils, where present, are found at concentrations in the low parts per million ranges. Concentrations of methyl mercury in the river are typically a thousand times less.

In October 2003, the Natural Resources Defense Council and the Sierra Club initiated a lawsuit against DuPont because it was felt that the RCRA activities focused almost exclusively on the plant site and neglected the effects of mercury that had already entered the South River. A negotiated settlement resulted in a Consent Decree that mandated a six-year Ecological Study. Phase I of the study began in March 2006. The ecological study is being conducted in conjunction with the investigations of mercury sources and transport described above. In 2012, approximately, DuPont will propose remedial actions, if any, for the South River. NRDC and the Sierra Club will evaluate whether the proposed remedial actions would protect public health and the environment.

Development of the Total Maximum Daily Load (TMDL) for mercury in the South River started in 2006. This will be a two-year study, required of Virginia by EPA under the authority of the Clean Water Act. A TMDL study calculates the maximum amount of a pollutant that the river can receive and still meet water quality standards. It also allocates proportional amounts of the total load to pollutant sources. The U.S. Geological Survey (USGS) is collecting data and will calculate the TMDL under the direction of VADEQ and with the cooperation of SRST. The result will determine what reductions in mercury loadings are required to lower concentrations of mercury to meet Virginia's standard of 0.5 parts per million in fish tissue. The TMDL should form the basis of an eventual cleanup plan for the South River and the South Fork of the Shenandoah River.

8 Fish Kills in the Shenandoah Watershed

From the spring of 2004 to the present time, a series of fish kills in the South Fork of the Shenandoah River, its tributaries (North, Middle, and South rivers), the North Fork of the Shenandoah River, and the Main Stem have occurred that are unlike any others in the recent past. These fish kills are different in that so far they cannot be explained solely by water quality parameters (such as found in this report), unique pathogens, or by point source toxic discharges. Similar fish kills were found in the watershed of the South Branch of the Potomac in West Virginia in 2002 and in the Cowpasture River, Maury River and Upper James River in Virginia in 2007.

Smallmouth bass and redbreast sunfish are the species most affected, although other affected species include hognose suckers, central stonerollers, and rock bass. The magnitude of the problem is great. For example, Virginia Department of Game and Inland Fisheries (VGDIF) estimate a loss of 80% of adult smallmouth bass and redbreast sunfish in the South Fork of the Shenandoah River from April to July 2005. The most widespread fish kill – throughout the Shenandoah River watershed – took place in 2007 and affected fish of all ages. Although losses in the various fish kills have been significant, fish spawns and hatches have been significant as well. An accurate assessment of fish losses, and gains by hatches, will be made by late 2007.

Sick or dead fish typically have skin lesions resembling burns, mucous coatings, or fungal growths. Pathologic studies show that the sick or dead fish have been attacked by any one of many bacteria, viruses, or parasites. Hypotheses for investigation concern multiple stressors on the fish, chemicals that can compromise the fish immune systems (such as endocrine disruptors) and constituents of agricultural waste.

To conduct these and other investigations, the Shenandoah River Fish Kill Task Force was formed in July 2005. Coordination is by the Virginia Department of Environmental Quality (DEQ) and VGDIF. Task Force members include people from State and federal agencies, academia, agriculture, and citizen environmental groups, including Friends of the Shenandoah River and Friends of the North Fork.

In addition to the Task Force, the state has formed a Research Advisory Committee to help direct and interpret research results. This spring there was extensive sampling of fish, sediment, and water quality by the State, federal agencies, Virginia universities, and local groups. As a result, information about the fish kill problem is growing rapidly. To keep up it is suggested that one view the Web sites of DEQ and VDGIF (www.deq.va.gov and www.dgif.state.va.us, respectively). These sites are updated regularly. They formed the basis of this section of the report.

Figure 8-1
Fish Kill Locations, Courtesy DEQ

9 Appendices

A: Methodology

Selection of the Sampling Sites

Before the start of the data collection program in 1997, the rivers, tributaries, and sewage treatment plants (STP) to be monitored were selected, in essence, by taking a 100% sample. The basis for this sample was the census of the population of rivers, tributaries, and STPs in the Shenandoah River Watershed as presented in the hydrologic unit maps for the Shenandoah River Watershed developed by the USGS. The objective was to monitor all of the rivers, tributaries, and STPs shown on those maps.

Ideally, if at the start of the monitoring program the characteristics of the streams and STPs had been known in terms of their flow, and statistical characteristics such as mean, variance, and shape of the distribution of the water quality parameters of nitrogen, phosphorus, and so forth, it would have been possible to apply random sampling. A scientifically designed random sample allows statistically valid deductions (without bias) about the characteristics of the population from which the sample is taken. A small random sample, of course, offers a great saving in labor, as compared to practically taking a 100 per cent sample that includes the whole population, as we did.

It should be noted that, at present, the FOSR database does contain the statistical information on water quality parameters necessary to prepare a scientifically designed random sampling plan. Such a plan will reduce the resources required in the future for the monitoring program and will reduce possible subjective selection of monitoring sites.

Good monitoring sites for the rivers, tributaries, and STP effluents could easily be found close to roads. However, a small number of runs, brooks, creeks, branches, and other small tributaries, most of them unnamed and some of them dry in the summer, were inaccessible by vehicle, and would require extensive time and effort to reach by foot or horse back. This was unfortunately beyond the limited time the volunteer monitors could make available. But there were not many of these inaccessible tributaries, and since these tributaries were located in the highlands far from human disturbances, their waters could safely be assumed to be quite pure. In addition, these tributaries almost all had very low stream flows and would therefore carry very low levels of pollution. Furthermore, these skipped tributaries eventually joined larger tributaries that could be monitored, and their water quality was therefore inferred indirectly.

For each tributary it was considered important to have at least one point at the mouth of each tributary. This would provide an estimate of the concentration of each parameter as it enters the river. It would also enable, in the future, once stream flow data were to become available, to calculate the loading (such as tons per day) of pollutant deposited into the river by each tributary. Another factor entering the site selection decision was to select, for large tributaries, and in addition to the site at the mouth, a site at the beginning of the tributary and in the middle. This sometimes was not possible because of limitations in the road network. By having several monitoring sites in each tributary increases the number of samples, and improves the reliability of the statistical measurements such as average value, median, variance, and trends of the water quality parameters.

Initially, in 1997, the database contained 252 monitoring sites. These included 70 monitoring sites on rivers, 165 on tributaries, and 17 for the effluents of STPs. By 2006, however, 135 of the sites had been dropped for several reasons. It was found that some (but not all) tributaries contained duplicate sites. That is that the multiple monitoring sites yielded values for the water quality parameters that were very similar. For example, Muddy Creek, Cooks Creek, and Pleasant Run each started with monitoring five sites. However, after 1998, four of the sites were dropped from each tributary as redundant because they all reported concentrations of nitrogen and phosphorus that were very similar. And the South River, Middle River, and North Fork started off with 10, 10, and 18 sites respectively. After 1998, and for the same reason as for the tributaries, the monitors dropped 5, 4, and 9 of the sites respectively.

B: Statistical Considerations

Simple versus weighted averages.

Some tributaries have several monitoring sites, typically one at the head of the tributary, one in the middle, and one at the mouth. The flow at the head will be small, and since tributaries usually start off in the highlands and away from human disturbances, their waters will be relatively pure. And at the mouth of the tributary, the water will almost always contain the highest concentrations of the water quality parameters. Using unweighted or "simple" averages therefore could probably result in averages that are lower than if an average weighted by stream flow had been calculated.

Because data on stream flow in tributaries and rivers are very sparse, however, we were restricted to calculating unweighted (simple) averages in this report. If a simple unweighted average is calculated, the calculation of the average concentration will give equal weight to "pure" and low flow sites, and "polluted" high-flow sites. This will result in an average indicating less pollution than that calculated by a weighted average. A weighted average would accurately discount the upstream sites where the flow is low, and would give more emphasis to the concentration at the mouth.

For tributaries that have only one monitoring site that is located at the mouth where the stream flow and concentrations are highest, the estimate for the average concentration will be somewhat overestimated. For example, the concentration of nitrogen will be higher than it would have been if an upstream sample could have been included.

For the case of rivers, the concentrations of the parameters taken at various monitoring sites along the river show less variation than for the case of tributaries. We have applied a statistical technique called analysis of variance (ANOVA) to test the hypothesis that there is no difference in average values (the means) of the concentration of the parameters collected at various points along the river. For most of the six rivers these calculations show that average concentrations do not vary much between the monitoring sites along a river. An exception is the North River where the first monitoring site is close to where the river originates in the highlands of West Virginia. At that site the concentrations of nutrients are low, as is the stream flow. Compared with a weighted average which takes into account the larger flow and loading at the mouth of the tributary, the simple average for the North River will underestimate the concentration. For the same reason, however, the error is small.

A special case is the pH parameter. pH is measured on a logarithmic scale to the base ten using the formula pH = -log(H^+), where the quantity within parenthesis is the concentration of hydrogen ions measures in moles per liter. This means that a small percentage change in pH implies a very large percentage change in H^+ concentration.

For example, water in a sample with a pH of 8 is ten times more alkaline (contains ten times fewer hydrogen ions) than water in a sample with a pH of 7. Similarly, water in a sample with a pH of 5 is ten times more acidic (contains ten times more hydrogen ions) than water in a sample with a pH of 6. Therefore, each pH value has a different H^+ concentration. Water with a pH of 7 has 0.0000001 moles per liter, whereas water with a pH of 4 has 0.0001 moles per liter, or one thousand times more..

Therefore, when calculating average pH, a "weighted" average rather than a simple average should be used. The weighting in this case is the molar concentration of H^+ in moles per liter.

An error that must be kept in mind is caused by the well known diurnal variation of pH in the waters of the Shenandoah River Watershed. As stated in the Fish Kill Science Team report,[17] the pH in the river shows daily swings from neutral to strongly basic (high pH) on days when water is clear; and pH daily highs may regularly exceed 9.0. As explained elsewhere in this report, the monitoring schedule misses capturing water samples when the diurnal swing is at its peak. It is therefore possible that, on balance, the estimates of pH underestimated, i.e., the alkalinity of water is higher than we think.

Frequency of monitoring

Regarding the frequency of monitoring, the policy at the outset of the monitoring program was to monitor as often as possible within the limits of the available monitor hours. At the beginning the frequency of monitoring was twice a month. This turned out to be an achievable level, and stayed at this level throughout the program.

17. Fish Kills in the Shenandoah River Basin: Preliminary Report of the Shenandoah Basin Science Team, Submitted to: Virginia Department of Environmental Quality, January 15, 2007.

Interdependence

Since water flows downstream, and depending on the time interval at which samples are taken and the distance between sampling sites, there could be an interdependence between upstream and downstream samples. If the interdependence is strong , simple trend analysis as used in this report is no longer valid, and considerably more complex techniques such as autoregressive integrated moving average (ARIMA) techniques[18] must be used. We have investigated the interdependence, and fortunately the interdependence is not strong.

The degree of interdependence is a function of a number of factors including the proximity of the monitoring sites. For example, the values of a parameter for a sample taken today at location x, and for a sample taken today at a point 100 yards upstream from x, will probably be close. Averages taken from sites that are very close together could introduce bias in the sample.

If the distance between the sites is large, say more than one mile, the two values of would probably differ significantly because the separation of the sites is of sufficiently great to allow many other factors to influence the downstream sample. In this case the average for each site would be unbiased, i.e., representative of the stream or tributary.

Another factor is the interval of time at which the samples are taken. If the time interval is short, consecutive samples taken from the same site could be interdependent. But for longer time intervals the interdependence will be weak. For example, a sample taken today will have parameter values close to those taken one hour or perhaps one day later. An exception would be that caused by a weather event such as sudden rainstorm occurring between the time the samples are taken. However, if the time between which the samples are taken is two weeks, as is the case for the FOSR monitoring program, the problem of interdependence becomes less important – there are simply too many short term factors that can affect water quality in two weeks.

C: Water Quality Parameters Measured by the FOSR and Supporting Organizations, and Suggested Standards

This chapter describes the six water quality parameters currently tested in the FOSR monitoring program,[19] and develops suggested standards enabling us to judge the concentration levels at which they impair the waters by stimulating eutrophication and harming aquatic life. The parameters that we believe are indicative of water quality fall into three groups. The first group consists of three nutrients: nitrate nitrogen (N), ortho phosphate (P); and ammonia nitrogen (NH_3 and NH_4).These nutrients are essential to the growth of aquatic plants. In turn, aquatic plants are essential to the healthy life of fish by generating oxygen during the daytime, by offering shelter for minnows, and by providing a healthy environment for the insects that fish feed on. The second group of water quality indicators includes dissolved oxygen (DO), acidity/alkalinity (pH), and turbidity (T). These parameters are also essential to healthy aquatic life in rivers and tributaries.

The EPA has developed a standard for phosphorus in fresh water as it affects eutrification. It has not yet developed standards for some of the other parameters, such as nitrogen and turbidity, as it affects eutrophication and aquatic life. (The EPA, however, has developed standards for nitrogen contained in drinking water, and as it affects human health. The maximum allowed level in drinking water is set at 10 PPM.)

We developed what we believe to be reasonable standards for nitrogen, ammonia, pH, turbidity and dissolved oxygen on how they affect eutrophication and aquatic life. The FOSR lacks the resources to engage in the substantial amount of basic research necessary to develop such standards. Our approach therefore was to research the literature to find reasonable suggestions from what are believed to be competent authorities on what the limits for nitrogen and other parameters should be regarding eutrophication and health of aquatic life. In the following sections we will discuss the characteristics of the water quality parameters, and will develop the standards needed for their evaluation.

Nutrients

Nutrients consist mostly of nitrogen, phosphorus, and ammonia. Usually phosphorus is the limiting nutrient in fresh water, while nitrogen is often limiting in the oceans and in coastal estuaries. But this is not always the case; as discussed below there are cases where nitrogen is the limiting factor in fresh water.

18. Box, G.E.P, and G.M. Jenkins, *Time Series Analysis Forecasting and Control, (San Francisco Holden- Day, 1977)*.

19. The FOSR has started monitoring for fecal coliform in several locations, and hopes to broaden its program to include PCBs and Mercury.

The growth of algae and other aquatic plants is normally limited by the supply of these nutrients. But if nutrients become excessive, as can occur during the summer months, they encourage excessive growth of algae and aquatic plants. This causes an unsightly scum on the water surface that spoils the enjoyment of swimming, canoeing, and other aquatic sports, and that can cause expensive problems by clogging water intake pipes.

The worst problem, however, is that excessive nutrients encourage eutrophication, or the process by which a body of water that is too rich in nutrients encourages the growth and decomposition of oxygen-depleting plant life. This can cause great harm aquatic life and other organisms. Water with low levels of oxygen, called hypoxia, causes stress and makes aquatic life vulnerable to disease. Water with no oxygen, called anoxic, will kill most aquatic animals, and may contribute to fish kills.

Although eutrophication is often thought of as accruing only in lakes and bays, high nitrate concentrations from nonpoint sources of nutrients from agricultural land can also cause extensive eutrophication, including within the fresh water streams in the Shenandoah Valley[20] as well as in the Potomac River. And as reported in the Fish Health Workshop[21] conducted by the USGS in January 2007, "eutrophication has initiated a cascade of deleterious water quality changes that may have adversely affected fish, and potentially made them more susceptible to infection." Also, as reported in (Johnson and others, 1993)[22] nonpoint pollution can potentially supply large quantities of nutrients through stream flow and groundwater inflow resulting in large nutrient accumulations downstream and extensive eutrophication." Subsequent algal decay causes the destruction of habitat and the depletion of dissolved oxygen, which usually results in the disappearance of intolerant aquatic insect species and fish.

Eutrophication probably contributes to major problems to our Shenandoah River and its tributaries. As reported in the preliminary report[23] of the Shenandoah Basin Science Team, infectious disease outbreaks in fishes in the Shenandoah River may coincide with a variety of stresses, such as eutrophication.

We don't know exactly how many of the excessive nutrients are carried into the waters of our downstream neighbors: the Potomac River and Chesapeake Bay. But according to the Chesapeake Research Consortium (CRC),[24] *"Because of the plausible link between water quality and fish disease, watershed restoration efforts to reduce input of nutrients, storm water, and other contaminants (e.g., EDCs)[25] to surface waters should be continued and expanded."*

Eutrophication is becoming a major problem in our rivers and the Chesapeake Bay. The latter is now troubled by large "dead zones" where oxygen levels are too low to support aquatic life ranging from free swimming fish to oysters living on the bottom. The decaying matter, even though temporary, can kill fish very quickly.

Nitrogen (N)

Nitrogen is a critical plant nutrient, and most nitrogen is used and reused by plants within an ecosystem.[26] Therefore, in streams that are not disturbed by human activity that results in nitrogen being deposited in streams, concentrations of nitrogen are very low. According to the USGS[27] nitrogen con-

---

20. Janet M. Denis and Joel D. Blomquist, *Nitrate in Streams in the Great Valley Carbonate Subunit of the Potomac River Basin*, USGS NAWQA Fact Sheet 161-95

21. Chesapeake Research Consortium (CRC) Publication No. 07-162, *Chesapeake Watershed Fish Health Workshop*, January 23 - 25, 2007

22. Johnson, R.K., Wiedertiolm, Torgny, and Rosenberg, D.M., 1993, Freshwater biomonitoring using individual organisms, populations, and species assemblages of benthic macroinvertebrates, in Rosenberg, D.M., and Resh, V.H., eds., Freshwater biomonitoring and benthic macroinvertebrates: New York, Routledge, Chapman & Hall, Inc.

23. Dr. Greg Garman, Center for Environmental Studies and Department of Biology at Virginia Commonwealth University, and Dr. Donald Orth, Department of Fisheries and Wildlife Sciences at Virginia Tech, 2007. *Fish Kills in the Shenandoah River Basin: Preliminary Report of the Shenandoah Basin Science Team*, Submitted to: Virginia Department of Environmental Quality, January 15, 2007.

24. Chesapeake Workshop Consortium (CRC) Publication No. 07162: *Summary of findings and recommendations, of a workshop entitled Fish Health in the Chesapeake Watershed: Synthesis and Evaluation*, January 2007, U.S. Fish and Wildlife Service's National Conservation Training Center, Shepherdstown, WV.

25. Endocrine disrupting compounds.

26. Vitousek, P., Mooney, H., Olander, L., and Allison, S. 2002. Nitrogen and nature. Ambio 31: 97-101.

27. David K. Mueller and Dennis R. Helsel, 1996, *Nutrients in the water: too much of a good thing*, U.S. Geological Survey circular 1136; and the National Water Quality Inventory – 1992 Report to Congress – U.S. Environmental Protection Agency.

centrations in samples from sites with little human disturbance were less than 0.6 Mg/L, and concentrations of phosphorus were usually less than 0.1 Mg/L. These human activities include such as polluting the air with nitrates that produce acid rain, the spreading of excess fertilizer, cutting away of forests, paving of large sections of land with asphalt and other impermeable surfaces, etc. And when nitrogen contained in fertilizer is applied to the land in amounts greater than can be synthesized into protein by plants, or released into the atmosphere by internal combustion engines and smoke stacks, nitrogen concentrations in streams will usually increase.

The major sources of excess nitrogen are fertilizer and animal waste; other sources include failed septic systems, sewage treatment plants, and deposition by the atmosphere.

Nitrogen standard

There are no EPA nitrogen guidelines for fresh water streams except that, for drinking water, the critical level for nitrates has been set at 10 parts per million (ppm). The EPA believes this level of protection would not cause any potential health problems. Drinking water containing nitrogen levels above 10 Mg/L may pose a risk of methemoglobinemia, a condition that interferes with oxygen transport in the blood of infants.[28]

Apart from how nitrogen affects drinking water, high levels of nitrogen/nutrients may result in overgrowth of algae which can decrease the dissolved oxygen content of the water and that can increase algal toxins that can harm or kill fish[29] and other aquatic species in the Shenandoah River Basin.

The EPA National Office has not yet set a standard for levels of nitrogen that can promote abnormally high growth of algae and other aquatic plants. However, the Region 3 Office of the EPA (Philadelphia), has carried out a water quality assessment in the Mid-Atlantic highlands (that includes the Shenandoah River Watershed) that develops standards for nitrogen. The standards is derived by calculating the ratio between nitrogen and phosphorus (for which the EPA already has provided a standard) that indicates when aquatic plants grow near their optimum rate.[30] The EPA considers that nitrogen levels below that value can be considered to be unimpaired.

According to the EPA, the nitrogen/phosphorus ratio found in streams undisturbed by human activity is 15:1. Since the EPA has developed threshold levels for phosphorus with below 0.05 ppm being low, between 0.05 and 0.1 being marginal, and above 0.1 ppm being high, the EPA calculates the nitrogen critical levels as 0.75 ppm for the standard separating good and fair; 0.75 to 1.5 ppm for the standard separating fair and poor, and larger that 1.50 ppm as poor. This calculation agrees well with the indicator suggested by the USGS[31] that states "streams with nitrogen concentration greater than 1 mg/L are considered unnaturally high, compared to streams with minimal human influences." These standards are not so much to protect human health, as they serve to protect the streams and rivers from eutrophication.

Phosphorus

Phosphorus is an essential nutrient for all life forms, and ortho-phosphate (referred to as phosphorus in this report) is the most easily metabolized form of dissolved phosphorus in water. At high concentrations this most biologically active compound of phosphorus can cause water quality problems by, in conjunction with nitrogen, over stimulating the growth of algae. And as discussed before, excess algal growth can contribute to the loss of oxygen needed by fish and other animals. Elevated levels of phosphorus in streams can result from fertilizer use, animal wastes and wastewater, and some detergents.

Phosphorus standard

Phosphorus in water is not considered directly toxic to humans or animals and therefore no drinking water standards have been established for phosphorus. Any toxicity caused by phosphorus pollution in fresh waters is indirect, through stimulation of toxic algal blooms resulting oxygen depletion. To

---

28. Consumer Fact Sheet On: Nitrates/Nitrites (EPA).

29. According to the Chesapeake Bay Foundation, (http://www.chesapeakebay.net/newsfishkills110906.htm) the high nutrient levels last summer were responsible for harmful algal blooms and low DO levels that led to fish kills in several Bay tributaries, including the Potomac River.

30. EPA Mid-Atlantic Highlands Streams Assessment, EPA/903/R-00/015, page 19, August 2000.

31. Maryland Department of Natural Resources," From the Mountains to the Sea – The State of Maryland's Freshwater Streams" Daniel Boward et at, December 1999, page 14.

control eutrophication, EPA[32] recommends that phosphorus concentrations in rivers should be less than 0.1 mg/L in rivers. And, as mentioned earlier, the EPA has developed threshold levels for phosphorus with below 0.05 ppm being low, between 0.05 and 0.1 being marginal, and above 0.1 ppm being high. These standards are mainly to control eutrophication in our rivers and tributaries.

Ammonia

In water, ammonia exists as a combination of two compounds, which, together, are called "total ammonia nitrogen." These two compounds are un-ionized ammonia (NH3) and ammonium ion ($NH4^+$). They exist in a state of equilibrium in the water solution, and the fractions of each depend on pH and temperature.

Un-ionized ammonia (NH3) is very toxic to fish and other aqueous organisms that breathe through gills. It is a dissolved gas that can pass unimpeded through the membranes of the gills. Continuous exposure[33, 34] to more than .02 to .05 PPM of the un-ionized toxic compound can cause reduced growth, increased susceptibility to disease and premature death. It is especially toxic to young fish and aqueous water life. At levels above .05 PPM the un-ionized ammonia causes more and more damage, and at 2.0 PPM all fish will die.

The FOSR laboratory test results are published for the level of total ammonia in the water. The ratio of toxic un-ionized ammonia and non-toxic ionized ammonia in total ammonia depend primarily on the level of pH and temperature of the water. Higher temperature and higher pH result in higher percentages of the toxic un-ionized ammonia. For lower pH and colder water the fraction of toxic ammonia decreases; and one would think this is a good thing. Unfortunately, at lower levels of pH, less un-ionized ammonia NH3 is needed to kill fish and other forms of water life.

Because the amount of un-ionized ammonia depends on both temperature and pH, it is not possible to prescribe a single number – one must refer to complex tables such as developed by Emerson.[35] Such tables state that, for example, at a pH of 8.0 and a temperature of 86 degrees Fahrenheit, a concentration of 1 PPM of total ammonia corresponds to a level of .074 PPM of un-ionized ammonia NH3. This is well above the impaired range of .02 to .05 for NH3.

And at the same pH of 8.0 but a lower temperature of 75 degrees Fahrenheit a concentration of 1 PPM of total ammonia corresponds to a level of .05 PPM of un-ionized ammonia. This is at the high end of the impaired range for NH3. At the same pH for a still lower temperature of 60 degrees Fahrenheit the level of un-ionized ammonia is .03 – this is also still within the impaired range.

After studying tables such as Emerson's for the values of pH and temperature prevalent in the waters of the Shenandoah River Watershed, and lacking guidance from the EPA or other authorities, we suggest the following standards: total ammonia is unimpaired at a level less than 1 PPM; it is impaired between 1 and 10 PPM, and is severely impaired for levels above 10 PPM. The purpose of this standard is primarily to protect the health of the fish.

Dissolved Oxygen, Acidity, and Turbidity

This section discusses the parameters that, although not classified as nutrients, are important for healthy rivers and tributaries.

Dissolved Oxygen

Dissolved oxygen (DO) refers to the amount of oxygen (O_2) dissolved in water. Because fish and other aquatic organisms cannot survive without oxygen, DO is one of the most important water quality parameters for healthy aquatic life. DO is usually expressed as a concentration of oxygen in a volume of water (milligrams of oxygen per liter of water, or mg/L, this is equivalent to PPM).

---

32. From page 7 of the 1998 USGS Report *'Water Quality in the Potomac River Basin: Maryland, Pennsylvania, Virginia, West Virginia and the district of Columbia, 1992-1996'.*

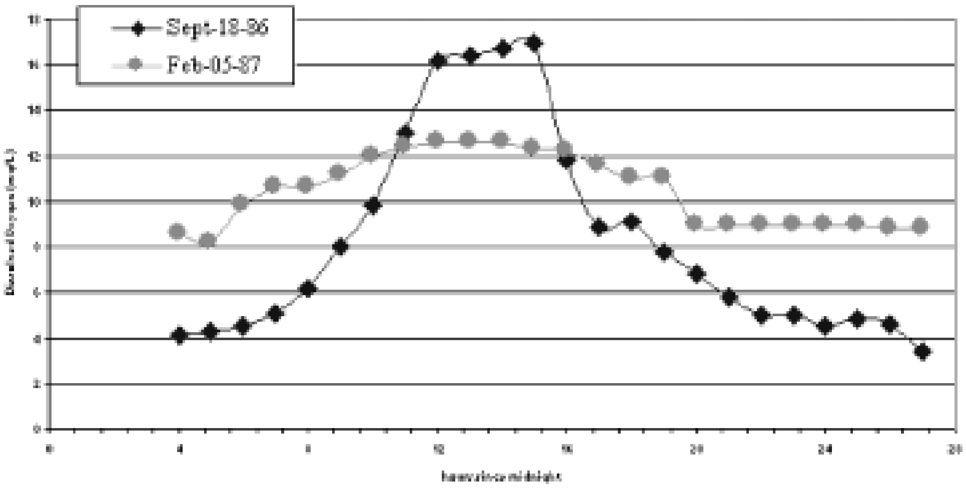
33. EPA "Fact sheet: 1999 Update of ambient Water Quality Criteria for Ammonia - Technical Version", EPA 823-F-99-024, December 1999.

34. Document FA-16, Fisheries and Aquatic Sciences, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida, June 1996

35. Emerson, K et al "Aqueous ammonia equilibrium calculations effect on pH and temperature," Journal of Fisheries Research Board of Canada. 32: 2379-2383.

Depleted oxygen levels as caused by microbial respiration, stagnant water, high temperatures, or other factors can quickly harm aquatic life (the most vulnerable are the game fish such as trout and bass) and may even cause large fish kills. Fortunately, the rivers and tributaries in the Shenandoah River Basin are usually rich in oxygen, especially in the daytime when aquatic plants generate oxygen, and also because most rivers and tributaries contain rapids and riffles that allow good mixing of water and air. At night, however, when plants do not generate oxygen, the levels may temporarily fall to low levels. Such levels may be dangerously low for fish when the water contains oxygen levels which are already low. The graph below shows this diurnal relationship as measured by the USGS in Boulder Creek, Colorado.

Figure 9-1
Diurnal Variation of Dissolved Oxygen



Cold water holds more oxygen than warm water. For example, pure water at 4°C can hold about 13.2 mg/L DO at 100% saturation, while pure water at 25°C can hold only 8.4 mg/L at 100% saturation. Turbid water with a high concentration of sediment cannot hold as much DO as pure water. Waters with high levels of sedimentation, a frequent occurrence in the rivers and tributaries of the Shenandoah Valley, could therefore impose stresses on fish and other forms of oxygen breathing water life.

Human activity can also affect DO levels. For example, during the summer the amount of nutrients that run off from lawn and farm fertilizers increases. The same is true for runoff from feedlots, storm water, and other discharges. This can result in the increased growth of plants and algae, and raises the possibility of eutrophication.

Dissolved Oxygen Standard

This material on standards for dissolved oxygen is taken largely from research done by the FM River partnership[36] because of their focus on the DO levels necessary to support healthy aquatic life in fresh-water streams, especially fish life. They found that aquatic life is put under stress when the DO concentration falls below 5 mg/L. If the DO concentration falls under 2 mg/L for just a few hours, large fish kills can result. The found that good fishing waters have a DO concentration around 9 mg/L. Fish are put under stress when dissolved oxygen falls below 5 mg/L and, fish kills can result if dissolved oxygen falls below 2 mg/L.

The FM River rating scale considers dissolved oxygen levels from 0 to 5 mg/L as ***Poor***, from 5 to 8 as ***Fair***, and above 8 as ***Good***.

Acidity/Alkalinity (pH)

pH measures the acidity or alkalinity of water. It is measured on a logarithmic scale from zero to 14. Acids such as vinegar, lemon juice, and battery acid generally have pH values under 7. The strongest acids such as hydrochloric, sulfuric, and nitric acids have a pH close to zero.

---

36. FM River is a partnership between Prairie Public Broadcasting, the Energy and Environmental Research Center, River Keepers, the Minnesota Pollution Control Agency, the North Dakota Department of Health, and the twin cities of Fargo in North Dakota and Moorhead in Minnesota, and that straddle the Red River. The partnership is funded in part through the U.S. Environmental Protection Agency (EPA) Region 8 EMPACT (Environmental Monitoring for Public Access and Community Tracking) project.

Alkalis such as baking soda, medications such as Tums and Roll Aids, and ammonia cleaning solution have pH values over 7. The strongest alkalis "or bases" such as sodium hydroxide, and paint strippers have a pH close to 14.

Substances that have a pH around 7, such as milk and pure water are neutral, i.e., neither acidic or alkaline.

pH is an important parameter because it can significantly influence the health of fish. There is broad agreement among the organizations that have developed standards for pH, including the EPA and VA DEQ, that the pH of water for the optimal range for fish falls between 6.5 and 9.0. Below 6.5 or above 9.0 is non-optimal. But at least two other organizations add a little more detail to the ratings. For example, the criteria used for the State of Maryland[37] is based an extensive inventory of their waters. They found that water with a pH <5.0 cannot sustain fish, with a pH between 5.0 to 6.0 there are few fish, and water with a pH > 6 contains ample fish. And the FM study mentioned above found that very high (greater than 9.5) or very low (less than 4.5) pH values are unsuitable for most aquatic organisms. The Shenandoah River Fishkill Science Team[38] states that high ambient pH (>9.0) affects the oxygen affinity of fish hemoglobin, and may result in sub lethal oxygen stress. High ambient pH (>9.0) may also increase the solubility and toxicity of some contaminants, including trace metals. The science team cites a number of other reports that corroborate that pH levels between 9.0 and 9.5 are likely to be harmful to fish if present for considerable lengths of time, and that extreme pH levels can eliminate certain fish species from highly eutrophic systems.

Young fish and immature stages of aquatic insects are extremely sensitive to pH levels below 5 and may die at these low pH values. High pH levels (9-14) can harm fish by denaturing cellular membranes. Alkaline pH values above 9.2 and acidity below 4.8 can damage and kill salmonids (e.g. brown and rainbow trout); and pH values above 10.8 and below 5.0 may be rapidly fatal to cyprinids (especially carp and tench). Thus salmonids, in comparison with cyprinids, are more vulnerable to high pH and more resistant to low pH. Below 6.5 large fish begin to die and below 5.0 all zooplankton disappears. Below 3.0 all fish disappear and below 2.0 all aquatic insects disappear.

As a defense against the effect of a low or high water pH, fish can produce an increased amount of mucus on the skin and on the inner side of the gill covers. Extremely high or low pH values cause damage to fish tissues, especially the gills, and hemorrhages may occur in the gills and on the lower part of the body. Excess amounts of mucus, often containing blood, can be seen in post mortem examination of the skin and gills. The mucus is dull-colored and watery.

We accepted the FM River rating scale because it is based on serious study and generally agrees with the findings of other research mentioned above. In addition it has the advantage that it introduces more detail than simply optimal or non-optimal It defines three ranges; unimpaired (good), impaired (fair), and severely impaired (poor). A pH between 6.5 and 8.4 is defined as unimpaired, between 4.8 and 6.5 or between 8.4 and 9.2 as impaired, and below 4.8 or above 9.2 as severely impaired.

Turbidity T

Turbidity, also called sedimentation, indicates the clarity of the water. Water can become turbid if there are too many suspended particles such as silt, clay, plankton, decaying organic matter, and from sewage and industrial waste.

Clear water has many benefits. It increases the enjoyment of sightseeing, fishing, underwater nature observation, and other recreational uses of the river, and thereby encourages tourism. Paddling a canoe and observing fish swimming along the plants on the river bottom is an experience treasured by many.

Perhaps a more important reason is that clear water is penetrated by sunlight necessary for photosynthesis by aquatic plants, and the generation of oxygen. It may promote hatching of fish eggs and survival of minnows. Stream bottoms with much sedimentation can bury the eggs and can clog the gills of small fish. And high turbidity allows less penetration of sunlight and the water is less able to support aquatic life, especially for the bottom dwellers. Finally, water with high turbidity absorbs more sunlight and therefore, especially in the summer, the warmer water may adversely affect the habitat for fish.

---

37. Maryland Department of Natural Resources," From the Mountains to the Sea – The State of Maryland's Freshwater Streams" Daniel Boward et at, December 1999.

38. *Fish Kills in the Shenandoah River Basin: Preliminary Report of the Shenandoah Basin Science Team*, Submitted to: Virginia Department of Environmental Quality, January 15, 2007.

Since much of the turbidity of water is due to sediment in the runoff from farm and urban land, clear water is an indication that runoff is probably low, and that therefore the nutrients in the river may be at moderate levels. More than 70% of the nitrogen and 85% of the phosphorus that enters streams via agricultural runoff is chemically bound to sediment.[39]

Water turbidity is measured by a nephelometer – an instrument that uses refracted light to measure the size or density of solid particles present in a liquid. Clarity is expressed in nephelometric turbidity units (NTU), with higher values indicating more turbidity.

Neither the State of Virginia nor the U.S. Environmental Protection Agency have yet developed criteria for turbidity relevant to the health of fish and other aquatic organisms for fresh water. Although a number of studies are addressing the issue of turbidity, the analysis is complex and involves difficult scientific issues. One of the problems is that the impact of turbidity is dependent on a large number of factors such as the amount and types of inorganic particles such as silt and clay; the organic plant particles, algae, and microbes; as well as possible contamination by chemicals. And as for pH, the temperature of the water affects the impact of turbidity on the health of fish.

In 1998 the U.S. Environmental Protection Agency started reviewing the efforts of the states[40] in developing standards for turbidity criteria related to fresh-water aquatic life. The state of Virginia had not developed any criteria for turbidity as it affects aquatic life, but nine other states, including Alaska, Arizona, Arkansas, Hawaii, Maryland, North Carolina, Oklahoma, Utah, and Wyoming were found to have developed criteria that were in fairly good agreement. In general, the EPA draft report indicated that for cold-water streams with game fish such as trout, there was good agreement that turbidity should not exceed from 5 to 10 NTU over the natural background level.

The natural background level is the condition of the surface water without the influence of man-made or man-induced causes, such as effluent discharge from STPs, runoff from impermeable surfaces in urban areas, and so forth. Background levels would be the levels during stable periods of time where there are no occurrences of severe rainfall or other climatic or man-made conditions. In essence, the natural background levels are those that occurred before development of population along the banks of the streams, and would reflect the pristine conditions of many years ago.

Although, to our knowledge, there are no quantitative data on what these levels might have been many years ago, we can estimate these levels by locating streams that currently still are more or less pristine. Typically, such streams would be in national parks and other areas with low population levels.

To find such streams, we studied the possible background levels for waters in the Shenandoah River Basin by going as far back as possible – to 1997 - in the FOSR database. In 1997, the date when monitoring by the FOSR and partners started, and when population and development levels were well below current levels, we found a few "pristine" streams with very low levels of turbidity. The first quartile (the lowest 25% of turbidity levels) for these streams ranged from 0.7 NTU for tributaries to 1.0 NTU for rivers,. We believe it is justified to assume that, for the purposes of this report, we can assume that a natural background level for turbidity is 1.0 NTU.

By adding the conclusions of the states as discussed in the EPA draft report that, for game fish in fresh water, turbidity levels should not be more than 5 to 10 NTU, it is reasonable to use a level exceeding between 6 to 10 NTU as severely impaired. This would be appropriate for the Shenandoah River Basin.

In the earlier studies carried out by the FOSR we used the levels for turbidity from 0 to 4 NTU as unimpaired, 4 to 7 NTU as impaired, and for more than 7.0 NTU as severely impaired. We recommend that these criteria be used in this report. An advantage of staying with these criteria is that this report will be consistent with the findings in our earlier reports. These values are far from final – considerable research by the state of Virginia and others will be required to improve upon these criteria.

Table 9-1 presents a summary of the critical levels discussed above, and used in assessing the concentrations of the parameters of nitrogen, phosphorus, ammonia, pH, turbidity, and oxygen.

---

39. Riley, Ann L. 1998. *Restoring Streams in Cities: A Guide for Planners, Policymakers, and Citizens*. Washington D.C. Island Press.

40. Draft: Developing Water Quality Criteria for suspended and bedded sediments (SABs); Potential Approaches, Appendix 3 – Sediment Related Criteria for Surface Water Quality, U.S. Environmental Protection Agency, unknown date but sometime between 1998 and 2003.

Table 9-1: Suggested Critical Levels for Water Quality Parameters

	Nitrogen, ppm	Phosphorus, ppm	Ammonia, ppm	pH	Turbidity, ntu	Oxygen, ppm
Not Impaired	< =0.75	<=0.05	<=1.0	6.5 to 8.0	0 to 4.0, clear	> 5, minimum for healthy fish
Impaired	0.75 to 1.5, some eutrophication	0.05 to 0.1, Eutrophication	1.0 to 10.0, fish start dying	5.0 to 6.5	4.0 to 7.0, cloudy	2 to 5, hypoxic and stressful to fish
Severely Impaired	> 1.5 Eutrophication	>0.1 Considered high by EPA guideline	>10.0, no fish	>8.0 too alkaline, <5 too acid,	>7, muddy	< 2 harmful or lethal to fish

D: The Laboratory in Shenandoah University, and the Monitoring Program

Shenandoah University provides the FOSR with laboratory space. Equipment, testing materials and staff are provided by the FOSR. The lab is well equipped and uses the best possible instruments, materials, procedures, and staff to test the water samples. The staff consists of a full time laboratory technician who is responsible for maintaining the high quality of the data and efficiency of the testing process. She is assisted by volunteers from the FOSR, students from Shenandoah University, and by several part-time paid lab assistants.

Operating the lab is financed from dues and donations from the FOSR members, special fund raising events, grants from local, state and federal governments and organizations including the Virginia Environmental Endowment, River Network, Robins Foundation, Canaan Valley Institute, Izaak Walton League, Chesapeake Bay License Fund, the Chesapeake Bay Alliance, and the Fish and Wildlife Foundation. The lab also tests, at cost, water samples submitted by other organizations.

The laboratory was modernized in 2001 by the addition of a Lachat QuickChem Flow Injection Analysis Instrument. This auto analyzer (financed by a grant from the Virginia General Assembly) automatically rather than manually measures concentrations of ammonia, nitrogen and phosphorus in water samples collected by trained volunteers. This enables more rapid analysis of the samples, reduces the cost of reagents used in the analyses, and also largely eliminates direct exposure of the staff to hazardous reagents.

Virtually all aspects involved in the determination of the concentrations of nutrients, pH, dissolved oxygen, turbidity, and temperature of the Shenandoah River water samples are strictly set out in the FOSR Quality Assurance Project Plan (QAPP). The QAPP was approved in 1997 by the Virginia Department of Conservation Resources (VADCR) and by the U.S. Environmental Protection Agency. In 2004 it was approved by the VA Department of Environmental Quality and the lab is now a DEQ certified laboratory. The QAPP specifies the protocols for sample collection, preservation, analytical methods, record-keeping, and presentation of the results.

FOSR's methods for analysis of nitrogen, orthophosphate, and ammonia are taken from Standard Methods for the Examination of Water and Wastewater (1992); they are methods 353.3, 365.4, and 350.1, respectively. All are colorimetric methods that use various reagents that are added to the water sample. These reagents change the color of the solution, and the specific wavelength of the colored solution is measured by means of a spectrophotometer. The absorbance at this wavelength is directly proportional to the concentration of the chemical being tested.

The FOSR is continually upgrading its field and laboratory instruments and procedures. For example, a recently acquired set of WTW Multilane P4 Field Instruments are now used by monitors to measure pH, temperature, and dissolved oxygen in the stream rather than by collecting water in a sample bottle for later analysis in the laboratory. The advantage of these streamside instruments (SSI) is that they provide an instantaneous reading of the three parameters (pH, temperature, and dissolved oxygen) and minimize possible change in the samples during transport to the laboratory. They also reduce the time spent by the lab in analyzing the samples.

The results of the analysis are tabulated on the FOSR computers and are reported to the US Environmental Protection Agency and the Virginia Department of Environmental Quality to be used in their water quality analysis. These data are added to the FOSR web page shortly after each monitoring date.

The data collected include the six water quality indicators: nitrogen, phosphorus, ammonia, pH (acidity), turbidity, and dissolved oxygen. The FOSR is examining how to broaden its testing program to include tests for fecal coliform bacteria as an indicator of contamination.

E: Description and Characteristics of Site names

The table below gives the Site Identification Number, Site Name (abbreviated) and coordinate information for each site in the FOSR database.

F: Table 9-2: List of Site Names (abbreviated) and Coordinates

SiteID	Site Name	Lat. (N)	Long. W)
CB01	Crooked Run	39.04637	-78.1363
CR01	Crooked Run @ Lake Frederick dam	39.04180	-78.15783
CR02	Nineveh Spring	39.01744	-78.16670
CR03	Crooked Run @ bridge Rt. 639	39.01690	-78.16696
CR04	McKay Spring	38.97854	-78.18530
CR05	Crooked Run @ Cabin Court road	38.97242	-78.19130
CR06	Crooked Run @ Townsend Drive	38.96432	-78.19464
CR07	Crooked Run, Reliance Road	38.97781	-78.18771
CR10	Crooked Run, Crooked Run off 522	39.02147	-78.1659
CR20	Crooked Run under Rt. 66 bridge	38.95660	-78.18527
CRDR	Dry Run @ Rt. 637 Cauthorn Mill Road	39.00761	-78.23132
CRMC	Molly Camel, Ritenour Hollow Road	38.97762	-78.19199
CRMC2	Molly Camel, Reliance Road Bridge	38.98674	-78.20244
CRWR	West Run @ Rt. 637 Cauthorn Mill Road	39.01345	-78.22174
FA01	North River	39.01345	-78.22174
FA02	Middle River	38.26972	-78.86444
FA03	South River	38.26528	-78.85333
FC01	Berry's Landing (Shen River @ Rt. 50 Bridge)	39.04165	-77.99320
FC02	Spout Run	39.06583	-78.00344
FC03	Lewis Run	39.09364	-77.97495
FC04	Berryville Water Intake	39.09911	-77.97494
FC05	Lockes Boat Landing	39.10155	-77.96477
FC06	Dog Run	39.10549	-77.92327
FC07	Berryville Sewage Outfall	39.10545	-77.90898
FC08	Shenandoah River	39.12388	-77.88792
FC09	Page Brook	39.09335	-78.05046
FC18	Chapel Run	39.08606	-77.98731
FC31	Boyce STP Outfall	39.08861	-78.06316
FC32	Wheat Spring Branch	39.13262	-77.88792
FJ01	Shenandoah River	39.24639	-77.81361
FJ02	Charlestown Water Intake @ Shenandoah River	39.25250	-77.81833
FJ03	Evitts Run mouth	39.25500	-77.81833
FJ04	Boat Ramp @ Millville Road	39.26333	-77.79111
FJ05	Millville @ Railroad Tracks	39.29111	-77.78694
FJ06	Shenandoah River @ Harper's Ferry	39.32139	-77.73194
FJ07	Potomac River @ Harper's Ferry	39.32333	-77.72806
FP01	Town of Shenandoah Dam, South Fork	38.48222	-78.62750
FP03	White House, South Fork	38.64611	-78.53472
FP05	Burner's Bottom, South Fork	38.80139	-78.36778
FP06	Hawkbill Creek	38.70806	-78.45583
FP07	Pass Run	38.70500	-78.44611
FP08	Hawksbill Creek Combined	38.65889	-78.46250
FP09	Luray Waste Water Plant	38.68444	-78.45917
FP10	Stanley Waste Water Plant	38.58106	-78.52708
FP11	Naked Creek	38.46469	-78.61947
FP12	Cub Run	38.55419	-78.59864
FP13	Mill Creek	38.65967	-78.51728
FP14	Jeremy's Run	38.76794	-78.39142
FP15	Overall Run	38.80550	-78.34867

FS02	Cedar Creek	39.00613	-78.31733
FS03	Cedar Creek @ RR 622 Bridge	39.04122	-78.33241
FW01	Manassas Run	38.91111	-78.09111
FW02	Snake Run	38.91194	-78.09611
FW03	Manassas Run @ Route 647	38.91361	-78.10306
FW04	Manassas Run Campground	38.92500	-78.13133
FW05	Happy Creek	38.92944	-78.19083
FW06	Shen River @ Poe's Campground	38.94917	-78.19861
FW07	Spring	38.97762	-78.19199
FW09	Happy Creek	38.94333	-78.18583
FW10	Happy Creek	38.88583	-78.17972
FW11	Happy Creek	38.90944	-78.18722
FW14	Front Royal Intake	38.91306	-78.21000
FW21	Gooney Run, west of Rte. 340	38.85028	-78.27833
FW22	Gooney Creek	38.87333	-78.25306
FW27	Happy Creek	38.94833	-78.19583
FW28	Above the Front Royal Sewage Outfall	38.94250	-78.19139
FW29	Leaches Run	38.93278	-78.18306
GA01	South River/Port Republic	38.29556	-78.80833
GA02	South River/Harriston	38.21833	-78.83667
GA04	South River/Below Waynesboro	38.08861	-78.87694
GA08	South River/Wilds	38.02183	-79.09300
GA10	Middle River/Mt. Meridan	38.26167	-78.86222
GA11*	Old Site Location	38.26283	-78.86050
GA11**	New Site Location: Knightly-Middle River Waters	38.23000	-78.92639
GA12	Middle River_Clines Lane - Route 642	38.19028	-78.97000
GA13	Middle River_Lebanon Church - Route 742	38.24333	-79.03583
GA17	Middle River_Route 703 bridge, below Back Creek	38.15194	-79.18000
GA18	Middle River/Summerdean	38.07483	-79.25500
GA19	Lewis Creek Upper_Near old Furr's Stockyard	38.13389	-79.08861
GA20	Lower Lewis Creek	38.18278	-78.97556
GA21	Jones Hollow_DuPont rec field	38.06556	-78.88361
GA22	Back Creek_Route 624 bridge	38.02833	-78.93250
GA23	South River_Lyndhurst - Route 664 bridge	38.04583	-78.94278
GA24	Stony Run_Route 608, South River Watershed	38.01444	-79.06250
GA25	Poor Creek_Below Campground dam	38.00972	-79.13528
GA26	Broadhead Creek_Route 675 bridge	37.99389	-79.19222
GA27	Meadow Run_Route 907 bridge	38.19083	-78.93278
GA28	Christians Creek Middle_Route 794 bridge	38.19194	-78.93500
GA29	Christians Creek Lower_Route 907 bridge	38.12833	-78.99500
GA30	Barterbrook Branch_Route 648 bridge	38.06778	-79.02833
GA31	Folly Mills Creek_Route 648 bridge	38.08500	-79.06333
GA32	Christians Creek Upper_Route 340 bridge	38.04389	-79.08806
GA33	Moffett Creek_Route 732 bridge	38.24417	-79.08472
GA34	Jennings Branch	38.29556	-79.13556
GA35	Eidson Creek_Route 703 bridge	38.14333	-78.80833
GA36	North River_Route 276 bridge	38.30611	-78.89333
GA37	North River_Forest Service Road 95	38.33417	-79.23917
JA01	Naked Creek-North River	38.30824	-78.92474
JR01	Muddy Creek-North River	38.43176	-78.98012
JR02	Dry River-North River	38.43371	-78.98571
JR03	Briery Branch-North River	38.39967	-79.02315
JR04	Upper North River-North River	38.39512	-79.03086
JR05	Mossy Creek-North river	38.38631	-79.01384
JR06	Long Glade Creek-North River	38.37739	-78.98153
JR07	Cooks Creek-North River	38.37284	-78.93459
JR08	Blacks Run-North River	38.37855	-78.92799
JR09	North River above HRRSA	38.34563	-78.93306
JR10	Pleasant Run-North River	38.34663	-78.92554
JR11	North River below HRRSA	38.34457	-78.91621
JR12	Mill Creek-North river	38.31574	-78.81860

JR13	Cub Run-North River	38.34526	-78.73152
NS05	Toms Brook (STP)	38.94350	-78.44056
NS10	North Fork, Edinburg	38.83139	-78.52278
NS13	Toms Brook above STP	38.90111	-78.48194
NS14	Stoney Creek at George's Chicken Plant outfall	39.07806	-78.32639
NS15	Rt. 55 Bridge - Strasburg	38.83139	-78.52278
NS17	Posey Creek/Tributary	39.07667	-78.32639
NS18	North Fork confluence with Posey Creek	38.94972	-78.43972
NS22	Pugh's Run/Tributary	38.94861	-78.39861
NS23	Woodstock STP	38.94722	-78.39306
NS25	North Fork at Lupton Bridge, Woodstock/Baseline data	38.87183	-78.49200
NS26	North Fork - Chapman Landing/Baseline data	38.90000	-78.45083
NS28	Edinburg STP	38.88528	-78.47944
NS29	Stoney Creek - Route 662 George's Chicken Plant	38.87278	-78.47694
NS30	Stoney Creek - Route 675 Bridge/Baseline, tributary	38.87528	-78.49778
NS42	Smith Creek @ Rt. 620 bridge	38.65250	-78.69850
NS44	Tumbling Run/Tributary	38.63278	-78.84194
NS46	Mill Creek at Rt. 614 Bridge/Tributary, TMDL stream	38.71528	-78.75556
NS52	Cedar Creek at Rt. 606/Baseline healthy stream	39.09778	-78.35528
NS59	North Fork at Old Mill Restaurant	38.98738	-78.37237
NS60	North Fork at Town Park	38.97373	-78.35245
NS63	North Fork north of 579	38.87950	-78.46197
NS64	Spring Hollow on south side of bridge	38.88225	-78.48442
NS70	Cedar Creek at Rt. 606	39.09560	-78.33650
PF01	Stephens Run @ RR 636 Bridge	39.04562	-78.18916
PF02	Stephens Run	39.05512	-78.20455
PF02BR	Culvert, Culvert into Stephens Run	#N/A	#N/A
Prison	Discharge @ Whitepost Correctional Facility	0.00000	0.00000
WB01	Willow Brook, Rockland Road	38.97943	-78.15045
WB02	Weddle Spring	0.00000	0.00000
WB03	Willow Brook at Mouth Shenandoah River	38.97084	-78.15438

G: Non-Profit Organizations Involved or Interested in Shenandoah River Watershed Water Quality Issues

1. Alliance for the Chesapeake Bay (ACB)
2. American Rivers
3. Boy Scouts
4. Chesapeake Bay Foundation (CBF)
5. Friends of Page Valley
6. Friends of the North Fork of the Shenandoah River (FNFSR)
7. Friends of the Rivers of Virginia (FORVA)
8. Friends of the Shenandoah River (FOSR)
9. Izaak Walton League IWLA
10. Lions Club
11. Northern Shenandoah Master Gardeners Association
12. Piedmont Environmental Council
13. Potomac Conservancy
14. Potomac Watershed Partnership
15. Robbins Foundation
16. Rotary Club
17. Pure Water 2000 Forum
18. Ruritans
19. Shenandoah Audubon Society
20. Shenandoah Valley Battlefields Foundation
21. Shenandoah Valley Battlefields Foundation (SVBF)
22. Shenandoah Valley Network (SVN)
23. The Opequon Watershed (TOW)

24. Trout Unlimited – Northern Shenandoah Valley Chapter
25. Valley Conservation Council (VCC)
26. Virginia Conservation Network (VCN)

H: References

Maryland Department of Natural Resources," From the Mountains to the Sea – The State of Maryland's Freshwater Streams" Daniel Boward et at, December 1999

U.S. Environmental Protection Agency, "Mid-Atlantic Highlands Streams Assessment," EPA-903-R-00-015, August 2000.

David K. Mueller and Dennis R. Helsel, 1996, Nutrients in the water: too much of a good thing", U.S. Geological Survey circular 1136; and the National Water Quality Inventory – 1992 Report to Congress – U.S. Environmental Protection Agency

EPA "Fact sheet: 1999 Update of ambient Water Quality Criteria for Ammonia - Technical Version", EPA 823-F-99-024, December 1999.

American Rivers, 1101 14th Street NW, Suite 1400 Washington, DC 20005, Phone: 202-347-7550

Document FA-16, Fisheries and Aquatic Sciences, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida, June 1996

Emerson, K et al "Aqueous ammonia equilibrium calculations effect on pH and temperature," Journal of Fisheries Research Board of Canada. 32: 2379-2383

Elizabeth A. Johnston and Woodward S. Bousquet, October 3, 2004. What happens when it rains; A study of water quality in Abrams Creek and Town Run, Winchester and Frederick County, Virginia .Environmental Studies Program, Shenandoah University, Virginia

Dr. Greg Garman, Center for Environmental Studies and Department of Biology at Virginia Commonwealth University, and Dr. Donald Orth, Department of Fisheries and Wildlife Sciences at Virginia Tech, 2007. Fish Kills in the Shenandoah River Basin:

Fish Kills in the Shenandoah River Basin: Preliminary Report of the Shenandoah Basin Science Team, Submitted to: Virginia Department of Environmental Quality, January 15, 2007

Chesapeake Workshop Consortium (CRC) Publication No. 07162 : Summary of findings and recommendations, of a workshop entitled Fish Health in the Chesapeake Watershed: Synthesis and Evaluation, January 2007, U.S. Fish and Wildlife Service's National Conservation Training Center, Shepherdstown, WV.

Committee on Nitrate Accumulation, Ag. Board, Div. Of Biology & Agriculture, National Research Council (1972) Hazards of Nitrate, Nitrite, and Nitrosamines to Man and Livestock. In: Accumulation of Nitrate, National Academy of Sciences, Wash., DC, pp. 46-75

FM River: A partnership between Prairie Public Broadcasting, the Energy and Environmental Research Center, River Keepers, the Minnesota Pollution Control Agency, the North Dakota Department of Health, and the twin cities of Fargo in North Dakota and Moorhead in Minnesota, and that straddle the Red River. The partnership is funded in part through the U.S. Environmental Protection Agency (EPA) Region 8 EMPACT (Environmental Monitoring for Public Access and Community Tracking) project.

Valley Conservation Council, State of the Valley Report, Staunton, Virginia, August 2003

Leslie D. Mitchell-Watson, The Making and Keeping of Friends: Building and Sustaining the Capacity of a Community Watershed Organization in the Shenandoah Valley of Virginia, Masters Thesis, Virginia Polytechnic Institute and State University, December 2006

Conservation Currents, Northern Virginia Soil and Water Conservation District, March 2000

Izaak Walton League of America, Breaking the Bank - America's Conservation Deficit , Spring 2007, page 23

Commonwealth of Virginia, Office of the Governor, Chesapeake Bay Nutrient and Sediment Reduction Tributary Strategy for the Shenandoah and Potomac River Basins March 2005

Marzolf, E.R., Mulholland, P.J., and Steinman,A.D., 1995, Improvements to the diurnal upstream-downstream dissolved oxygen change technique for determining whole-stream metabolism in small streams: Canadian Journal of Fisheries and Aquatic Sciences, v. 51, no. 7, p. 1591-1599.

Marzolf, G.R., Bowser, C.W., Hart, R.J., Stevens, D.W., and Vernieu, W.S., 1999, Photosynthetic and respiratory processes— An open-stream approach, in Webb, R.H., Schmidt, J.C., and Valdez, R.A., eds., The controlled flood in Grand Canyon: American Geophysical Union, Monograph No. 110, p. 205-215.

Johnson, R.K., Wiedertiolm, Torgny, and Rosenberg, D.M., 1993, Freshwater biomonitoring using individual organisms, populations, and species assemblages of benthic macroinvertebrates, in Rosenberg, D.M., and Resh, V.H., eds., Freshwater biomonitoring and benthic macroinvertebrates: New York, Routledge, Chapman & Hall, Inc., p. 40-125. (eutrophication can occur in fresh water)

Janet M. Denis and Joel D.. Blomquist, Nitrate in Streams in the Great Valley Carbonate Subunit of the Potomac River Basin, USGS NAWQA Fact Sheet 161-95. (eutrophication in fresh water, Shenandoah Valley.

Chesapeake Research Consortium (CRC) Publication No. 07-162, Chesapeake Watershed Fish Health Workshop, January 23 - 25, 2007. (fish kills caused by excessive nutrients).

Box, G.E.P, and G.M. Jenkins, Time Series Analysis Forecasting and Control, (San Francisco Holden- Day, 1977)