Nitrate TMDL Development for Muddy Creek/Dry River, Virginia

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Watershed Background

The Muddy Creek/Dry River watershed is located in Rockingham County, Virginia, approximately 15 miles to the west-northwest of Harrisonburg, Virginia. Muddy Creek generally flows south to its confluence with Dry River, which joins the North River approximately 2.25 miles farther to the south. Sections of Muddy Creek, Dry River, and the North River are designated for public drinking water use because they are less than 5 miles upstream of the intakes for the Bridgewater and Harrisonburg Water Treatment Plants (WTPs) on the North River. Virginia's water quality standard for nitrate in the reaches designated for drinking water is 10 mg/l nitrate as nitrogen (9 VAC 25-260-140).

Nitrate Impairment

Water quality monitoring of Muddy Creek by the Virginia Department of Environmental Quality (VADEQ) confirmed instances of nitrate levels above the water quality standard. A subsequent preliminary modeling study, *Assessment of Sources and Transport of Nitrate: North River Watershed in Rockingham County*, concluded that, due to point and nonpoint source contributions, the nitrate standard for public drinking water supply would be violated within the 5 mile stream reach above the WTP intakes during certain low flow conditions. Therefore, the VADEQ concluded that the drinking water use is only being partially supported and 7.04 miles of Muddy Creek, Dry River, and North River were designated on the Virginia 1998 303(d) list as impaired due to nitrate.

Sources of Nitrogen

Nitrogen is attributed to both point and nonpoint sources in the watershed. The only active and significant permitted point source within the watershed is Wampler Foods, Inc. (WFI). In general, nonpoint source nitrogen originates from residential, agricultural, and natural sources. Specific nonpoint sources include land application of cattle manure and poultry litter, runoff from concentrated animal operations, grazing livestock, nitrogen-based fertilizer applications to agricultural and residential lands, septic tanks, atmospheric deposition, wildlife waste, and decaying organic matter.

Water Quality Modeling

The water quality/quantity model, Hydrologic Simulation Program-FORTRAN (HSPF), version 11.0, was used to predict stream flow and in-stream water quality and to perform the Total Maximum Daily Load (TMDL) allocations. HSPF is well suited to simulate both nonpoint and point source loads, as well as the transport and flow of pollutants through each stream reach. In addition, HSPF is able to assess in-stream water quality response to changes in flow, season, and load. Seasonal variations in hydrology, weather conditions, and watershed activities were accounted for by the use of the continuous simulation model.

The Muddy Creek/Dry River watershed was subdivided into eleven subwatersheds. The Muddy Creek and Dry River watersheds were divided into eight and three subwatersheds, respectively. The study area was divided to allow for spatial variation of nitrogen loading throughout the watershed and to permit the relative contribution of sources to each stream segment to be determined. Each subwatershed was further segmented into land use types using data provided by the Virginia Department of Conservation and Recreation (VADCR). The North River segment was not modeled due to its historically low nitrate concentrations.

Model Calibration

A hydrologic model was developed for the Muddy Creek watershed by the Muddy Creek fecal coliform TMDL. Flows were calibrated to the observed flows at the United States Geological Survey (USGS) gage 01621050 (Muddy Creek at Mt. Clinton) from 4/13/93 to 12/31/97. For the Dry River watershed, model parameters relating to the hydrologic cycle were calibrated to flows recorded between 9/93-10/96 near Dry River's confluence with the North river at the Virginia State Water Control Board (VASWCB) station 1BDUR000.02 . The 1993-1997 simulation period includes a variety of both wet-weather conditions and low flow periods. The period, therefore, covers the critical conditions involved with both point and nonpoint pollution sources within the study area.

The impacts of both point and nonpoint sources of nitrogen were modeled. The watershed's only active point source (Wampler Foods, Inc.) was represented as a direct discharge varying over time. Septic tanks and cows-in-stream were modeled as direct discharges along each stream reach. Nonpoint source loads varied monthly depending on the numbers of animals grazing in pasture and the amount of manure, litter, and fertilizer applied to the land. Atmospheric deposition was also included as a background non-point source.

The existing water quality conditions for the Muddy Creek/Dry River watershed over the simulation period were modeled using contributions from all of these sources. Model transport parameters were adjusted until model results matched observed values. Important calibration parameters included those controlling plant uptake of nitrogen, nitrification, denitrification, and ammonia volatilization. When the HSPF model results adequately matched the VADEQ monitoring data using reasonable parameters, the model was calibrated.

Consistent with the observed data, the model accurately identifies that the most limiting conditions occur at the VASWCB station 1BMDD000.4 on Muddy Creek, which is in the upper portion of the listed reach. In both the model results and the monitoring record, the fall is the season with the highest nitrate concentrations. Sixteen percent of the samples taken between October and December at this location were above the drinking water standard. Elevated nitrate concentrations typically occur when low flows (where concentrations are primarily controlled by point source and background sources) are combined with small storms that add nonpoint source pollutants to already elevated in-stream nitrate concentrations. Furthermore, under current loads, based on both monitoring and modeling, no nitrate violations are expected in either the Dry River or North River segments of the listed reach.

Margin of Safety

A TMDL must include a margin of safety (MOS) that accounts for the uncertainty about the relationship between the pollutant loads and the water quality of the receiving body. The Muddy Creek/Dry River nitrate TMDL allocation scenarios were designed to meet the Virginia water quality standard for public drinking water supplies of 10 mg/L NO_3-N with no violations. In addition to using conservative assumptions for source inputs, an explicit 5 percent margin of safety was incorporated into the TMDL allocations. Therefore, the modeled concentrations were targeted for a maximum of 9.5 mg/L NO_3-N within the segment designated for drinking water at all times. If the maximum concentration of nitrate in the Dry River at its confluence with the North River is within this acceptable range, and the nitrate concentrations in the North River above the confluence are also acceptable (as they have been historically), then after mixing it can be assumed that the North River concentrations will be acceptable in the short reach below the confluence with the Dry River.

Load Allocations

After model calibration, the next step in the TMDL process is to determine how to reduce current loads to levels that will be protective of water quality, including a margin of safety. Based on current conditions, forest lands, row crops, haylands, pasture land, loafing lots, the point source and cows in-stream each contribute over 5% of the annual total nitrogen reaching Muddy Creek. Although the impact of cows in the stream is relatively small during critical nitrate conditions, all allocation scenarios will assume that this load has been reduced as specified by the coliform TMDL. The nitrogen contribution per acre is lower for forest than any other land use. The total forest load is only significant due to the large acreage of forests in the watershed; over one third of the Muddy Creek watershed is forested. Thus the load allocation scenarios will focus on reductions in the other significant nitrogen sources (row crops, haylands, pasture land, loafing lots, and the point source).

A variety of load reduction scenarios were developed and simulated with the water quality model. Percent reductions to the point source load were modeled as evenly distributed throughout the year, while reductions to nonpoint sources were modeled as seasonal reductions. These differences reflect operational considerations between point sources and nonpoint sources. Extending nonpoint source reductions throughout the year has no significant impact on the predicted magnitudes of the peak concentrations during critical conditions. Preliminary scenarios demonstrated that reductions in both point source and nonpoint source loads would be required. This is consistent with critical flow conditions (low flows with small storms) when impacts of both point sources and nonpoint sources are combined.

Given the complexity of this system and the interaction between the point source and the significant nonpoint sources, there exist a variety of allocation scenarios with similar impacts on the peak nitrate levels. The selection of the best combination of source reductions is a subjective decision. In order to aid decision-makers, several allocation scenarios that meet the TMDL target of 9.5 mg/L nitrate-nitrogen using reductions in both the point and nonpoint sources have been developed. In all cases, the percent reduction in nonpoint source loads was based on the reduction in the fall loads only. Significant trade-offs exist between the sources. In general, as the point source reduction is raised, the requisite nonpoint source reductions can be decreased. Feasible allocations range from a 48% reduction at the point source combined with 25% reductions in nonpoint sources (Fall only) to a 20% reduction in the point source load combined with a 40% reduction in most nonpoint sources and a 50% reduction in loafing lot loads (Fall only). The final selection of an allocation scenario (and management plan) should consider cost-effectiveness, equity, and potential impacts on the coliform impairment.

Selected Scenario

Allocation Scenario #4 in Table 5.1 has been selected for this TMDL to meet the target of 9.5 mg/L nitrate-nitrogen necessary for the attainment of water quality standards. This allocation scenario requires nitrate load reductions of 35% from Wampler Foods, Inc., 25% from crops, 30% from hay, 20% from pastures, and 50% from loafing lots. The reduction from the point source is to be evenly distributed thoughout the year and the nonpoint reductions are seasonal. DEQ plans to implement the waste load allocation portion of the TMDL at the time of reissuance of the NPDES permit for Wampler Foods, Inc.

During the implementation planning process, the State expects to remodel the nitrate TMDL using more recent data, including the quantified nitrate reductions expected as a result of the Muddy Creek fecal coliform TMDL. At that time, the following options may be considered: 1. the state may proceed to delist Muddy Creek for nitrate impairment if water quality standards are attained; 2. Another allocation scenario in Table 5.1 may be selected and EPA will be informed; or 3. Another allocation scenario outside of those listed in Table 5.1 may be selected and the TMDL will be resubmitted to EPA for approval.

Public Participation

Public participation proceeded through both informal and formal public meetings. Because of support from the Virginia Environmental Endowment, we were able to devote more attention than usual to outreach, with the goal of developing a model that can be used for communicating with the public as additional TMDLs are developed throughout the state and the nation. The first informal meeting, held in Harrisonburg on August 23, 1999, reviewed the TMDL process and introduced the Muddy Creek/Dry River Nitrate TMDL study. A second informal meeting was held October 25, 1999 with the Muddy Creek Citizens' Advisory Group at the Mt. Clinton Elementary School. This meeting focused on outreach and was specifically aimed at determining (1) what had worked and not worked in terms of establishing effective communication between citizens and legislators and (2) how the lessons learned so far could be applied through the remainder of this project and in future TMDLs. A third informal meeting with the Citizens' Advisory Group and others was held in Harrisonburg on November 29, 1999. The purpose of that meeting was to provide a preview of the presentation that our team would make at the first formal public meeting.

The first formal public meeting associated with this project was held in Dayton on December 8, 1999. This meeting focused on the development of the Muddy Creek/Dry River Nitrate TMDL; our presentation reflected the comments and suggestions received at the November 29 informal meeting. The December 8 meeting was advertised in the *Harrisonburg Daily News-Record* on December 2, 1999. Copies of presentation materials, nutrient management assumptions, data sources, preliminary calibrations and other information were available for public distribution. Approximately 30 people attended this meeting. The second formal public meeting to discuss the draft Nitrate TMDL for Muddy Creek/Dry River, Virginia was held March 14, 2000 in Dayton. A draft report was distributed in advance of that meeting.

Additional informal meetings were held on March 20, 2000, and April 4, 2000. These meetings resulted in the selection of allocation scenario #4.

1 INTRODUCTION

1.1 Watershed Background

The Muddy Creek/Dry River watershed is located in Rockingham County, Virginia, approximately 15 miles to the west-northwest of Harrisonburg, Virginia. Rockingham County has the highest poultry and dairy production levels of any county in Virginia (VADEQ, 1997). Figure 1.1 shows the complete study area. Muddy Creek generally flows south to its confluence with Dry River, which joins the North River approximately 2.25 miles farther to the south. The North River discharges to the South Fork of the Shenandoah River, a tributary of the Potomac River. The Potomac River eventually flows into the Chesapeake Bay. The Muddy Creek/Dry River watershed is part of the South Fork Shenandoah hydrologic unit (No. 02070005). The land area of the Muddy Creek watershed is approximately 20,025 acres, with forest and agriculture as the primary land uses. The Upper Dry River watershed is approximately 46,711 acres, with over 99 percent of the land forested. The Lower Dry River watershed is approximately 10,007 acres, with the primary land uses of forest and agriculture. Detailed land use summaries of the Muddy Creek and Lower Dry River watersheds can be found in Appendix A. The entire Muddy Creek/Dry River watershed encompasses almost 77,000 acres.

1.2 1998 303(d) Listing

All waters in Virginia are designated for the following uses: recreational uses (e.g., swimming and boating); the propagation and growth of a balanced, indigenous population of aquatic life, including game fish, which might reasonably be expected to inhabit them; wildlife; and the protection of edible and marketable natural resources (e.g., fish and shellfish) (9 VAC 25-260-10). In addition, sections of Muddy Creek, Dry River and North River are designated for public drinking water use because they are less than 5 miles upstream of the intakes for the Bridgewater and Harrisonburg Water Treatment Plants (WTPs) on the North River. Virginia’s water quality standard for nitrate in the portions of Muddy Creek, Dry River, and North River designated for drinking water is 10 mg/l nitrate as nitrogen (9 VAC 25-260-140). Infants are especially susceptible to

TMDL Study Area

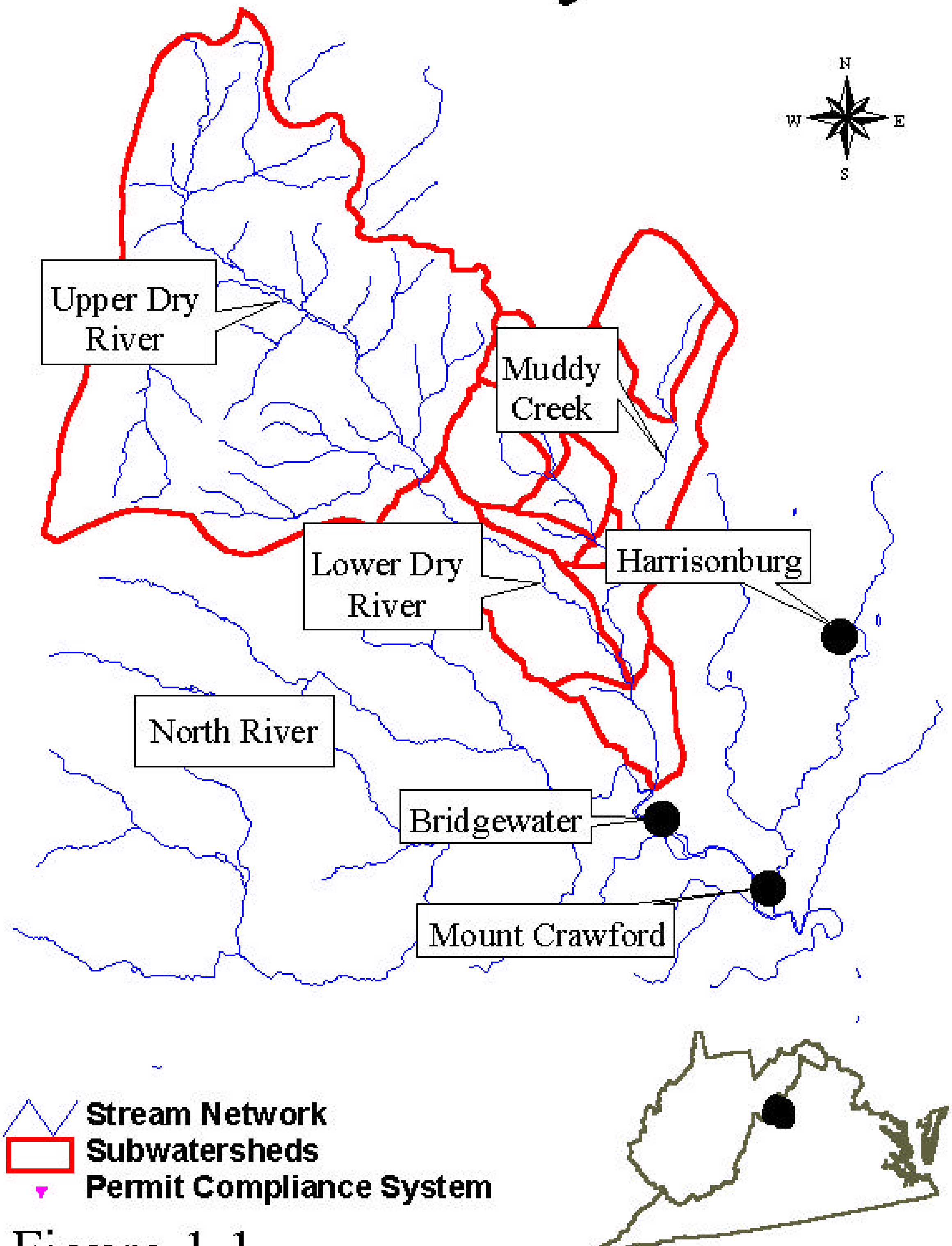

Figure 1.1

high levels of nitrate intake and may develop methemoglobinemia ("blue-baby" disease), a potentially fatal blood disorder (USEPA, 1996 and USEPA, 1/31/00).

States are required by the Clean Water Act to identify and report to the U.S. Environmental Protection Agency (EPA) their water quality-impaired waters. The Town of Bridgewater (WTP), located on the North River below the confluence with the Dry River, first expressed concerns over elevated nitrate concentrations (VADEQ, 08/23/99). In addition, VADEQ monitoring of Muddy Creek (see section 2.1.1) confirmed instances of nitrate levels above the water quality standard. This led to a subsequent preliminary modeling study, *Assessment of Sources and Transport of Nitrate: North River Watershed in Rockingham County* (Yu and Barnes, 1998). The study concluded that, during certain low flow conditions, contributions from point and nonpoint sources would cause violations of the nitrate standard for public drinking water supply within the 5 mile stream reach above the Town of Bridgewater and the City of Harrisonburg WTP intakes (VADEQ, 1998).

Therefore, VADEQ concluded that the drinking water use is only being partially supported, and the Virginia 1998 303(d) List designated 7.04 miles of Muddy Creek/Dry River as impaired due to elevated nitrate levels (VADEQ, 1998). The impaired segment begins on Muddy Creek 0.06 miles above the Rt 914 bridge (river mile 2.15) and continues downstream through the lower Dry River (2.56 miles) and into North River to the City of Harrisonburg water treatment plant (WTP) intake (2.33 miles, river mile 19.55).

1.3 Overview of the Total Maximum Daily Load Process

Section 303(d) of the Clean Water Act and EPA's Water Quality Management and Planning Regulation (40 CFR Part 130) require states to develop total maximum daily loads (TMDLs) for an impaired waterbody. A TMDL is the greatest amount of a pollutant that a waterbody can receive without violating applicable water quality standards. Background concentrations, point source, and nonpoint source loadings are considered. Furthermore, a fraction of the allowable load is reserved for a margin of safety (MOS) to account for uncertainty, variability and future development. Through the TMDL process, states can establish water-quality based controls to reduce pollution and restore the quality of their water resources (USEPA, 1991). A TMDL should set bounds for long-term, sustainable watershed management. Muddy Creek and Dry River are prioritized as “high” on the list for TMDL development and have waterbody codes of VAV-B22R and VAV-B21R, respectively. Waters ranked as high priority in 1998 are targeted for TMDL development before the end of 2000.

2 WATER QUALITY ASSESSMENT AND TMDL ENDPOINTS

2.1 Record of Water Quality Monitoring

The five primary sources of water quality data are:

- three VADEQ sampling stations on Muddy Creek and Dry River
- water quality samples taken by Wampler Foods, Inc. (WFI), in accordance with their VPDES discharge permit
- three VADEQ sampling stations on the North River
- VA Department of Health (VDH) sampling at Bridgewater WTP, and
- the report titled *Total Maximum Daily Load Study on Six Watersheds in the Shenandoah River Basin* (VADEQ, 1997).

2.1.1 VADEQ Water Quality Monitoring Stations on Muddy Creek/Dry River

Samples taken by VADEQ are sent to the Virginia Division of Consolidated Laboratory Services (DCLS). DCLS utilizes automated colorimetry, EPA method 353.2, for nitrate-nitrite analysis (VADEQ, 01/13/00). The record of nitrate data from the three VADEQ in-stream sampling stations is summarized below in Table 2.1. The station locations are shown in Figure 2.1. Ambient nitrate levels for Muddy Creek and Dry River are available from September 1993 to the present, and the VADEQ continues to monitor water quality at stations 2, 4, and 9. Stations 2, 4, and 9 correspond to Virginia State Water Control Board (VASWCD) stations 1BDUR000.02, 1BMDD000.40, and 1BMDD005.81, respectively.

Table 2.1. VADEQ Ambient Water Quality Stations on Muddy Creek and Dry River

Station #	Location	Sampling Frequency	Dates
2 (1BDUR000.02)	Dry River, N. River Rd., just upstream of North River	Monthly	9/93 – Pres.
4 (1BMDD000.40)	Muddy Creek, Rt. 737	Monthly	9/93 – Pres.
9 (1BMDD005.81)	Muddy Creek, Rt. 726 at USGS gage (01621050) in Mount Clinton	Monthly	9/93 – Pres.

Water Quality Monitoring Stations

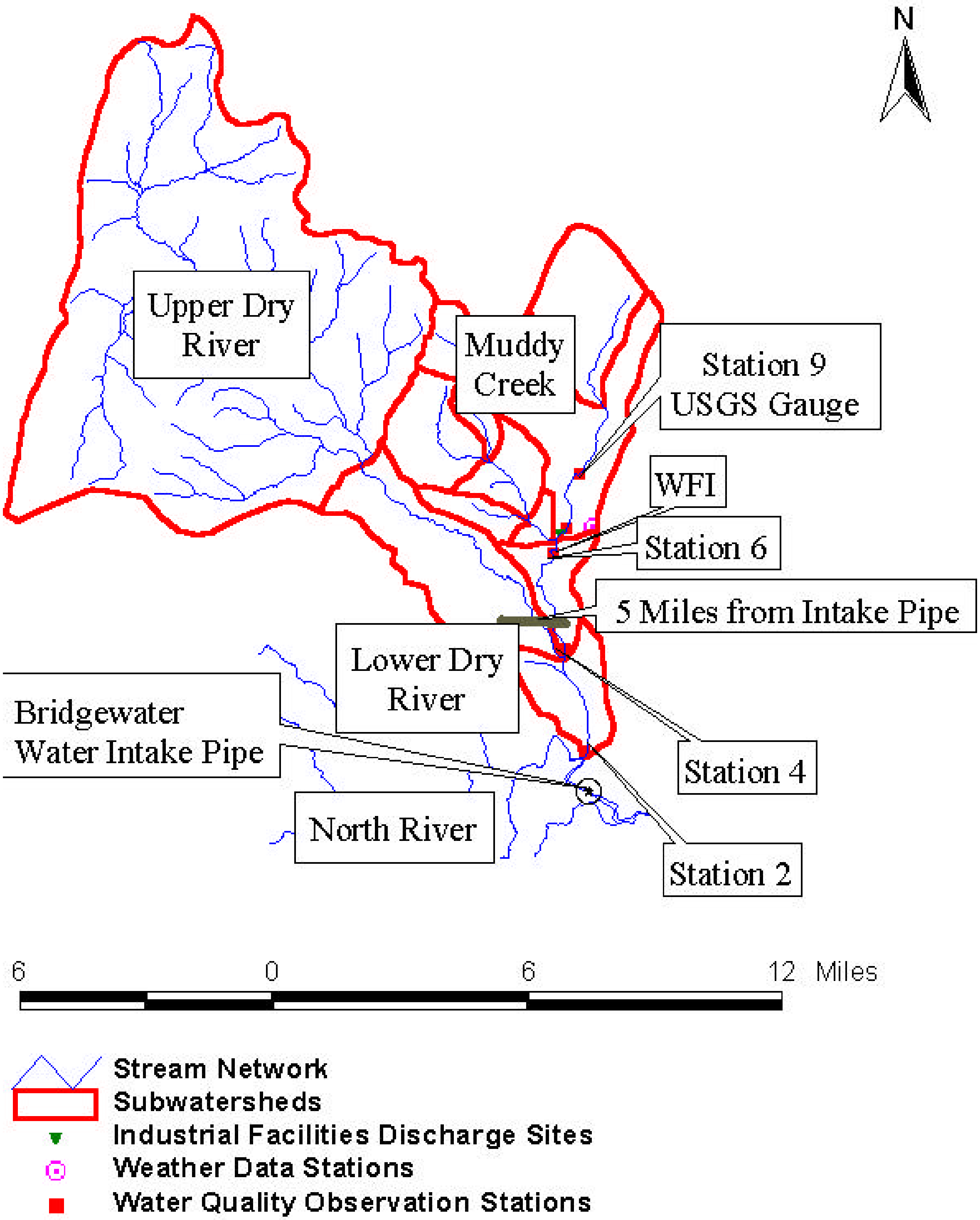

Figure 2.1

2.1.2 Data Reported by Wampler Foods, Inc.

From January 1995 to the present, WFI analyzed nitrate samples from three sites along Muddy Creek and reported their findings to VADEQ. The Wampler QA laboratory analyzes for nitrate using EPA method 352.1, colorimetric – brucine (VADEQ, 01/13/00). The available data is summarized in Table 2.2. WFI continues to actively collect and analyze samples from stations 6, 6a, and 7.

Table 2.2. Wampler Foods, Inc. Sampling Sites on Muddy Creek

Station #	Location	Sampling Frequency	Dates
6	Muddy Creek, Rt. 752	Weekly	1/95 – Present
6a	Muddy Creek at Onyx Hill	Weekly	1/95 – Present
7	Muddy Creek, Rt. 33 in Hinton	Weekly	1/95 – Present

2.1.3 VADEQ Water Quality Stations on North River

There are three VADEQ in-stream sampling stations on North River upstream of the Harrisonburg WTP intake (the end of the listed segment). The record of nitrate data from the three monitoring stations is shown in Table 2.3. Ambient nitrate levels for North River are available from August 1988 to December 1998.

Table 2.3. VADEQ Ambient Water Quality Stations on North River

Station	Location	Dates
1BNTH021.00	River Mile 21 at Wildwood Park Dam in Bridgewater	8/88 – 12/98
1BNTH030.35	River Mile 30.35 at Rt. 674 Bridge	7/93 – 4/97
1BNTH036.96	River Mile 36.96 at Rt. 718 near Stokesville	9/94 – 7/97

2.1.4 Virginia Department of Health Sampling

VDH measured nitrate levels in North River at the Bridgewater WTP intake through 1994. Mean annual concentrations are available for most of the period from 1974 to 1994.

2.1.5 Six Watershed Study

VADEQ's *Total Maximum Daily Load Study of Six Watersheds in the Shenandoah River Basin* supplied additional information. The purposes and goals of the study were to assess the current condition of streams in the study area, establish a data base for determining trends in water quality, and to provide information for developing TMDLs (VADEQ, 1997). Seven VADEQ monitoring stations provided the data reported in the study.

2.2 Summary of Ambient Water Quality Monitoring Data

2.2.1 Muddy Creek/Dry River Summary

Table 2.4 contains the minimum, maximum, average, and median for the nitrate data from the six in-stream water quality monitoring stations. Stations 2, 4, and 9 cover the period from September 1993 to October 1999 while WFI data extends from January 1995 to April 1999. As shown in Figures 2.2, 2.3, and 2.4, there is significant variability in nitrate concentrations measured by VADEQ at stations 2, 4, and 9.

Table 2.4. Summary of Ambient Nitrate Data for Muddy Creek and Dry River, NO_3-N Concentrations in mg/l

Station #	No. of Samples	Minimum	Maximum	Median	Average
2	75	0.04	9.55	3.51	3.83
4	75	1.16	13.54	5.76	5.75
9	75	0.04	8.14	4.49	4.56
6	207	0.45	15.88	6.42	6.63
6a	207	1.20	16.11	6.98	6.93
7	207	1.4	12.36	5.18	5.34

VADEQ measured three violations of the 10 mg/l nitrate-nitrogen standard at station 4 between September 1993 and October 1999. Stations 2 and 9 did not produce any samples above 10 mg/l, having maximum values of 9.55 mg/L and 8.14 mg/L, respectively. Between January 1995 and April 1999, WFI reported twenty NO_3-N values above 10 mg/l at station 6 (0.1 miles downstream of WFI discharge) and three at Station 7 (0.2 miles upstream of discharge). However, stations 6, 7, and 9 are not within the segment designated for public drinking water supply and, therefore, are not subject to the 10 mg/l standard.

2.2.2 North River Data Summary

Table 2.5 contains the minimum, maximum, average, and median for the nitrate data from the three in-stream VADEQ water quality monitoring stations on North River. Each station covers a different time period, as shown in Table 2.3.

Table 2.5. Summary of Ambient Nitrate Data for North River, NO_3-N Concentrations in mg/l

Station	No. of Samples	Minimum	Maximum	Median	Average
1BNTH021.00	100	0.32	4.5	1.73	1.77
1BNTH030.35	17	0.16	4.32	0.52	1.13
1BNTH036.96	4	0.04	0.23	0.11	0.12
TOTAL	121	0.04	4.5	1.66	1.62

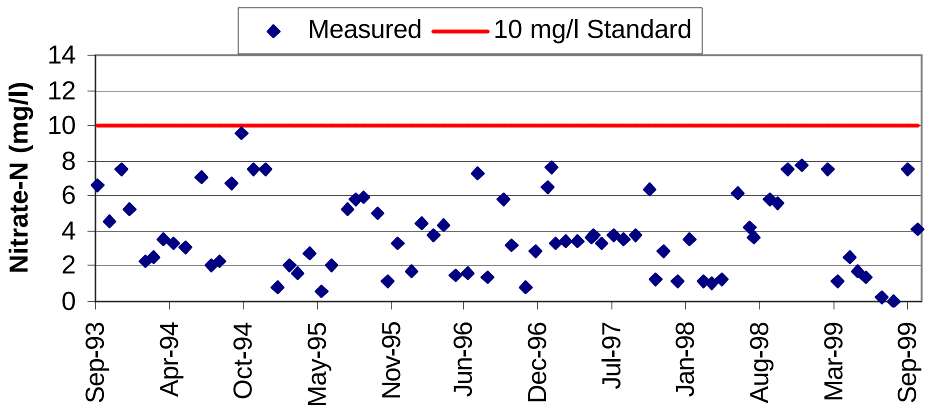

Figure 2.2. Nitrate Levels Measured at Station 2

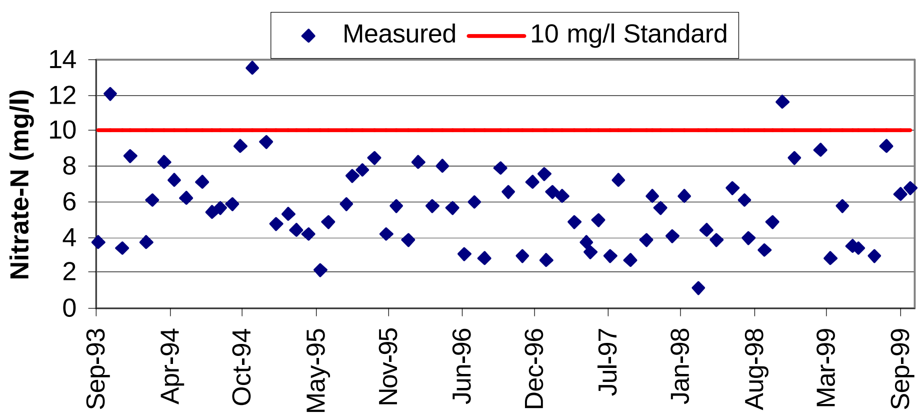

Figure 2.3. Nitrate Levels Measured at Station 4

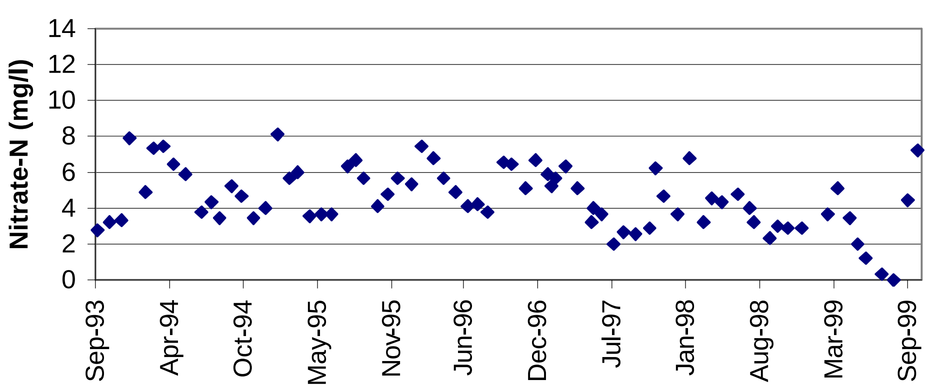

Figure 2.4. Nitrate Levels Measured at Station 9

Station 1BNTH021.00 is located within the segment listed on the Virginia 1998 303(d) list. VADEQ monitored this site for over 10 years, analyzing 100 samples. Only one measured nitrate concentration exceeds 4 mg/l NO_3-N, and the average is less than 2 mg/l. The two stations upstream of the listed segment, 1BNTH030.35 and 1BNTH036.96, have even lower nitrate concentrations, averaging 1.13 and 0.12 mg/l, respectively. Examining the whole data set results in an average of 1.62 mg/l, with only 2 values out of 121 over 4 mg/l, and none reaching even half of the nitrate standard for drinking water supplies.

In addition, the VA Department of Health (VDH) measured the nitrate levels in North River at the Bridgewater WTP intake through 1994. In a report presented by the Town of Bridgewater, the annual mean nitrate-nitrogen concentrations measured by VDH from 1989 to 1994 average 1.80 ± 0.61 mg/l (Town of Bridgewater, 1998).

The data clearly shows that the North River, upstream of the Harrisonburg WTP intake, is not subject to violations of the nitrate standard. This conclusion is supported by the preliminary modeling study, *Assessment of Sources and Transport of Nitrates: North River Watershed in Rockingham County* (Yu and Barnes, 1998). Although this preliminary modeling study indicated that segments of Muddy Creek could exceed the nitrate drinking water standard under critical conditions (low flows combined with small storms), the study found that nitrate concentrations on the North River at the Bridgewater WTP intake (river mile 21.59) would remain significantly below the 10 mg/L standard.

2.3 Relationships between Water Quality, Stream Flow, and Season

The relationship between stream flow and nitrate concentration in the Muddy Creek watershed is complex. The highest recorded values at station 9 occurred during substantial stream flows, at or above the 60^{th} percentile. This is expected because Muddy Creek is dominated by nonpoint source pollution upstream of the WFI discharge. This relationship does not continue below the point source. All three violations of the nitrate standard at Station 4 occurred in October or November during low stream flow conditions – below the 25^{th} percentile. However, rain events were associated with two of the three violations. Six of the highest seven values at both stations 2 and 4 occur during low flow conditions (less than 30^{th} percentile). Conversely, other relatively high measurements were recorded during average and higher flows. In addition, there are numerous low flow measurements with relatively low nitrate concentrations. This indicates that nitrate levels are impacted by both point and nonpoint sources.

For the Muddy Creek data shown in Figures 2.2 - 2.4, all samples with greater than 9 mg/L NO_3-N were collected between August and December, and the three samples above 10 mg/L NO_3-N were collected in October or November. For station 4, the only station with historical violations of the 10 mg/L NO_3-N standard within the 5-mile reach above the drinking water intake, the average sample concentration collected between October and December is 7.31 ± 2.99 mg/L NO_3-N. This range suggests that violations of the 10 mg/L NO_3-N standard would be uncommon, but not rare in the late fall at station 4. In fact, during the VADEQ sampling period (9/1993 - 10/1999), 16% of the samples taken at station 4 between October and December were above the drinking water standard. In addition, May, June, and July tend to have relatively low concentrations, averaging only 4.61 ± 1.52 mg/L NO_3-N at station 4.

2.4 Selection of a TMDL Endpoint, Study Area, and Critical Conditions

A TMDL must establish in-stream goals or endpoints which are used to ensure that adequate water quality is achieved. The numeric or narrative requirements found in state water quality standards are generally used to determine the endpoints. For the Muddy Creek/Dry River nitrate TMDL, the endpoints are derived from the Virginia water quality regulations with an additional 5 percent margin of safety. Thus, the in-stream nitrate goal for this TMDL is 9.5 mg/l nitrate-nitrogen (NO_3-N), with 0 percent violations within the segment designated for drinking water.

The detailed load assessment and modeling analysis in the following chapters will focus on the Muddy Creek and Dry River watersheds (as shown in Figure 2.1, page 2-2). As described in the previous section, the average nitrate concentration for the historical data for the North River, above its confluence with the Dry River down to the Harrisonburg WTP intake, is only 1.62 mg/l. The maximum sample concentration observed in the VADEQ sampling program for this reach was only 4.5 mg/L. Given that the North River flow is also significantly larger than Dry River flow, one can see that the North River, with its low nitrate concentrations, will act to dilute the nitrate load entering from the Dry River. Thus, if the TMDL allocations for nitrates can maintain the nitrate concentration in Dry River at 9.5 mg/L or less, the concentrations in the North River from the confluence to the Harrisonburg WTP intake will also be below the nitrate goal for the TMDL.

Nitrate impairment in the Muddy Creek/Dry River watershed is caused by both point and nonpoint sources. Streams impaired by point sources typically have critical conditions associated with low flow conditions. Conversely, critical conditions for systems dominated by nonpoint source pollution generally are correlated with storm events and high surface runoff. Therefore, an extended analysis period of several years was used to encompass a wide range of conditions. The 1993-1997 simulation period includes a variety of both wet-weather conditions and low flow periods. Thus, the period covers the critical conditions involved with all potential pollution sources within the study area.

3 Nitrogen Sources

3.1 Point Source Assessment

Two point sources in the study area have a Virginia Pollutant Discharge Elimination System permit. They are the Wampler Foods, Inc. (WFI) wastewater treatment facility at Hinton (river mile 3.7) and the Mount Clinton Elementary School at Mount Clinton. WFI is a poultry slaughtering and processing facility. The elementary school has never discharged to Muddy Creek and is scheduled to be closed (MCTEW, 1999).

WFI is the major point source in the watershed. Point source load information was obtained from monthly wastewater analysis reports submitted by WFI to the DEQ. The available data covers the period from 1/95 to the present, with weekly analyses. The average concentration of the WFI effluent is 50 mg/L nitrate-nitrogen, ranging from 19.2 mg/L to 98.8 mg/L nitrate-nitrogen, and 1.15 mg/L ammonia-nitrogen, ranging from 0.1 mg/L to 30.50 mg/L. The average daily flow from WFI is 0.56 MGD, ranging from 0.06 MGD to 0.76 MGD. Overall, the resulting daily mass loadings from WFI, based on the reported flows and concentrations, is highly variable. The average daily nitrate-nitrogen load is 238 lb/day with a range of 20 lb/day to 472 lb/day nitrate-nitrogen, and the average daily ammonia-nitrogen load is 5.3 lb/day with a range of 0.1 lb/day to 150 lb/day ammonia-nitrogen. In the water quality model, the point source load was modeled as varying monthly, based on the measured weekly loads, as shown in Figure 3.1. For the period prior to January, 1995, the average monthly load of 6118 lb of nitrate-nitrogen was used in the model.

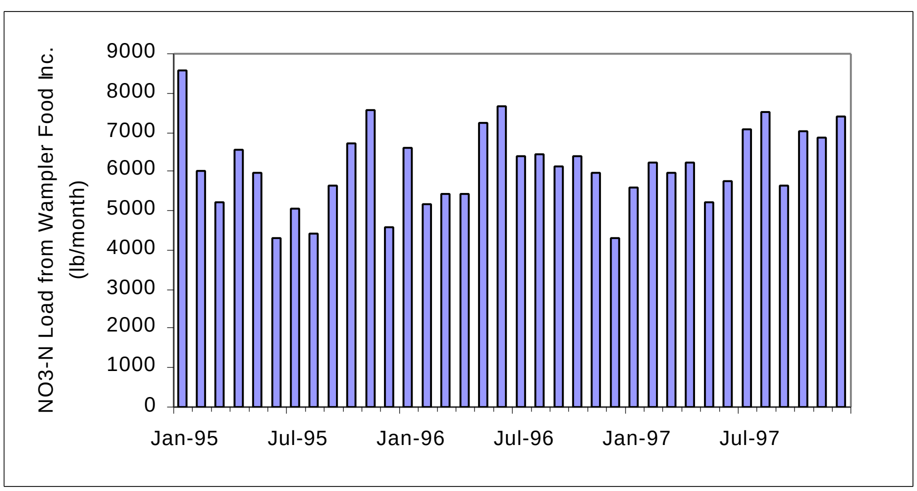

Figure 3.1: Average monthly Nitrate-nitrogen contribution to Muddy Creek from WFI.

3.2 Assessment of Nonpoint Sources

Nonpoint sources of nitrogen species in the Muddy Creek watershed originate from agricultural, residential, and atmospheric sources. Agricultural sources include animal waste, runoff from concentrated animal operations, and nitrogen based fertilizers. Residential sources include properly functioning septic tanks and fertilizer. Atmospheric sources of nitrogen include both dry and wet deposition. In addition, there are natural sources of nitrogen compounds present in the environment that are the result of decomposing wildlife waste and decaying organic matter.

To analyze the nitrogen loading, Muddy Creek watershed was separated into eight sub-basins, and the Dry River watershed was divided into three sub-basins. Each sub-basin was further segmented into land use types using data provided by the Virginia Department of Conservation and Recreation (VADCR). The VADCR used information obtained from the 1989 and 1991 National Aerial Photography Program (NAPP) and 1992 and 1994 Farm Service Aerial Slides to determine land use classifications. Rockingham DOQQ orthophotographs (1990) were used for field boundaries (MCTEW 1999). The twenty-five land use types classified by the VADCR were further aggregated into nine land use categories. Table 3.1 shows the land use categories used in the watershed model, the VADCR land categories, and the percents perviousness and imperviousness for each land use category. The percent perviousness is an important parameter in the watersheds calculation of infiltration and runoff. Nitrogen loads were attributed to each land use category.

The nitrogen loading was evaluated for each land use. Runoff from each area plus background and point sources account for the simulated nitrogen concentration in the modeled streams. The nonpoint sources of nitrogen discussed in this section include

- Septic systems
- Wildlife
- Atmospheric deposition
- Land application of liquid and semi-solid dairy manure
- Land application of poultry litter
- Cattle contributions directly deposited to streams
- Grazing animals
- Agricultural and residential fertilizer applications

Table 3.1: Land use categories and percent pervious/impervious land.*

TMDL (Nitrate) Land use Categories	Pervious/Impervious (Percentage)	VADCR Land use Categories (Class No.)
Developed	Pervious (75%) Impervious (25%)	Built up < 50% Porous (11) Built up > 50% Porous (12) Wooded Residential (44) Rural Residential (14) Unclassified (999)
Farmstead	Pervious (72%) Impervious (28%)	Housed Poultry (2321) Farmstead (13) Farmstead w/Dairy waste facility (813) Large individual dairy waste facilities (8)
Forest/Wooded	Pervious (100%)	Forest Land (40)
Row Crops	Pervious (100%)	Row crop (2110) Gullied row crop (2111) Row crop stripped (2113) Rotational hay (2114) Orchard (221)
Pasture 1	Pervious (100%)	Improved pasture/hayfield (2122, 2121)
Pasture 2	Pervious (100%)	Unimproved pasture (2133) Grazed woodland (43)
Pasture 3	Pervious (100%)	Overgrazed pasture (2124)
Barren	Pervious (100%)	Recently harvested woodland, clear cut (41) Recently harvested woodland, not clear cut (42) Transitional/disturbed sites (7)
Loafing Lots	Pervious (100%)	Dairy Loafing Lots (2312) Unhoused Poultry (2322)

* Land use categories and percent pervious/impervious same as MCTEW (1999).

Each nitrogen source is modeled as a flux to a land use category or deposited directly to a stream reach. Nitrogen from liquid dairy manure, poultry litter, fertilizer, grazing animals, atmospheric deposition and wildlife is modeled as a flux to the land. Cows in the stream and septic tanks are modeled as direct inputs to each stream reach. Septic tanks, wildlife and atmospheric deposition of nitrogen are considered background sources, which remain unchanged in all scenarios. The magnitudes of other sources vary over time, often seasonally or based on agricultural management practices. The following section describes how each source is represented in the model.

3.2.1 Septic Tank Systems

Onsite septic tank treatment systems are a source of nitrate-nitrogen to the groundwater and eventually surface water streams. No specific information regarding septic tank locations, septic tank densities, or effluent concentrations within the Muddy Creek/Dry River watershed is available. However, the entire study area is unsewered. Therefore, septic tank loads can be estimated from the watershed population. Nitrate-nitrogen discharge varies from 4.0 to 8.5 lb/person/year effluent from septic tank systems (Alhajjar, 1985; Frimpter et al., 1988; Horsely et al., 1991; Metcalf & Eddy, 1991; Porter, 1980). Septic tank effluent was modeled as a direct discharge to the stream. A loading was calculated for each sub-basin based on population estimates and added uniformly along the stream at a constant rate each day. The low end of the range (4.0 lb/person/year) was chosen to account for plant uptake and denitrification of nitrogen as it travels through the subsurface to the surface water streams. Population estimates for the watershed were calculated using 1990 US Census data. Table 3.2 shows the estimated population and nitrate-nitrogen contribution from septic tanks in each Muddy Creek and Dry River watershed sub-basin.

Table 3.2: Sub-basin populations and septic tank nitrate-nitrogen contributions,

Sub-basin	Population	Monthly NO_3-N Contribution (lb/month)	Daily NO_3-N Contribution (lb/day)
Muddy Creek 3	171	57.1	1.9
Muddy Creek 2	770	256.7	8.4
Muddy Creek 1	514	171.2	5.6
War Branch 3	86	28.5	0.9
War Branch 2	171	57.1	1.9
War Branch 1	342	114.1	3.8
Buttermilk Creek	171	57.1	1.9
Patterson Creek	259	85.6	2.8
Upper Dry River	0	0.0	0.0
Lower Dry River 2	1288	429.3	14.1
Lower Dry River 1	429	143.1	4.7
Total	4,199	1,399.8	46.0

3.2.2 Wildlife

Forested areas within the Muddy Creek and Dry River watersheds support a diverse and healthy animal population. All wild animals and decaying vegetation contribute some nitrogen to the land surface. For modeling purposes nitrogen loads were not discretized between different species and/or sources. Instead, a nitrogen loading value was chosen for forested land that includes natural nitrogen sources as well as the forests natural attenuation of nitrogen. Runoff from forested lands in the eastern region of the United States was measured at 480 kg Nitrogen/km^2 (4.28 lb Nitrogen/acre) per year (Omernik, 1976). An organic nitrogen load was applied to forested areas until average nitrogen runoff simulated by the model was 4.28 lb/acre in the Muddy Creek watershed. The average organic nitrogen load, in addition to atmospheric deposition, for the forested land was 10.0 lb/acre.

3.2.3 Atmospheric Deposition

Atmospheric deposition of nitrogen can be either wet or dry. Wet deposition containing nitrogen is commonly referred to as acid rain. Nitrogen and other compounds contained in the rain droplets lower the pH. Precipitation-weighted means for nitrates and ammonium measured in rainfall within the Shenandoah National Park are 0.91 mg/L and 0.21 mg/l, respectively, for 1996 through 1998 (National Acid Deposition Program, 1988). The wet deposition data was input as a time series, which covered the entire simulation period. Table 3.2 contains average nitrate and ammonia nitrogen contribution from rainfall.

Table 3.3: Average contribution of nitrate and ammonia nitrogen from rainfall.

Month	Average NO_3-N (lb/acre)	Average NH_3-N (lb/acre)
January	0.81	0.62
February	0.44	0.25
March	0.86	0.45
April	0.60	0.41
May	0.55	0.39
June	0.64	0.54
July	0.78	0.60
August	1.02	0.77
September	0.55	0.38
October	0.61	0.52
November	0.65	0.46
December	0.42	0.28
Annual Total	7.95	5.67

Dry deposition of particles containing nitrogen is a common occurrence. Automobiles and farm machinery are a major source of nitrogen dry deposition. A representative dry deposition rate of 0.27 lb/acre/month nitrate-nitrogen, taken from the Chesapeake Bay Program watershed model, was assumed.

3.2.4 Dairy Manure

Liquid and semi-solid dairy manure is applied to land designated as pasture 1 (hay) and cropland. For modeling purposes, an application rate of manure and its nitrogen content is needed to simulate the build-up of nitrogen on the surface of the land. The VADCR specified manure application rates commonly used within the watershed. Recommended nutrient management techniques call for 6,600 gallons of liquid manure per acre of cropland, and 3,900 gallons of liquid manure per acre of hay. Twelve tons of semi-solid dairy manure should be applied to an acre of crop or hay land. The application schedule by month for liquid manure is 5% of the total in February, 25% in March, 20% in April, 5% in May, 10% in June, 5% in August, 15% in September, 5% in October and 10% in November. The application schedule for semi-solid dairy manure is 5% of the total in February, 25% in March, 20% in April, 5% in May, 5% in June, 5% in July, 5% in August, 10% in September, 10% in October and 10% in November. The average nutrient content of liquid dairy manure for Virginia cows is 13.4 lb organic nitrogen and 9.6 lb ammonium nitrogen per 1000 gallons (VADCR, 1999a). Average nutrient content for semi-solid dairy manure is 7.4 lb organic nitrogen and 3.2 lb ammonium nitrogen per ton (VADCR, 1999a). Table 3.4 shows the recommended liquid manure application schedule and the resulting nitrogen application. Table 3.5 shows the recommended semi-solid manure application schedule and the resulting nitrogen application.

It was assumed that no manure was transferred outside the watershed. To determine the amount of land that received liquid dairy manure applications, a manure balance was completed. The following assumptions were used to calculate the total amount of liquid dairy manure produced within the watershed:

(1) A confined dairy cow produces 17 gallons or 115 lb of waste/day

(2) The average dairy cow is confined for 157 days

(3) All dairy manure is collected, stored, and applied at the appropriate times

(4) 30% of dairy farms in the Dry River watershed collect semi-solid dairy manure (VADCR, 1999b).

This amounts to 17,436,577 gallons of liquid dairy manure produced in the Muddy Creek watershed each year. In the Dry River watershed 7,344,585 gallons and 10,647 tons of liquid and semi-solid dairy manure are produced each year. The total volume is sufficient for 33% of cropland and hayland to receive manure applied at the recommended rates in the Muddy Creek watershed, and 45% in the Dry River watershed.

Table 3.4: Recommended manure application rates (gal/acre) for the Muddy Creek/Dry River watersheds.

Month	Liquid Manure Application Rates (gal/acre-year)		Nitrogen Application Rates (lb N/acre-year)			
	Pasture 1	Cropland	Pasture 1		Cropland	
			Organic N	Ammonium N	Organic N	Ammonium N
January	0	0	0.0	0.0	0.0	0.0
February	195	330	2.6	1.9	4.4	3.2
March	975	1650	13.1	9.4	22.1	15.8
April	780	1320	10.5	7.5	17.7	12.7
May	195	330	2.6	1.9	4.4	3.2
June	390	660	5.2	3.7	8.8	6.3
July	0	0	0.0	0.00	0.0	0.0
August	195	330	2.6	1.9	4.4	3.2
September	585	990	7.8	5.6	13.3	9.5
October	195	330	2.6	1.9	4.4	3.2
November	390	660	5.2	3.7	8.8	6.3
December	0	0	0.0	0.0	0.0	0.0
Annual Total	3900	6600	52.3	37.4	88.4	63.4

For modeling purposes dairy manure was applied to 100% of cropland and hay land at a reduced rate. Based on a manure balance completed for each watershed, 33% of recommended application rates was applied to all of the crop and hay land within Muddy Creek and 45% within Dry River watershed.

Table 3.5: Recommended semi-solid dairy waste application schedule for Muddy Creek/Dry River watersheds.

Month	Semi-solid Manure Application Rates (Tons/acre-year)	Nitrogen Application Rates (lb N/acre-year)	
	Pasture 1 & Cropland	Pasture 1 and Cropland	
		Organic N	Ammonium N
January	0.0	0.0	0.0
February	0.6	4.4	1.9
March	3.0	22.2	9.6
April	2.4	17.7	7.6
May	0.6	4.4	1.9
June	0.6	4.4	1.9
July	0.6	4.4	1.9
August	0.6	4.4	1.9
September	1.2	8.9	3.8
October	1.2	8.9	3.8
November	1.2	8.9	3.8
December	0.0	0.0	0.0
Annual Total	12.0	88.8	38.4

3.2.5 Poultry Litter Application

Poultry litter is applied to crop and hay land in the Muddy Creek and Dry River watersheds that do not receive liquid dairy manure. A ton of poultry litter contains 46.7 lb organic nitrogen and 14.4 lb ammonium nitrogen (Patterson, 1999). Poultry litter is a potentially significant source of nitrogen pollution. Average poultry numbers and accompanying litter production for the Muddy Creek watershed are 50,098 chickens/751 tons; 508,325 broilers/3966 tons; 351,336 turkeys/17,565 tons (MCTEW 1999). The Dry River watershed houses 50,098 chickens, 5,337411 broilers, and 1,204,580 turkeys per year. Estimated poultry litter production for each is 15, 1.3, and 9 tons/1000 birds/year respectively (VADCR, 1999b. This amounts to a total of 22,282 and 18,531 tons of litter produced in the Muddy Creek and Dry River watersheds, respectively, each year.

Recommended litter applications are 3.0 tons/acre-year for cropland and 1.5 tons/acre-year (or 3 tons/acre every other year) for hay and pasture land. It is acceptable for up to two tons/acre-year to be applied to hay or improved pasture land during the winter. Table 3.6

shows the recommended litter application schedule and the resulting nitrogen contribution (VADCR, 1999b.

Table 3.6: Recommended poultry litter application schedule.

Month	Litter Application Rates (tons/acre)		Nitrogen Application Rates (lb/acre)					
	Cropland	Hay land	Cropland		Pasture 1 (Hay)		Pasture 2, 3	
			Org. N	NH_4- N	Org. N	NH_4-N	Org. N	NH_4-N
Jan	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0
Feb	0.15	0.08	7.0	2.2	3.7	1.2	3.5	1.1
March	0.75	0.38	35.0	10.1	17.8	5.5	17.5	5.4
April	0.60	0.30	28.0	8.6	14.0	4.3	14.0	4.3
May	0.15	0.08	7.0	2.2	3.7	1.2	3.5	1.1
June	0.15	0.08	7.0	2.2	3.7	1.2	3.5	1.1
July	0.15	0.08	7.0	2.2	3.7	1.2	3.5	1.1
Aug	0.15	0.08	7.0	2.2	3.7	1.2	3.5	1.1
Sep	0.30	0.15	14.0	4.3	7.0	2.2	7.0	2.2
Oct	0.30	0.15	14.0	4.3	7.0	2.2	7.0	2.2
Nov	0.30	0.15	14.0	4.3	7.0	2.2	7.0	2.2
Dec	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0
Total	3.00	1.50	140.1	43.2	70.0	21.7	70.1	21.6

It was assumed that poultry litter was applied to all crop and hay land not receiving dairy manure, and to as much of the pasture land as possible. In the Muddy Creek watershed 67% of crop and hay land received poultry litter, and 55% in the Dry River received poultry litter. One hundred percent of land designated as pasture 2 and 3 received poultry litter applications in both watersheds. For modeling purposes the rate of application was reduced by the appropriate amount for crop and hay land, so that a reduced application rate was applied to 100% of the land. It was assumed that poultry litter was only applied at the recommended rates and the excess manure produced is exported outside of the watershed. Based on a mass balance calculation, 31% and 59% of poultry litter is exported from the Muddy Creek and Dry River watersheds, respectively. This percentage of litter export is supported by information contained in nutrient management plans and area nutrient management specialists (Patterson 1999).

3.2.6 Commercial Fertilizer Applications to Cropland

Commercial fertilizers are also applied to cropland within the watershed. However, little information is known concerning specific nitrogen fertilizer application rates on a farm-by-farm basis. Common agricultural practices in the watershed include using nitrogen fertilizer prior to, or immediately after, planting corn in the spring. A suggested application rate is 20-30 lb N/acre depending on soil nitrogen content (Schroeder, 1999). Nitrogen fertilizer data was analyzed for Rockingham County for six years (1985-1991). The amount of nitrogen fertilizer sold within the county was obtained from a national database (Battaglin and Goolsby, 1994). An amount was then calculated for the Muddy Creek Watershed, based on the proportional area of the watershed to the county. If this mass of fertilizer is applied to cropland, the resulting fertilization rate is 60 pounds of nitrogen fertilizer per acre of cropland. Thus, the calculated amount of fertilizer used in the watershed on a pounds per acre basis greatly exceeds the value estimated by the VCE.

The use of fertilizer varies greatly from farm to farm within the watershed. According to the Rockingham County Nutrient Specialist factors affecting fertilizer use include soil N content and availability of manure or litter. The Nutrient Specialist estimated fertilizer applications to be 50 – 60 lb N/acre for about 50% of the cropland in the watershed, and 10 –20 lb N/acre for 10% of the watershed. It was suggested that a representative application rate for the watershed would be 30 lb N/acre for cropland applied in March, April, or May.

For modeling purposes 30 lb N/acre was applied to land areas classified as cropland during March, April, and May. Half of the fertilizer was modeled as readily available ammonium-nitrogen, and half was modeled as a slow release fertilizer. Seventeen percent of fertilizer was applied in March, 75% applied in April, and 8% applied in May. Fertilizer applications were distributed between March, April, and May to represent variability of fertilizer applications in the watershed. Identical amounts were applied in the Muddy Creek and Dry River watersheds on a per acre basis.

3.2.7 Cattle Contributions Directly to Stream

Many grazing beef and dairy cows have access to the streams in the Muddy Creek watershed, while no cows are allowed access in the Dry River watershed (VADCR, 1999b). The number of cattle in Muddy Creek varies by month. To calculate the nitrogen contribution from grazing animals it was assumed that each dairy cow deposited 0.45 lb N/day and each beef cow deposited 0.43 lb N/day (Cramer et al., 1986). For modeling purposes, this was applied directly to each reach in the Muddy Creek watershed as pounds of N per stream mile. The nitrogen in the manure was assumed to be 42.3% ammonium-nitrogen and 57.7% organic nitrogen for both beef and dairy cattle (VADCR, 1999a). Table 3.7 shows the numbers of cattle in the stream each month and their nitrogen contribution to the streams. The numbers of cows in and around the stream were taken from the previous work completed by the Muddy Creek TMDL Establishment Workgroup (1999). For modeling purposes, the monthly nitrogen loads were converted to daily averages and supplied directly to the stream.

Table 3.7: Numbers of cattle in Muddy Creek and their predicted nitrogen deposition.

Month	Beef Cows in Stream	Dairy Cows in Stream	Organic N deposited in stream (lb/month)	Ammonium N deposited in stream (lb/month)
Jan	2	0	15.1	11.2
Feb	2	0	15.1	11.2
March	109	68	1,358.9	1,012.7
April	217	159	2,891.8	2,155.1
May	217	159	2,891.8	2,155.1
June	326	238	4,337.5	3,232.4
July	326	238	4,337.5	3,232.4
Aug	326	238	4,337.5	3,232.4
Sep	217	159	2,891.8	2,155.1
Oct	217	159	2,891.8	2,155.1
Nov	109	68	1,358.9	1,012.7
Dec	2	0	15.1	11.2
Annual Total			27,342.6	20,376.6

3.2.8 Nitrogen Application by Grazing Animals

Animals in pasture are a significant source of nitrogen that is applied to the land in both the Muddy Creek and Dry River watersheds. Grazing animals present in the watersheds include dairy cows, beef cattle, and sheep. The VADCR estimates that there are 6,533 dairy cows, 3,134 beef cattle and unconfined replacement cows, and 1,317 sheep in the Muddy Creek watershed. The Dry River has 4075 beef and unconfined replacement cows, 3,448 dairy cows, and 219 sheep.

Beef cattle, replacement dairy cows and sheep are in pasture throughout the year, while dairy cows are confined some of the time. Animal distributions were estimated by the VADCR for each pasture type. For beef cattle and replacement dairy cows, it was assumed that 40% were in pasture 1, 10% in pasture 2, and 50% in pasture 3. Unconfined dairy cows spend 25% of their time in loafing lots, 28% in pasture 1, 7% in pasture 2, 35% in pasture 3, and 5% of their time in the stream. Sheep are located in pasture 3 lands only (MCTEW, 1999). Table 3.8 and 3.9 show the resulting numbers of animals per acre present in each land use category in the Muddy Creek and Dry River watershed. Animals are distributed so that the highest animal densities are in loafing lots, then pasture 3, pasture 2, and lowest animal density in pasture 1.

Table 3.8: Density of grazing animals in Muddy Creek Watershed.

Month	Loafing Lots	Pasture 1		Pasture 2		Pasture 3		
	# Dairy Cows	# Beef Cows	#Dairy Cows	# Beef Cows	#Dairy Cows	# Beef Cows	#Dairy Cows	# Sheep
Jan	2.60	0.27	0.10	1.07	0.42	1.53	0.60	1.28
Feb	2.60	0.27	0.10	1.07	0.42	1.53	0.60	1.28
March	6.13	0.26	0.25	1.04	0.99	1.48	1.41	1.28
April	7.02	0.25	0.28	1.00	1.14	1.42	1.62	1.28
May	7.02	0.25	0.28	1.00	1.14	1.42	1.62	1.28
June	6.90	0.24	0.28	0.96	1.12	1.37	1.59	1.28
July	6.90	0.24	0.28	0.96	1.12	1.37	1.59	1.28
Aug	6.90	0.24	0.28	0.96	1.12	1.37	1.59	1.28
Sep	7.02	0.25	0.28	1.00	1.14	1.42	1.62	1.28
Oct	7.02	0.25	0.28	1.00	1.14	1.42	1.62	1.28
Nov	6.13	0.26	0.25	1.04	0.99	1.48	1.41	1.28
Dec	2.60	0.27	0.10	1.07	0.42	1.53	0.60	1.28

To calculate the nitrogen contribution from grazing animals it was assumed that each dairy cow deposited 0.26 lb organic nitrogen and 0.19 lb ammonium nitrogen per day. Beef cows deposit 0.25 lb organic nitrogen and 0.18 lb ammonium nitrogen per day and sheep produce 0.045 lb organic nitrogen per day. Table 3.10 and 3.11 show the total amount of organic and ammonium nitrogen produced and deposited on each land use in Muddy Creek and Dry River Watersheds.

Table 3.9: Grazing animal densities in Dry River watershed.

Month	Loafing Lots	Pasture 1		Pasture 2		Pasture 3		
	# Dairy	# Beef	#Dairy	# Beef	#Dairy	# Beef	#Dairy	# Sheep

	Cows	Cows	Cows	Cows	Cows	Cows	Cows	
Jan	1.18	1.23	0.19	2.47	0.39	4.65	0.74	0.68
Feb	1.18	1.23	0.19	2.47	0.39	4.65	0.74	0.68
March	2.84	1.23	0.47	2.47	0.94	4.65	1.77	0.68
April	3.31	1.23	0.55	2.47	1.10	4.65	2.07	0.68
May	3.31	1.23	0.55	2.47	1.10	4.65	2.07	0.68
June	3.31	1.23	0.55	2.47	1.10	4.65	2.07	0.68
July	3.31	1.23	0.55	2.47	1.10	4.65	2.07	0.68
Aug	3.31	1.23	0.55	2.47	1.10	4.65	2.07	0.68
Sep	3.31	1.23	0.55	2.47	1.10	4.65	2.07	0.68
Oct	3.31	1.23	0.55	2.47	1.10	4.65	2.07	0.68
Nov	2.84	1.23	0.47	2.47	0.94	4.65	1.77	0.68
Dec	1.18	1.23	0.19	2.47	0.39	4.65	0.74	0.68

Table 3.10: Nitrogen produced by grazing animals in Muddy Creek Watershed.

Month	Loafing Lots		Pasture 1		Pasture 2		Pasture 3	
	Org N lb/acre	NH4 lb/acre	Org N lb/acre	NH4 lb/acre	Org N lb/acre	NH4 lb/acre	Org N lb/acre	NH4 lb/acre
Jan	20.5	15.3	2.8	2.1	11.4	8.5	18.0	12.1
Feb	20.5	15.3	2.8	2.1	11.4	8.5	18.0	12.1
March	48.4	36.1	3.9	2.9	15.7	11.7	24.0	16.6
April	55.5	41.3	4.1	3.1	16.5	12.3	25.2	17.5
May	55.5	41.3	4.1	3.1	16.5	12.3	25.2	17.5
June	54.5	40.6	4.0	3.0	16.1	12.0	24.6	17.0
July	54.5	40.6	4.0	3.0	16.1	12.0	24.6	17.0
Aug	54.5	40.6	4.0	3.0	16.1	12.0	24.6	17.0
Sep	55.5	41.3	4.1	3.1	16.5	12.3	25.2	17.5
Oct	55.5	41.3	4.1	3.1	16.5	12.3	25.2	17.5
Nov	48.4	36.1	3.9	2.9	15.7	11.7	24.0	16.6
Dec	20.5	15.3	2.8	2.1	11.4	8.5	18.0	12.1
Total	543.5	405.00	44.8	33.4	179.8	134.0	276.8	190.6

Table 3.11: Nitrogen produced by grazing animals in Dry River Watershed.

Month	Loafing Lots		Pasture 1		Pasture 2		Pasture 3	
	Org N lb/acre	NH4 lb/acre	Org N lb/acre	NH4 lb/acre	Org N lb/acre	NH4 lb/acre	Org N lb/acre	NH4 lb/acre
Jan	9.3	7.0	10.8	8.1	21.7	16.2	40.9	30.5
Feb	9.3	7.0	10.8	8.1	21.7	16.2	40.9	30.5
March	22.4	16.7	13.0	9.7	26.0	19.4	49.1	36.6
April	26.1	19.5	13.6	10.1	27.3	20.3	51.4	38.3
May	26.1	19.5	13.6	10.1	27.3	20.3	51.4	38.3
June	26.1	19.5	13.6	10.1	27.3	20.3	51.4	38.3
July	26.1	19.5	13.6	10.1	27.3	20.3	51.4	38.3
Aug	26.1	19.5	13.6	10.1	27.3	20.3	51.4	38.3
Sep	26.1	19.5	13.6	10.1	27.3	20.3	51.4	38.3
Oct	26.1	19.5	13.6	10.1	27.3	20.3	51.4	38.3
Nov	22.4	16.7	13.0	9.7	26.0	19.4	49.1	36.6
Dec	9.3	7.0	10.8	8.1	21.7	16.2	40.9	30.5
Total	255.5	190.4	153.4	114.3	308.1	229.6	580.5	432.6

3.2.9 Commercial Fertilizer Applications to Residential Land

While the majority of fertilizer used within the watershed is used for agricultural purposes, some commercial fertilizer is used for residential homes and gardens. The recommended application rate for lawn fertilization is 1-2 lb nitrogen per 1000 square feet (VCE, 1999). Application should occur in the fall for most grasses present in the watershed. Half of the fertilizer was modeled as organic nitrogen and half as ammonium nitrogen. Fertilizer was applied to lands designated as developed following the schedule listed in Table 3.12 (VCE, 1999).

Table 3.12: Residential fertilizer application rates (lb/acre).

Month	May	June	July	August	September	October
N lb/acre	32.7	32.7	0.0	43.5	43.5	65.3

3.3 Nitrogen Loads by Land Use

Each land use accumulated nitrogen from various sources (Table 3.13) on a monthly basis to account for seasonal variations in litter and liquid manure application and grazing schedules. For example, the nitrogen accumulation rate for cropland is the sum of all sources contributing nitrogen to the land's surface. This includes liquid dairy manure, poultry litter, commercial fertilizer and atmospheric deposition. For each land use, a total nitrogen load was calculated by summing the individual nitrogen loads, as described in section 3.2, from each applicable source.

The annual nitrogen loads applied to each land use can be found in Tables 3.14 – 3.18. These tables describe the annual amount of nitrogen applied to the lands surface. These tables do not include the wet deposition load, which varies yearly depending on the depth of precipitation. As summarized in Table 3.2, the average annual wet deposition load is 7.95 lb NO_3-N/acre and 5.67 lb NH_3-N/acre. The total nitrogen loads by land use are used as input for the watershed model. The model analysis is described in chapter 4. The total annual nitrogen loads by source are summarized in Appendix B.

Table 3.13: Nitrogen sources applied to each land use.

Land use category	Nitrogen Sources
Cropland	Dairy manure, poultry litter, commercial fertilizer, atmospheric dep.
Pasture 1	Poultry litter, grazing animals, atmospheric deposition
Pasture 2	Poultry litter, grazing animals, atmospheric deposition
Pasture 3	Poultry litter, grazing animals, atmospheric deposition
Farmstead	Atmospheric deposition
Forest	Atmospheric deposition, background forest load
Barren	Atmospheric deposition
Residential	Commercial fertilizer, Atmospheric deposition

Table 3.14: Nitrogen application to crop and hay land in the Muddy Creek Watershed model, excluding wet deposition.

Month	Cropland		Pasture 1 (hay)	
	Organic N (lb/acre)	Ammonium N (lb/acre)	Organic N (lb/acre)	Ammonium N (lb/acre)
Jan	0.27	0.00	3.11	2.12
Feb	6.38	2.49	6.30	3.46
March	33.37	15.00	20.09	9.61
April	35.96	21.21	17.12	8.43
May	7.58	3.69	7.56	4.40
June	7.82	3.54	8.30	4.94
July	4.95	1.44	6.61	3.70
Aug	6.38	2.49	7.45	4.32
Sep	13.93	6.03	11.60	6.37
Oct	11.06	3.92	9.90	5.12
Nov	12.49	4.98	10.54	5.58
Dec	0.27	0.00	3.11	2.12
Annual Total	140.46	64.78	111.69	60.17

Table 3.15: Total nitrogen application to crop and hay land in the Dry River watershed model, excluding wet deposition.

Month	Cropland		Pasture 1 (hay)	
	Organic N (lb/acre)	Ammonium N (lb/acre)	Organic N (lb/acre)	Ammonium N (lb/acre)
Jan	0.27	0.00	11.07	8.05
Feb	6.09	2.37	16.43	10.09
March	31.92	14.42	40.01	19.82
April	34.80	20.75	35.27	18.25
May	7.29	3.57	19.20	12.15
June	7.23	3.21	19.87	12.64
July	4.95	1.54	18.53	11.66
Aug	6.09	2.37	19.20	12.15
Sep	13.05	5.58	25.23	14.67
Oct	10.78	3.92	23.88	13.69
Nov	11.91	4.75	23.94	13.72
Dec	0.27	0.00	11.07	8.05
Annual Total	131.68	62.48	260.73	154.95

Table 3.16: Total nitrogen applied to pasture 2, pasture 3, and loafing lots in the Muddy Creek watershed, excluding wet deposition.

Month	Pasture 2		Pasture 3		Loafing Lots	
	Org. N Lb/acre	NH4-N lb/acre	Org. N lb/acre	NH4-N lb/acre	Org. N lb/acre	NH4-N lb/acre
Jan.	11.42	8.51	17.99	12.11	20.52	15.29
Feb	14.92	9.59	21.50	13.18	20.52	15.29
March	33.16	17.05	41.52	21.97	48.38	36.06
April	30.52	16.61	39.24	21.81	55.45	41.32
May	20.01	13.38	28.74	18.58	55.45	41.32
June	19.57	13.05	28.11	18.11	54.45	40.58
July	19.57	13.05	28.11	18.11	54.45	40.58
Aug.	19.57	13.05	28.11	18.11	54.45	40.58
Sep.	23.52	14.46	32.24	19.66	55.45	41.32
Oct.	23.52	14.46	32.24	19.66	55.45	41.32
Nov.	22.65	13.82	31.01	18.74	48.38	36.06
Dec.	11.42	8.51	17.99	12.11	20.52	15.29
Annual Total	249.86	155.55	346.79	212.13	543.45	405.00

Table 3.17: Total nitrogen applied to pasture 2, pasture 3, and loafing lots in the Dry River watershed, excluding wet deposition.

Month	Pasture 2		Pasture 3		Loafing Lots	
	Org. N Lb/acre	NH4-N lb/acre	Org. N lb/acre	NH4-N lb/acre	Org. N lb/acre	NH4-N lb/acre
Jan.	21.98	16.18	41.86	30.48	9.60	6.95
Feb	25.49	17.26	45.37	31.56	9.60	6.95
March	43.85	24.80	67.56	41.96	22.65	16.68
April	41.58	24.64	66.38	42.61	26.38	19.46
May	31.05	21.40	55.85	39.37	26.38	19.46
June	31.05	21.40	55.85	39.37	26.38	19.46
July	31.05	21.40	55.85	39.37	26.38	19.46
Aug.	31.05	21.40	55.85	39.37	26.38	19.46
Sep.	34.56	22.48	59.36	40.45	26.38	19.46
Oct.	34.56	22.48	59.36	40.45	26.38	19.46
Nov.	33.32	21.56	57.03	38.72	22.65	16.68
Dec.	21.98	16.18	41.86	30.48	9.60	6.95
Annual Total	381.53	251.20	662.17	454.23	258.77	190.43

Table 3.18: Total nitrogen applied to barren, forest, residential, and farmstead land in the Muddy Creek and Dry River watershed, excluding wet deposition.

Month	Barren and Farmstead		Forest		Residential	
	Org. N lb/acre	NH4-N lb/acre	Org. N lb/acre	NH4-N lb/acre	Org. N lb/acre	NH4-N lb/acre
Jan.	0.27	0.0	0.36	0.0	0.27	0.0
Feb	0.27	0.0	0.36	0.0	0.27	0.0
March	0.27	0.0	0.36	0.0	0.27	0.0
April	0.27	0.0	0.36	0.0	0.27	0.0
May	0.27	0.0	0.36	0.0	16.6	16.4
June	0.27	0.0	0.36	0.0	16.6	16.4
July	0.27	0.0	0.36	0.0	0.27	0.0
Aug.	0.27	0.0	0.36	0.0	22.0	21.8
Sep.	0.27	0.0	0.36	0.0	22.0	21.8
Oct.	0.27	0.0	0.36	0.0	32.9	32.7
Nov.	0.27	0.0	0.36	0.0	0.27	0.0
Dec.	0.27	0.0	0.36	0.0	0.27	0.0
Total	3.24	0.0	4.32	0.0	112.3	109.1

4 Modeling Procedure

4.1 Modeling Framework Selection

For this TMDL analysis, the water quality/quantity model, Hydrologic Simulation Program-FORTRAN (HSPF) version 11.0 (Bicknell et al., 1997), was used to predict stream flow, in-stream water quality and the significance of nitrogen sources. HSPF was selected because of its ability to simulate both nonpoint and point source loads, as well as the flow and transport of pollutants in each stream reach. In addition, HSPF is able to assess in-stream water quality response to changes in flow, season, and load (Bicknell et al., 1997). HSPF is supported by both the U.S. EPA and U.S. Geologic Survey. While HSPF is a component of the U.S. EPA BASINS watershed model (USEPA, 1998), the nitrogen chemical cycle is not supported within the BASINS modeling framework. Thus HSPF was used outside of the BASINS modeling system.

4.2 Model Setup

The Muddy Creek/Dry River watershed was subdivided into eleven subwatersheds. The Muddy Creek and Dry River watersheds contained eight and three subwatersheds, respectively (Figure 4.1). The study area was divided to allow for spatial variation of nitrogen loading throughout the watershed and to allow the relative contribution of sources to each stream segment to be determined. Subwatershed delineation was based on a topographic analysis of the region and past work completed by the VADCR. Delineation of subwatersheds occurred along topographic drainage divides. In addition, nitrogen nonpoint source loads differed between the Muddy Creek and Dry River watersheds due to variations in farm management practices.

4.3 Source Representation

Chapter 3 provides a detailed description of each source and describes how each is incorporated into the watershed model, thus only a brief summary of source representation is given here. The impacts of both point and nonpoint sources of nitrogen are modeled. The watershed's only active point source (Wampler Foods, Inc.) was represented as a direct discharge varying over time (Section 3.1). Septic tanks (Table 3.2) and cows-in-stream

TMDL Subwatersheds

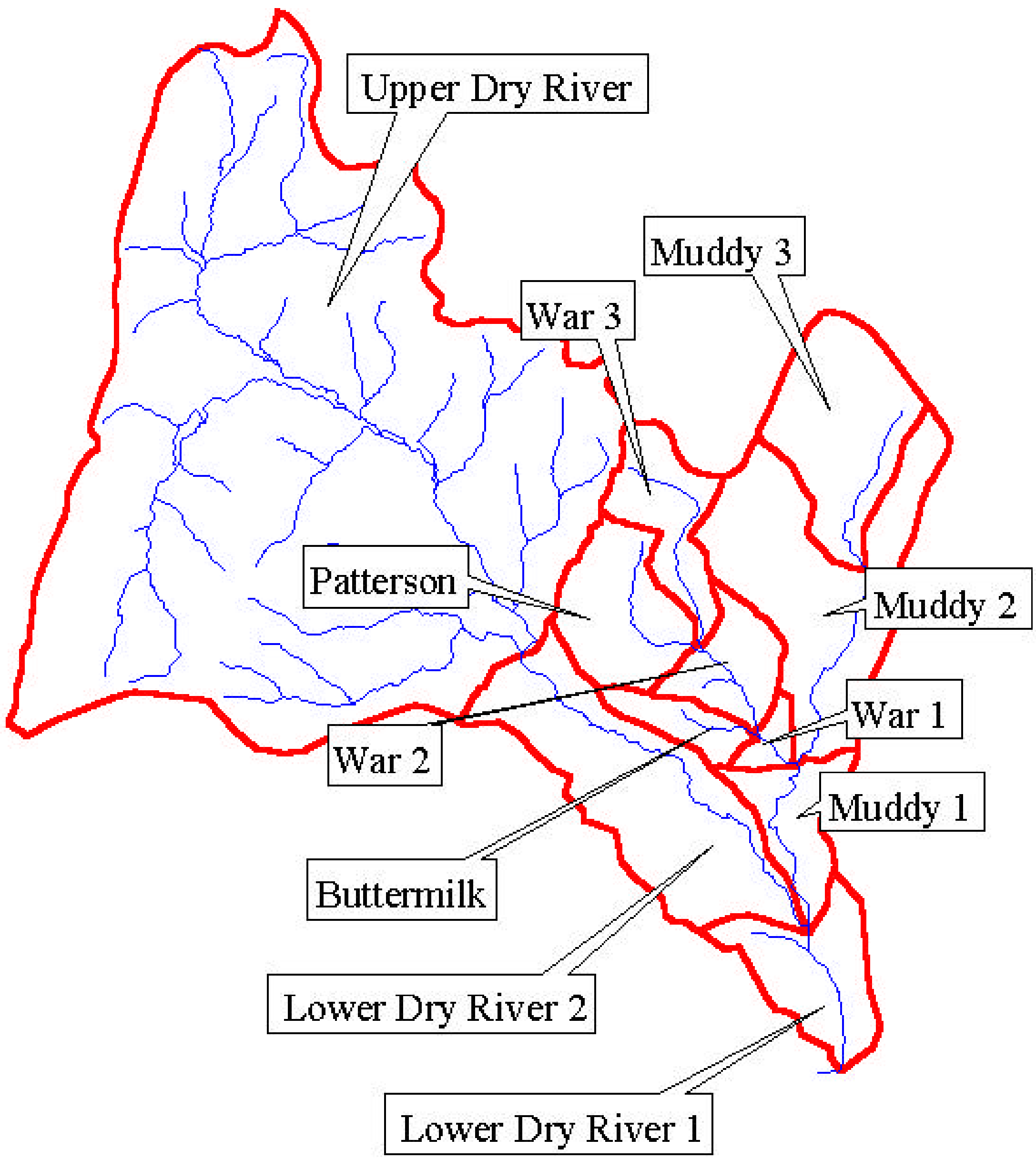

Figure 4.1

(Table 3.7) were modeled as direct discharges along each stream reach. Nonpoint source loads varied monthly depending on numbers of animals grazing in pasture and the amount of manure, litter, and fertilizer applied to the land. Atmospheric deposition was also included as a background non-point source (Section 3.2.3).

4.4 Stream Characteristics

Stream channel geometry for the reaches in the Muddy Creek watershed were based on measurements taken at three sites in the watershed by the Water Resources Division of the State Water Control Board (VASWCB). Segment lengths, average depth, maximum depth, average width, and slope were calculated by the MCTEW for the fecal coliform TMDL (MCTEW, 1999). Channel characteristics for the Dry River were derived from measurements taken at station #2, USGS topographical maps, and visual inspection of the stream at several sites. Table 4.1 shows the stream length, slope, average depth, average width and maximum depth for each stream modeled in the watershed.

Table 4.1: Stream characteristics of Muddy Creek and Dry River watersheds.

Subwatershed	Length (mile)	Average Depth (ft)	Maximum Depth (ft)	Average Width (ft)	Slope
Muddy 1	3.57	0.8	1.2	15	0.002
Muddy 2	3.39	0.68	1.05	15	0.0025
Muddy 3	3.35	0.5	0.75	10	0.0045
War 1	0.89	0.6	0.9	15	0.0025
War 2	1.67	0.5	0.75	13	0.003
War 3	3.44	0.4	0.6	9	0.006
Buttermilk	1.60	0.5	0.75	13	0.004
Patterson	2.98	0.4	0.6	9	0.006
Upper Dry River	14.70	1.4	1.6	4	0.021
Lower Dry River 2	8.10	1.4	1.6	8	0.007
Lower Dry River 1	2.63	1.6	1.8	20	0.007

4.5 Weather Data

Weather and climate data from the Dale Enterprise climatological station were used to represent the weather in Muddy Creek and Dry River watersheds. Continuous hourly data sets for precipitation, evaporation, evapotranspiration, temperature, windspeed, solar radiation, dewpoint temperature, and cloud cover were developed for the HSPF model. This information was gathered and formatted by the MCTEW and used for the Fecal Coliform TMDL. Table 4.2 shows the climatological normals for the Dale Enterprise Station from 1961 through 1991. It includes the minimum, average, and maximum temperatures and average rainfall recorded at this station.

Table 4.2: Climatological Normals (1961-90) Dale Enterprise, Virginia

Month	Min Temp (F)	Max Temp (F)	Average Temp (F)	Average Rainfall (in)
January	21.1	40.9	31.0	1.87
February	23.6	44.8	34.2	2.02
March	32.1	55.7	43.9	2.47
April	39.8	65.4	52.6	2.52
May	49.2	74.6	61.9	3.38
June	57.2	82.6	69.9	2.96
July	61.4	85.8	73.6	3.57
August	60.0	84.3	72.2	3.58
September	53.5	77.3	65.6	3.29
October	42.4	66.7	54.5	3.00
November	34.5	55.5	45.0	2.70
December	25.6	44.8	35.2	2.23
Annual	41.7	64.9	53.3	33.59

4.6 Model Calibration

Calibration of HSPF is a two step process. The hydrology of the watershed must first be calibrated before simulation of nitrogen can proceed. Model calibration is an iterative process where model parameters are varied within reasonable ranges until the model results adequately match observed measurements.

4.6.1 Hydrologic Calibration

In the development of the coliform bacteria TMDL for Muddy Creek, a hydrologic model was developed for the Muddy Creek watershed by the MCTEW (1999). The coliform study calibrated flow to that observed at the USGS gage 01621050 (Station 9, Muddy Creek at Mount Clinton). At this station, the observed flow was recorded every 15 minutes from 4/13/93 to 12/31/97, our simulation period. For this nitrate study, the same values of the hydrological parameters, determined in the previous study, were applied to the Muddy Creek watershed. However, the boundaries of the Muddy Creek watershed and subwatersheds were re-entered into the geographical information system for this study. The resulting flow at Station #4 (Virginia State Water Control Board, VASWCB, monitoring station 1BMDD000.4), which is within the listed reach, is shown in Figure 4.2. Note the excellent fit of the observed flows at Station #4, in the lower Muddy Creek watershed where the water quality violations have been observed. When flow predictions based on the watershed boundaries used in the coliform study and this nitrate analysis are compared, no statistically significant differences between the estimated flows at Station #4 are found.

Calibration of flows for the Dry River watershed began by using the hydrological parameter values as developed for Muddy Creek. Given the unusual hydrogeology in the Dry River watershed, there was good reason to believe that infiltration rates (both surface and deep infiltration) varied between the Muddy Creek watershed and Dry River watershed. Thus, parameter values for Dry River watershed were adjusted to calibrate flows at Station #2 near Dry River's confluence with the North River (VASWCB station 1BDUR000.02) as show in Figure 4.3.

Based on the similarity of modeled and observed flows using model parameters within normal ranges, it was determined that the model adequately represents the hydrology of the Muddy Creek and Dry River watersheds.

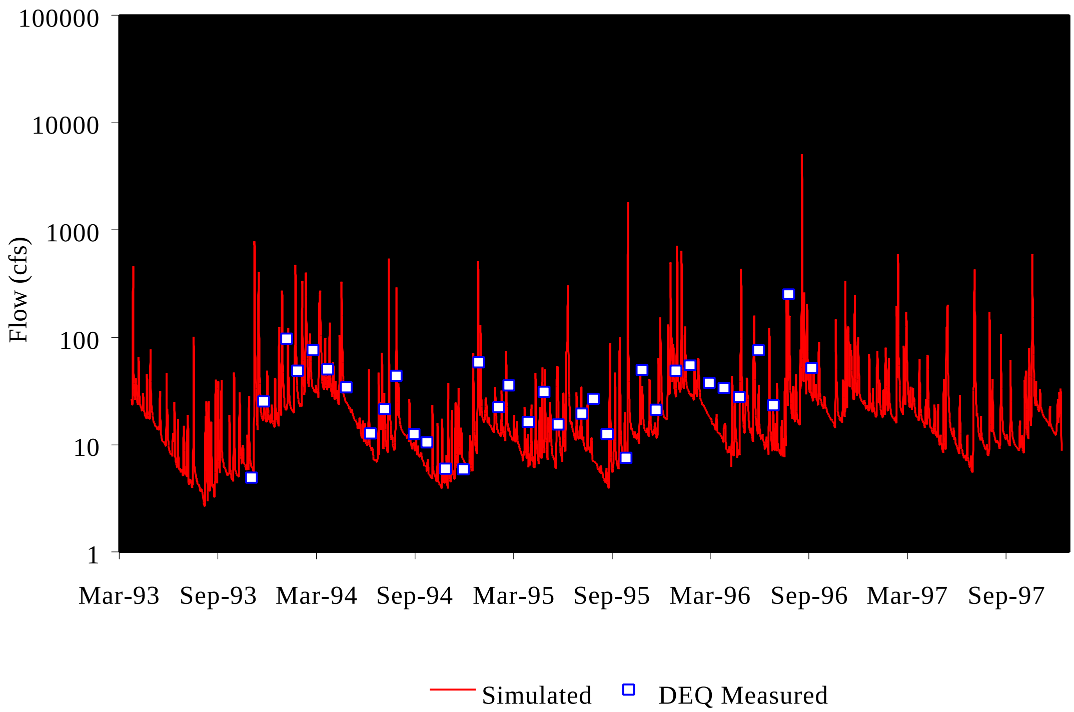

Figure 4.2: Simulated and observed flow at station #4.

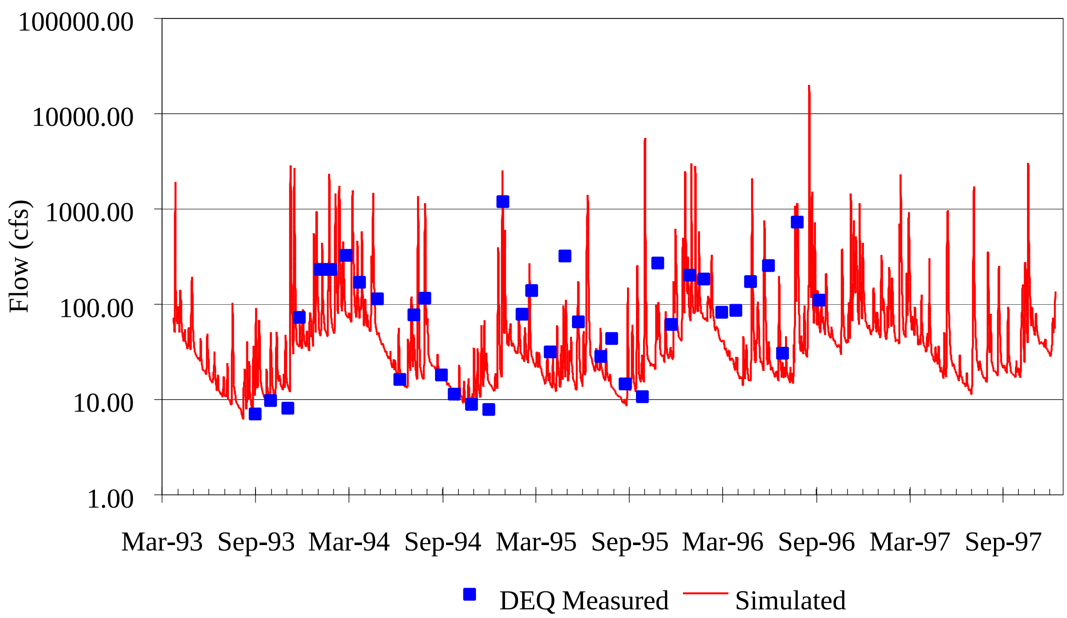

Figure 4.3: Simulated and observed flow at station #2.

4.6.2 Nitrate-nitrogen Calibration

The calibration of the nitrate-nitrogen water quality portion of the model was completed by applying current nitrogen loads, as described in chapter 3, to each land use present in the watersheds. Model transport parameters were adjusted until model results matched observed values. Important calibration parameters included those controlling plant uptake of nitrogen, nitrification, denitrification, and ammonia volatilization. The U.S. EPA database, HSPFParm (1999), was used to evaluate potential parameter ranges.

The model was first calibrated to Station #4, the only site within the reach designated for drinking water use with historical samples above the standard (Figure 4.4). Consistent with the observed data, the model accurately identifies the fall as the period with the highest nitrate concentrations. The simulated periods of violation are consistent with the observed violations, and the concentration ranges are similar. The calibrated set of model parameters was then used to simulate nitrate concentrations, lower in the listed reach at station #2 on Dry River (Figures 4.5). Consistent with the data, the model predicts that the nitrate concentrations at Station 2 (on the Dry River near its confluence with the North River) were below the drinking water standard. It is clear from both the data and the calibrations that the only violations of the nitrate standard occur in the upper portion of the listed reach (Station #4). The TMDL allocations (Chapter 5) will thus focus on reducing the nitrate concentrations at Station #4 to the desired endpoint level of the TMDL (9.5 mg/L NO_3-N).

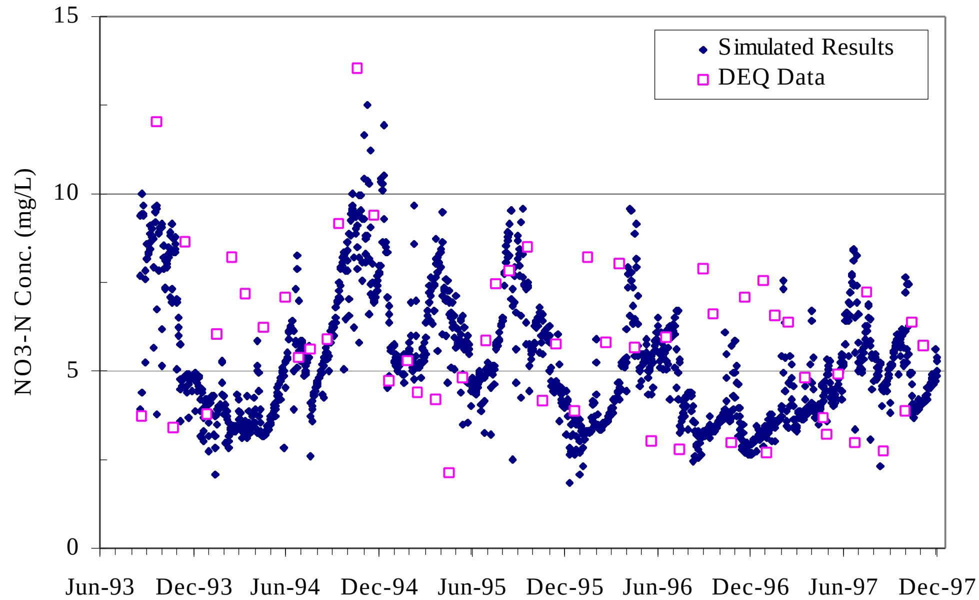

Figure 4.4: Nitrate-nitrogen calibration at Station #4.

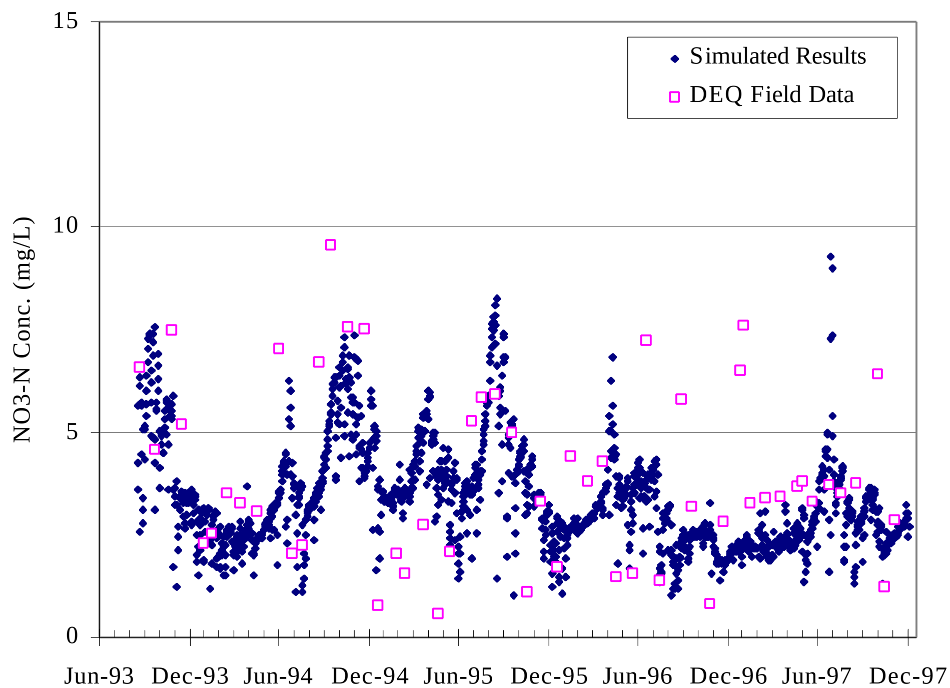

Figure 4.5: Nitrate-nitrogen calibration at station #2.

4.6.3 Nitrogen Contributions to Stream under Current Conditions

Using the calibrated HSPF model, the total nitrogen loads applied to the land surface, which were summarized in Section 3.3, can be translated into contributions to the stream. The fraction of the nitrogen applied to each acre that eventually reaches the surface water stream depends on the land use, season, precipitation, and nitrogen species. Total mass of nitrogen reaching the stream throughout the watershed is also dependent on the amount of acreage of each land use. Based on current conditions, forest lands, row crops, haylands, over-grazed pastures, loafing lots, the point source, and cows in-stream each contribute over 5% of the total nitrogen reaching Muddy Creek annually (Table 4.3). The important contributors are slightly different in the Dry River watershed (Table 4.4) primarily due to different livestock densities and different land use patterns.

Table 4.3: Simulated average annual total nitrogen contribution from land uses in the Muddy Creek watershed. (NA = Not Applicable).

Land Use	Total N (lb/ac)	Acreage (acres)	Total N (lb)	% of Total N Contribution
Forest	4.1	6849	28,354	7.2%
Developed	12.9	979	12,478	3.2%
Farmstead	5.8	869	4,364	0.97%
Row Crop	16.6	5154	85,403	21.6%
Pasture 3	25.3	1025	25,911	6.5%
Pasture 1	12.5	4686	58,737	14.8%
Pasture 2	19.7	292	5740	1.4%
Loafing Lots	182.6	157	28,684	7.2%
Barren	20.8	13	270	0.1%
WFI	NA	NA	88380	22.3%
Septic Tanks	NA	NA	9,929	2.5%
Cows	NA	NA	47718	12.1%

It must be cautioned that Table 4.3 and 4.4 are insufficient to determine relative impacts on nitrate levels at any specific point in the watersheds. While the tables indicate total nitrogen contributions, each land use or source contributes different ratios of nitrate, ammonium, and organic nitrogen. Once in stream, chemical reactions will occur, allowing nitrogen to continue to change form. In general, sources with high percentages of nitrate, such as the point source, will have a more immediate impact on in-stream nitrate levels, than highly organic sources such as forest lands. Furthermore, the annual total nitrogen reported in these tables will be spread unequally over the year and will also vary in how they spatially enter the stream. For instance, the entire point source (WFI) contribution is added at a single location in the watershed while forest and row crops loads are spread over approximately one third of the watershed.

Table 4.4: Simulated total nitrogen contribution from land uses in Dry River watershed. (NA = Not Applicable).

Land Use	**Total N (lb/ac)**	**Acreage (acres)**	**Total N (lb)**	**% of Total N Contribution**
Forest	4.4	3119	13,661	5.42%
Developed	19.7	785	15,449	6.13%
Farmstead	5.2	544	2,801	1.11%
Row Crop	15.3	3434	52,603	20.86%
Pasture 3	63.3	438	27,723	10.99%
Pasture 1	65.9	1327	87,463	34.68%
Pasture 2	119.1	165	19,660	7.80%
Loafing Lots	14.19	182	25,875	10.26%
Barren	23.1	4	102	0.04%
Septic Tanks	NA	NA	6869	2.72%

5 LOAD ALLOCATION

5.1 TMDL Allocation Approach

A total maximum daily load (TMDL) is the sum of individual waste load allocations for point sources, for nonpoint sources and for natural background sources. In addition, a TMDL must include a margin of safety (MOS) that accounts for the uncertainty about future conditions and about the relationship between the pollutant loads and the water quality of the receiving body. A TMDL is the greatest amount of a pollutant that a waterbody can receive without violating applicable water quality standards.

The Muddy Creek/Dry River nitrate TMDL allocation scenarios were designed to reliably meet the Virginia water quality standard for public drinking water supplies of 10 mg/L NO_3-N with no violations. An explicit 5 percent margin of safety was incorporated into the TMDL; therefore the modeled concentrations were targeted for a maximum of 9.5 mg/L NO_3-N within the segment designated for drinking water. As was demonstrated in Section 2.2 and Section 4.5.2, no violations of this targeted endpoint are expected in the Dry River or North River segments of the listed reach, even under current loading. Therefore no load reductions are required to meet the TMDL water quality goals in the Dry River or North River watersheds. Thus the following sections will focus on determining the requisite load allocations within the Muddy Creek watershed to bring the nitrate concentrations in the listed segment of Muddy Creek below the targeted concentration endpoint.

5.2 Scenario Development

Allocation scenarios were evaluated using the HSPF watershed model developed for this study. Existing loads to the point and nonpoint sources in the Muddy Creek watershed were reduced until the water quality goal of 9.5 mg/l nitrate-nitrogen was met at station #4. Percent reductions to the point source load are modeled as evenly distributed throughout the year, while reductions to nonpoint sources are modeled as seasonal reductions. These differences reflect operational considerations between point sources and nonpoint sources. Extending nonpoint source reductions throughout the year has no significant impact on the predicted magnitudes of the peak concentrations during critical conditions. In addition, seasonal reductions result in lower magnitudes for the total annual reductions.

The allocation scenarios described below take into account seasonal variation of nitrogen loads, rainfall, and stream flows by explicitly including them in the modeling approach. Nitrate-nitrogen and ammonia-nitrogen loads were determined on a monthly basis. Monthly loads account for temporal variations in agricultural management practices that take place within the watershed (Chapter 3). The use of a continuous simulation model takes into account the seasonal variations in rainfall, temperature, and stream flow.

First, possible impacts on the nitrate concentrations due to coliform load allocations determined for the Muddy Creek coliform bacteria TMDL (MCTEW 1999) were considered. The coliform bacteria load allocations require removal of the direct manure load caused by cows in the stream. This management approach was also assumed in all nitrate load allocations. For the coliform study, the most limiting conditions occurred in summer when large numbers of cattle were frequenting the stream; thus removing cattle from the stream was an important management strategy for the coliform bacteria levels. However, during the period with the highest nitrate peaks, there are either no cattle or extremely few cattle in the creek. Thus peak nitrate levels and load allocations are not sensitive to reductions in the number of cows in the stream. Removing cows from Muddy Creek reduces the daily average nitrate level by only 0.15 mg/L NO_3-N. Until a management plan is in place for the Muddy Creek coliform TMDL, it cannot be determined whether the other required coliform load reductions will also reduce the nitrate loads. For the nitrate load allocations, no other load reductions were presumed due to coliform management. However, when management plans are developed for Muddy Creek, any possible synergistic effects between coliform management and nitrate management strategies should be considered.

To identify potential feasible allocation strategies, the analysis began by modeling extreme cases. Even with complete removal of the point source (which is not expected or desired) or complete removal of agricultural non-point sources (which is not expected or even physically feasible to a land use nonpoint source contribution to zero), the peak nitrate concentrations remained above or near the targeted endpoint of 9.5 mg/L nitrate-nitrogen. These allocation scenarios are summarized in Appendix C. These extreme allocations demonstrated that reductions in both point source and nonpoint source loads will be required. This result could be anticipated based on the analysis of historical water quality critical conditions (Section 2.3). All other scenarios explored will consider combinations of reductions in both the point source and nonpoint sources.

Based on current conditions, as summarized in Table 4.3, forest lands, row crops, haylands, pasture land, loafing lots, the point source (WFI), and cows in-stream each contribute over 5% of the annual total nitrogen reaching Muddy Creek. Although the impact of removing cows in the stream is relatively small, all allocation scenarios will assume that this load has been reduced as specified by the coliform bacteria TMDL. The nitrogen contribution per acre is lower for forest than any other land use. The total forest contribution of nitrogen is only significant on a watershed scale due to the large acreage of forests in the watershed; over one third of the Muddy Creek watershed is forested. Thus the load allocation scenarios will focus on reductions in the other significant nitrogen sources (row crops, haylands, pasture land, loafing lots, and the point source).

Given the complexity of this system and the interaction between the point source and the significant nonpoint sources, there exist a variety of allocation scenarios with similar impacts on the peak nitrate levels. The selection of the best combination of source reductions is a subjective decision. Several allocation scenarios that meet the TMDL target of 9.5 mg/L nitrate-nitrogen using more reasonable reductions in both the point and nonpoint sources have been developed. These feasible scenarios are summarized in Table 5.1. In all cases in Table 5.1, the percent reduction in nonpoint source loads is based on the reduction in the fall loads only. (A summary of tested scenarios, both feasible and infeasible, is included as Appendix C). Table 5.2 shows the corresponding load reductions in terms of annual load reductions for Scenarios 5-9. Significant trade-offs exist between the sources. For instance, scenario 9 shows that a 48% reduction at the point source allows nonpoint source reduction to be 25% (Fall only) for each land use, while in scenario 5, a 20% reduction to the point source results in required nonpoint source loading reductions of 40% for most land uses and 50% for loafing lots (Fall only). The final selection of allocation scenario (and management plan) should consider cost-effectiveness, equity, and potential impacts on the coliform bacteria impairment.

Table 5.1: Summary of feasible allocation scenarios that meet water quality goals. Numbers for each load are percent load reductions from current levels. Agricultural percent reductions are relative to the seasonal loading as indicated in comments.

No.	WFI	Crop	Hay	Pastures 2 and 3		Loafing Lots	Peak NO_3-N (mg/L)	Comments
1	20	40	40	40	40	50	9.47	NPS Reductions from Sep.-Dec., LL (Jan.-Dec.)
2*	20	45.5	40	0	40	50	9.50	NPS Reductions from Sep.-Dec., LL (Jan.-Dec.)
3*	30	40	40	0	40	40	9.50	NPS Reductions from Sep.-Dec.
4	35	25	30	20	20	50	9.46	NPS Reductions from Sep.-Dec., LL (Jan.-Dec.)
5*	35	27	30	0	20	50	9.49	NPS Reductions from Sep.-Dec., LL (Jan.-Dec.)
6*	45	25	25	0	30	50	9.45	NPS Reductions from Sep.-Dec.
7	50	25	25	25	25	25	9.50	NPS Reductions from Sep.-Dec.
8*	50	30	25	0	25	25	9.50	NPS Reductions from Sep.-Dec.

* Indicates alternative not in February 2000 Draft, but presented at public meeting (3/14/2000)

Table 5.2: Summary of feasible allocation scenarios that meet water quality goals. Numbers for each load are percent annual load reductions from current levels.

No.	WFI	Crop	Hay	Pastures 2 and 3		Loafing Lots	Peak NO_3-N (mg/L)	Comments
1	20	10.6	12.6	13.0	13.0	50.0	9.47	NPS Reductions from Sep.-Dec., LL (Jan.-Dec.)
2*	20	11.6	12.6	0.0	13.0	50.0	9.50	NPS Reductions from Sep.-Dec., LL (Jan.-Dec.)
3*	30	10.2	12.6	0.0	13.0	13.2	9.50	NPS Reductions from Sep.-Dec.
4	35	6.0	9.5	6.5	6.5	50.0	9.46	NPS Reductions from Sep.-Dec., LL (Jan.-Dec.)
5*	35	6.9	9.5	0.0	6.5	50.0	9.49	NPS Reductions from Sep.-Dec., LL (Jan.-Dec.)
6*	45	6.4	8.0	0.0	9.8	16.5	9.45	NPS Reductions from Sep.-Dec.
7	48	6.0	8.0	8.2	8.2	8.3	9.50	NPS Reductions from Sep.-Dec.
8*	50	7.7	8.0	0.0	8.2	8.3	9.50	NPS Reductions from Sep.-Dec.

* Indicates alternative not in February 2000 Draft, but presented at public meeting (3/14/2000)

5.3 Selected Scenario

Allocation Scenario #4, shown below in Table 5.3 and is selected for this TMDL to meet the target of 9.5 mg/L nitrate-nitrogen necessary for the attainment of water quality standards.

Table 5.3: Selected allocation scenario. Numbers for each load are percent load reductions from current levels. Agricultural percent reductions are relative to the seasonal loading as indicated in comments.

	WFI	**Crop**	**Hay**	**Pasture 2 and 3**	**Loafing Lots**	**Comments**
# 4	35	25	30	20	50	Sep.-Dec. (Crop, P1,2,3), LL (Jan.-Dec.)

DEQ is required by the Code of Virginia to develop implementation plans for TMDLs. The Code of Virginia also requires the TMDL implementation plan to contain the date of expected achievement of water quality objectives, measurable goals, the corrective actions necessary, and the associated costs. DCR has a proposal from the Rockingham County Farm Bureau Association for the development of TMDL implementation plans for the fecal coliform bacteria TMDLs on Muddy Creek, Lower Dry River, Mill Creek, and Pleasant Run. The development of these implementation plans is to begin in early 2000 and is scheduled for completion on July 31, 2002. Implementation plan development will include an extensive public participation process in order to allow the stakeholders an opportunity to provide input and comment on the plan.

An implementation plan for the nitrate TMDL is not scheduled at this time. Once the fecal coliform reduction strategies and BMP mix are identified, the nitrate reductions resulting from the bacteria BMPs can be quantified. DEQ and DCR will work through a public participation process to develop an appropriate implementation plan for the nitrate TMDL. As part of this implementation planning process the State will re-model the nitrate TMDL using more recent data, including the quantified nitrate reductions expected as a result of the fecal coliform TMDL. If monitoring data shows that water quality standards are attained prior to the State's submission to EPA of its 303(d) lists due on April 1, 2002 and April 1, 2004, DEQ plans to follow EPA's procedures for delisting Muddy Creek for nitrate impairment.

During the development of the Muddy Creek fecal coliform and nitrate implementation plans, the state reserves the right to select one of the other EPA-approved scenarios presented in the Muddy Creek Nitrate TMDL report. After public input, if one of the other EPA-approved scenarios proves to be better for the attainment of water quality standards than scenario #4, Virginia may consider changing the allocation scenario. This selected scenario section of the Muddy Creek nitrate TMDL report will be revised to include the new scenario, and EPA will be notified of the change by letter. If a scenario not identified in the TMDL report is chosen during implementation plan development, then a revised TMDL would be submitted to EPA for review and approval. Public input would be required in this situation as well.

DEQ is not going to take a TMDL-related action on any existing permit in the Muddy Creek watershed until re-issuance. However, any permit up for re-issuance (or issuance for any new discharge) in the nitrate-impaired segment shall be consistent with the selected allocation plan in the TMDL. If a different EPA-approved scenario is selected during the development of the implementation plan, after public input, any permit up for re-issuance or issuance shall be consistent with the allocation in that scenario. If a scenario other than those presented in Table 5.1 is chosen during implementation plan development, then public input would be obtained and the revised TMDL would be re-submitted to EPA for review and approval. Any permit up for re-issuance or issuance shall be consistent with the allocation in the most recent EPA-approved scenario identified in this TMDL as the selected option. DEQ will not use the lack of an implementation plan as a reason to extend any permit beyond its normal expiration date.

6 Public Participation

6.1 Outreach Overview

A TMDL is expected to have a higher probability of successful implementation if local communities are involved in the decision making process (USEPA, 1991). Public participation is therefore one of the necessary components of a TMDL and has been a very important part of this project.

There were two distinctive features involved in the public participation related to this particular study. The first feature grew out of this project's emphasis on public participation. Because of support from the Virginia Environmental Endowment, we were able to devote more attention than usual to outreach with the goal of developing a model that can be used for communicating with the public as additional TMDLs are developed throughout the state and the nation. The effort to develop such a model goes beyond the scope of the work reported here and is not yet complete, but some of the preliminary conclusions are summarized below.

The second distinctive feature emerged through our interaction with the Muddy Creek Citizens' Advisory Group, which was formed early in 1999 for the Fecal Coliform TMDL for Muddy Creek (MCTEW, 1999). The existence of this group and their willingness to cooperate with us made it possible to interact informally with members of the community. One outcome of this interaction was that we scheduled a number of informal meetings in addition to the required formal public meetings. Another outcome was an interative process in which we received feedback and critique as the project proceeded and adjusted our efforts appropriately.

6.2 Public Meetings

The first informal meeting, in Harrisonburg on August 23, 1999, reviewed the TMDL process and introduced the Muddy Creek/Dry River Nitrate TMDL study. Initial questions and concerns from the audience were also addressed. A second informal meeting was held October 25, 1999 with the Muddy Creek Citizens' Advisory Group at the Mt. Clinton Elementary School. This meeting focused on outreach and was specifically aimed at determining (1) what had worked and not worked in terms of establishing effective communication between citizens and legislators and (2) how the lessons learned so far could be applied through the remainder of this project and in future TMDLs.

This was a productive meeting with outcomes too numerous to be listed in their entirety here. Three major issues emerged: (1) the importance of citizens feeling that they have a voice; (2) the difficulties arising from the complexity and abstract nature of the modeling that is central to the TMDL process; and (3) concerns about the bureaucratic and impersonal nature of the TMDL process. We also agreed that it was desirable to review technical issues and results with the Muddy Creek Citizens' Advisory group before raising those issues or presenting those results at large public meetings.

Consequently, a third informal meeting with the Citizens' Advisory Group and others was held in Harrisonburg on November 29, 1999. The purpose of this meeting was to provide a preview of the presentation that our team would make at the first formal public meeting. Although some useful questions were raised at this meeting, the technical content of the presentation was generally well received. We also received a number of helpful suggestions about how the presentation might be modified for the first large public meeting on the project. The essence of the feedback was that members of the public would care most about the key conclusions and their significance from the audience's point of view. The primary suggestion was that the presentation should begin with the key conclusions reached and then proceed with detail on assumptions and methods.

The first formal public meeting associated with this project was held in Dayton on December 8, 1999. This meeting focused on the development of the Muddy Creek/Dry River Nitrate TMDL; our presentation reflected the comments and suggestions received at the November 29 informal meeting. The December 8 meeting was advertised in the *Harrisonburg Daily News-Record* on December 2, 1999. Copies of presentation materials, nutrient management assumptions, data sources, preliminary calibrations and other information were available for public distribution. Approximately 30 people attended this meeting. The second public meeting to discuss the draft Nitrate TMDL for Muddy Creek/Dry River, Virginia is scheduled for March 14, 2000 in Dayton. This draft report is being distributed in advance of that meeting.

6.3 Public Participation Summary

Our experience throughout this project suggests that small-scale, informal meetings and other forms of informal interaction are in many ways much more effective than large, formal public meetings, especially when the informal meetings are called through the initiative of members of the community. We have particularly benefited from feedback and assistance provided for us by community representatives, including Carl Luebben, Chuck Ahrend, and Rick Blackwell, who helped us establish contacts in the community and plan various aspects of public outreach.

The most important conclusion emerging from our work over the last few months is this: effective outreach is as much a matter of building relationships and trust as it is of providing pertinent information. This conclusion is not particularly surprising, but it does have significant implications, especially if we consider the TMDL process on a national scale. As we have found on numerous occasions throughout this project, establishing relationships means adapting to the schedules, customs, and rhythms of the community. It involves flexibility and the willingness to operate within a give-and-take relationship - features not typically associated with bureaucratic efficiency. To move effectively toward generalizing our conclusions into a model for outreach, we will have to deal with the challenge of reconciling the requirements of relationship-building with the fact that the TMDL process is embedded in bureaucracy.

We have begun a series of interviews with citizens that are aimed at exploring the validity of the conclusions we have generated so far and at gathering additional information that will be helpful in creating a model for public participation in TMDL development.

Appendix A: Land use characteristics

Table A.1

Muddy Creek Watershed Land Use Characteristics		
Land use	Area (acres)	% of Total Watershed
Forest / Wooded	6,848.8	34.2%
Developed	966.9	4.8%
FARMSTEAD	868.5	4.3%
Row Crops	5,154.1	25.8%
PASTURE 3	1,024.8	5.1%
PASTURE 1	4,685.5	23.4%
PASTURE 2	291.5	1.5%
LOAFING LOTS	157.1	0.8%
Barren	13.0	0.1%
Total	20,010.2	100.0%

Table A.2

Lower Dry River Watershed Land Use Characteristics		
Land use	Area (acres)	% of Total Watershed
Forest / Wooded	3,118.9	31.2%
Developed	785.4	7.9%
FARMSTEAD	543.8	5.4%
Row Crops	3,433.6	34.3%
PASTURE 3	438.1	4.4%
PASTURE 1	1,326.8	13.3%
PASTURE 2	165.1	1.7%
LOAFING LOTS	182.4	1.8%
Barren	4.4	0.0%
Total	9,998.5	100.0%

Appendix B: Nitrogen loads by source for each watershed.

For sources to land, the nitrogen loads indicate the amount of nitrogen applied. They do not indicate the contribution of nitrogen to the stream itself. Contributions to the stream are summarized in section 4.6.3.

Table B.1: Lower Dry River Watershed Nitrogen Loads

Source To Land	**Organic N (lb/yr)**	**NH3-N (lb/yr)**	**NO3-N (lb/yr)**	**Total N (lb/yr)**	**% of Total**
Unconfined Cattle	555,262	413,800	0	969,062	46.3
Poultry Litter	266,450	82,903	0	349,353	16.7
Dairy Manure	285,485	151,519	0	437,004	20.9
Fertilizer	0	51,504	51,504	103,008	4.9
Atmospheric Deposition	0	15,985	101,665	117,650	5.6
Forest	31,189	0	0	31,189	1.5
Residential Fertilizer	0	42,804	42,804	85,609	4.1
Total	1,138,386	758,516	195,973	2,092,876	100.0
Source to Stream	**Organic N (lb/yr)**	**NH3-N (lb/yr)**	**NO3-N (lb/yr)**	**Total N (lb/yr)**	**% of Total**
Cattle in Stream	0	0	0	0	0.0
Septic Tanks	0	0	6,869	6,869	100.0
Total	0	0	6,869	6,869	100.0

Table B.2: Upper Dry River Watershed Nitrogen Loads

Source To Land	**Organic N (lb/yr)**	**NH3-N (lb/yr)**	**NO3-N (lb/yr)**	**Total N (lb/yr)**	**% of Total**
Unconfined Cattle	0	0	0	0	0.0
Poultry Litter	0	0	0	0	0.0
Dairy Manure	0	0	0	0	0.0
Fertilizer	0	0	0	0	0.0
Atmospheric Deposition	0	74,680	336,227	410,908	46.8
Forest	467,110	0	0	467,110	53.2
Residential Fertilizer	0	0	0	0	0.0
Total	467,110	74,680	336,227	878,018	100.0
Source to Stream	**Organic N (lb/yr)**	**NH3-N (lb/yr)**	**NO3-N (lb/yr)**	**Total N (lb/yr)**	**% of Total**
Cattle in Stream	0	0	0	0	0.0
Septic Tanks	0	0	0	0	0.0
Total	0	0	0	0	0.0

Table B.3: Muddy Creek Watershed Nitrogen Loads					
Sources to Land	**Organic N (lb/yr)**	**NH3-N (lb/yr)**	**NO3-N (lb/yr)**	**Total N (lb/yr)**	**% of Total**
Unconfined Cattle	631,075	454,260	0	1,085,335	36.7
Poultry Litter	700,295	215,395	0	915,689	30.9
Dairy Manure	227,373	166,868	0	394,241	13.3
Fertilizer	0	77,312	77,312	154,623	5.2
Atmospheric Deposition	0	31,992	203,464	235,456	8.0
Forest	68,488	0	0	68,488	2.3
Residential Fertilizer	0	52,696	52,696	105,392	3.6
Total	1,627,230	998,522	333,472	2,959,225	100.0
Sources to Stream	**Organic N (lb/yr)**	**NH3-N (lb/yr)**	**NO3-N (lb/yr)**	**Total N (lb/yr)**	**% of Total**
Cattle in Stream	27,343	20,377	0	47,719	33.1
WFI	0	1,980	86,400	86,400	60.0
Septic Tanks	0	0	9,929	9,929	6.9
Total	27,343	22,357	96,329	144,048	100.0

Appendix C: Allocation Scenario Summary

Table C.1 Summary of allocation scenarios and resulting nitrate-nitrogen concentrations. Percent NPS reductions are relative to the seasonal load in comments. Scenario numbers do not correspond to those in Chapter 5. Table is organized relative to WFI reductions.

	WFI	Crop	Hay	Pasture 2	Pasture 3	Loafing Lots	Peak mg/L	Peak Day	Avg mg/L	Comments
1	0	100	100	100	100	100	9.03	1/5/95	3.48	Jan. – Dec.
2	0	100	100	100	100	100	9.90	1/5/95	4.60	Sep. – Dec.
3	5	100	100	100	100	100	9.52	1/5/95	4.46	Sep. – Dec.
4	20	40	40	40	40	50	9.47	12/6/94	4.03	Sep.-Dec. (Crop, P1,2,3), LL (Jan.-Dec.)
5	20	45.5	40	0	40	50	9.50			Sep.-Dec. (Crop, P1,3), LL (Jan.-Dec.)
6	25	40	40	40	40	50	9.27	12/6/94	3.89	Sep.-Dec. (Crop, P1,2,3), LL (Jan.-Dec.)
7	30	40	40	40	40	40	9.40	12/6/94	3.96	Sep.- Dec.
8	30	40	40	0	40	40	9.50			Sep.- Dec.
9	35	25	30	20	20	50	9.46	12/6/94	3.69	Sep.-Dec. (Crop, P1,2,3), LL (Jan.-Dec.)
10	35	27	30	0	20	50	9.49			Sep.-Dec. (Crop, P1,3), LL (Jan.-Dec.)
11	40	25	25	30	30	50	9.54	12/6/94	3.75	Sep.- Dec.
12	45	25	25	30	30	50	9.37	1/8/95	3.61	Sep.- Dec.
13	45	25	25	0	30	50	9.45			Sep.- Dec.
14	50	25	25	25	25	25	9.50	1/8/95	3.53	Sep.- Dec.
15	50	30	25	0	25	25	9.50			Sep.-Dec.
16	100	0	0	0	0	0	10.11	1/8/95	2.51	no NPS reduction

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