Bacteria TMDL for
Great Run
Fauquier County, Virginia

Submitted by

Virginia Department of Environmental Quality

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Executive Summary

This report presents the development of a Bacteria Total Maximum Daily Load (TMDL) for the Great Run watershed. The Great Run watershed is located in Fauquier County in the Rapidan-Upper Rappahannock Basin (USGS Hydrologic Unit Code 02080103). The waterbody identification code (WBID, Virginia Hydrologic Unit) for Great Run is VAN-E02R in the Northern Virginia region of Virginia.

The impaired segment includes all of Great Run, from the headwaters downstream to the confluence of Great Run with the Rappahannock River. The length of the impairment was extended in the 2004 *Virginia Water Quality Assessment 305(b)/303(d) Integrated Report* (Integrated Report) to include all of Great Run. Prior to the 2004 Integrated Report, the impaired length was 2.76 miles in length. The upper limit was the confluence of Great Run and an unnamed tributary and extended downstream to the confluence of Great Run with the Rappahannock River.

The drainage area of the Great Run watershed is approximately 28.3 square miles and is west of Warrenton in Fauquier County. The average annual rainfall as recorded at Lincoln, VA (NCDC station 448888, ~2 miles east of study area) is 41.17 inches. The watershed study area is approximately 18,100 acres, which is predominately forest land (50.6 percent), with the majority of the remaining area in pasture land (44.7 percent). The remaining 4.7 percent of the watershed consists of residential areas, crop land, and open water. A map of the distribution of land use in the watershed indicates that the pasture land tends to be located closer to the stream, while the forest land is farther from the stream and near the headwaters. This is most likely due to the relatively more hilly topography in the headwaters of the watershed. The steeper slopes at the edges of the watershed have remained forested while the shallower slopes near the stream are used for agriculture.

Great Run was listed as impaired on Virginia's 1998 *303(d) Total Maximum Daily Load Priority List and Report*, the 2002 *303(d) Report on Impaired Waters*, and the 2004 *Virginia Water Quality Assessment 305(b)/303(d) Integrated Report* (VADEQ, 1998, 2002, and 2004) due to exceedances of the State's water quality standard for fecal coliform bacteria. Out of 18 samples collected during the 1998 assessment period, 5 exceeded the water quality standard for fecal coliform at station 3-GRT001.70 located at the Route 687 bridge. Three of 18 samples exceeded the water quality standard at station 3-GRT001.70 during the 2002 assessment period, and 4 of 18 samples exceeded the criterion during the 2004 assessment period. The length of impairment on Great Run was expanded in 2004 based on the water quality monitoring results from station 3-GRT007.72 at the Route 802 bridge. The bacteria impairment was also expanded to include exceedances of the water quality criterion for *E. coli*. During the 2004 assessment window, two of 4 samples exceeded the *E. coli* criteria at station 3-GRT001.70 and three of 4 samples exceeded the instantaneous *E. coli* criteria at station 3-GRT007.72.

According to Virginia Water Quality Standards (9 VAC 25-260-10A), "all state waters 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 be reasonably expected to inhabit them; wildlife; and the production of edible and marketable natural resources (e.g., fish and shellfish)."

As indicated above, Great Run must support all designated uses and meet all applicable criteria. The Great Run does not currently support primary contact recreation.

The load-duration approach was used to develop the TMDL for this watershed. Under this approach, the allocation of reductions to individual sources is accomplished by determining the relative contribution from these sources based on Biological Source Tracking (BST) data. A total of 12 ambient water quality samples were collected at one site in the watershed on a monthly basis from December 2002 through January 2004 and analyzed for source identification using antibiotic resistance analysis (ARA) which is a form of BST. The results indicate that the majority of in-stream bacteria are coming from anthropogenic sources (humans, pets and livestock). Four categories of sources were considered: human, pet, livestock and wildlife. The analyses determined the relative contribution of bacteria by each of these sources. The data indicated that on an average basis, relative contributions of bacteria are 4% human, 30% pet, 32% livestock, and 33% wildlife. Fecal coliform and *E.coli* bacteria were also enumerated as part of the BST analysis.

The bacteria loads in the watershed were calculated for both point sources and non-point sources. The study area has one permitted sewage treatment plant with a design flow of 2.5 MGD. The permitted loads were calculated by multiplying the permitted discharge concentration (126 cfu/100 ml) by the permitted flow and the appropriate unit conversions. For non-point sources (human, pets, livestock, and wildlife) total annual bacteria productions were calculated separately. Data on population density and waste production by septic systems, pets, livestock and wildlife were collected from various sources, and total bacteria production was calculated for each source category.

The load-duration method essentially uses the entire stream flow record to provide insight into the flow conditions under which exceedances of the water quality standard occur. The flow-duration curve was developed using flow data collected on Great Run and correlating it with the flow record for the Rappahannock River (USGS gaging station 01664000). The load-duration curve was then developed by multiplying each flow level along the flow-duration curve by the applicable water quality standard and required unit conversions. Each water quality observation is then assigned to a flow interval by comparing the date of each water quality observation to the flow record of the reference stream. The stream flow from the date of the water quality observation is then used to calculate a flow-duration interval and observed load in the stream. The loads on the load-duration curve are multiplied by 365 days/year to determine the annual loads. When E. coli data were not available, fecal coliform data were converted to E. Coli using a translator equation developed based on 493 simultaneous fecal coliform and E. coli observations collected by DEQ across the state. The observed loads were plotted on the load-duration curve to determine the number and pattern of exceedances of water quality standards (TMDL).

The results indicate that the highest exceedance of the water quality standard occurred at a high flow that is virtually never exceeded (~100 cfs). This represents the flow condition under which the largest bacteria reduction is required in order to meet water quality standards. The translated load at this flow condition is 3.43×10^{15} cfu/yr. To meet the instantaneous water quality standard for *E. coli* of 235 cfu/100mL, this load would have to be reduced by 94% to an allowable load of 2.11×10^{14} cfu/yr. The allowable load is simply the *E. coli* standard multiplied by the applicable flow condition and the proper unit conversions.

For the Great Run watershed, the average annual *E. coli* load is 4.61×10^{14} cfu/yr, and the TMDL under average flow conditions is 2.83×10^{13} cfu/yr. These values are used to calculate required reductions. By subtracting the waste load allocation (known value) from the TMDL (as computed), and using an implicit margin of safety, the load allocation was determined. These values are presented in the following table.

Table Exec-1. TMDL for the Great Run watershed (cfu/yr)

Wasteload Allocation (WLA)*	Load Allocation (LA)	Margin of Safety (MOS)	Total Maximum Daily Load (TMDL)
4.35×10^{12}	2.40×10^{13}	(implicit)	2.83×10^{13}

* The point sources permitted to discharge in the Great Run watershed are presented in section 5.2.

For Great Run, the WLA represents 15% of the TMDL load. The required reduction of 94% is to be applied to each of the four non-point sources identified in the BST analysis.

The Great Run TMDL development presented in this report is the first step toward the attainment of water quality standards. The second step is to develop a TMDL implementation plan, and the final step is the field implementation of the TMDL to attain water quality standards.

The Commonwealth intends for this TMDL to be implemented through a process of phased implementation of best management practices (BMPs). The Great Run TMDL requires a 95% reduction in non-point source loading in order to attain a 0% violation of water quality standards with no reductions to the point source loading. In order to evaluate interim reduction goals for a phased implementation plan, several reduction levels (83%, 50%, and 25%) and their associated violation rates were assessed. Reduction curves similar to the maximum exceedance/reduction curve were plotted and are presented in this report.

Results also indicate that approximately 58% of the violations occurred during times of precipitation and increasing stream flow or just after a precipitation event with stable or decreasing stream flow. This suggests that those violations could be related to runoff events. Some of the BMPs effective in reducing bacteria runoff from such precipitation events include: riparian buffer zones, retention ponds/basins, range and pasture management, and animal waste management. Detailed lists of BMPs and their relative effectiveness will be included in the eventual TMDL implementation plan for the watershed.

Public participation in the Great Run TMDL process plays a vital role in developing a TMDL that is accurate, reflecting actual conditions in the watershed, and can be supported by local stakeholders through implementation measures to achieve improvements in water quality. A first public meeting was held in Marshall, Virginia on January 28, 2004 to discuss the process for TMDL development and the source assessment input. Five people attended. Copies of the presentation materials were available at the meeting and on the DEQ website. The meeting was public noticed in the Virginia Register and an announcement was included in the community calendars of the Fauquier Times Democrat newspaper. There was a 30 day-public comment period following the first public meeting during which no written comments were received.

A second and final public meeting was held in Warrenton, Virginia on November 16, 2004, to present the draft TMDL report. Twenty-one people attended. Copies of the presentation materials and draft report were available at the meeting and on the DEQ website. The meeting was public noticed in the Virginia Register and an announcement was included in the community calendars of the Fauquier Times Democrat and The Times Citizen newspapers. Flyers announcing the meeting were sent to all members on the technical advisory committee for distribution, and a mailing was sent from the John Marshall Soil and Water Conservation District announcing the meeting. There was a 30 day-public comment period following the final public meeting during which no written comments were received.

1. Introduction

Section 303(d) of the Clean Water Act and US Environmental Protection Agency's (EPA's) Water Quality Planning and Management Regulations (40 CFR Part 130) require states to develop Total Maximum Daily Loads (TMDLs) for waterbodies which are exceeding water quality standards. TMDLs represent the total pollutant loading that a waterbody can receive without violating water quality standards. The TMDL process establishes the allowable loadings of pollutants for a waterbody based on the relationship between pollution sources and in-stream water quality conditions. By following the TMDL process, states can establish water quality based controls to reduce pollution from both point and non-point sources to restore and maintain the quality of their water resources (EPA, 1991).

The Commonwealth of Virginia's (Virginia's) 1997 Water Quality Monitoring, Information, and Restoration Act (WQMIRA) codifies the requirement for the development of TMDLs for impaired waters. Specifically section § 62.1-44.19:7 C states:

"The plan required by subsection A shall, upon identification by the Board of impaired waters, establish a priority ranking for such waters, taking into account the severity of the pollution and the uses to be made of such waters. The Board shall develop and implement pursuant to a schedule total maximum daily loads of pollutants that may enter the water for each impaired water body as required by the Clean Water Act. "

The EPA specifies that in order for a TMDL to be considered complete and approvable, it must cover the following eight elements:

1. It must be designed to meet applicable water quality standards,
2. It must include a total allowable load as well as individual waste load allocations and load allocations,
3. It must consider the impacts of background pollution (in the case of Great Run this is wildlife),
4. It must consider critical environmental conditions or those conditions (stream flow, precipitation, temperature, etc.) which together can contribute to a worst-case exceedance of the water quality standard,
5. It must consider seasonal variations which together with the environmental variations can lead to a worst-case exceedance,
6. It must include an implicit or explicit margin of safety to account for uncertainties inherent in the TMDL development process,
7. It must allow adequate opportunity for public participation in the TMDL development process,
8. It must provide reasonable assurance that the TMDL can be met.

The following document details the development of a bacteria TMDL for Great Run which was listed as impaired in Virginia's 1998 *303(d) Total Maximum Daily Load Priority List and Report*, the 2002 *303(d) Report on Impaired Waters*, and the 2004 *Virginia Water Quality Assessment 305(b)/303(d) Integrated Report* (VADEQ, 1998, 2002, and 2004). The impairment includes all of Great Run, from the headwaters downstream to the confluence of Great Run with the Rappahannock River. The length of the impairment was extended in the 2004 *Virginia Water Quality Assessment 305(b)/303(d) Integrated Report* (Integrated Report) to include all of Great Run. Prior to the 2004 Integrated Report, the impaired length was 2.76 miles in length.

A glossary of terms used throughout this report is presented as Appendix A.

2. Physical Setting

2.1. Listed Water Bodies

Great Run is located in Fauquier County in the Rapidan-Upper Rappahannock Basin (USGS Hydrologic Unit Code 02080103). The waterbody identification code (WBID, Virginia Hydrologic Unit) for Great Run is VAN-E02R. The impaired segment is 2.76 miles in length and is presented in Table 1. The upper limit is the confluence of Great Run and an unnamed tributary and it extends downstream to the confluence of Great Run with the Rappahannock River. The Great Run watershed is presented in Figure 1.

Table 1. Impaired segment description (Great Run)

Water Body	Cause	Stream Name	Length (Miles)	Years Listed
VAN-E02R	Bacteria	Great Run (from confluence with an unnamed tributary to confluence with Rappahannock River)	2.76	1998, 2002

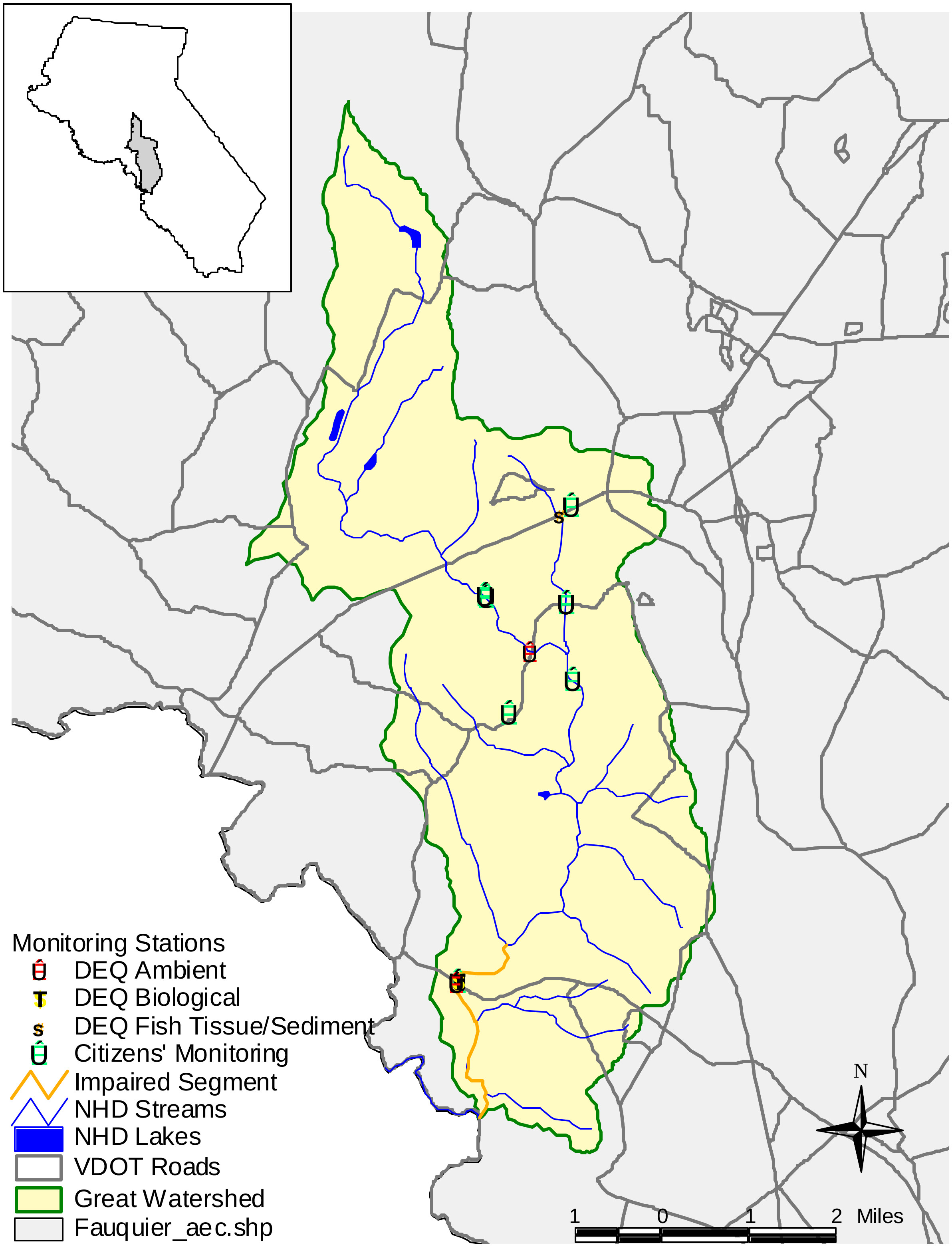
2.2. Watershed

2.2.1. General Description

The Great Run watershed is located entirely within Fauquier County, Virginia. The watershed is approximately 11 miles long and 2.5 miles wide, having an area of approximately 28.3 square miles.

Great Run flows south from its headwaters just west of Warrenton, Virginia, under Routes 211, 802 and 687, and finally into the Rappahannock River near Foxville. Eventually, the Rappahannock River flows into the Chesapeake Bay.

Figure 1. Map of the Great Run watershed



2.2.2. Geology, Climate, Land Use

Geology and Soils

Great Run is located in Fauquier County within the Piedmont Physiographic Province. Topography varies significantly in the watershed, with elevations ranging from 91 m (299 ft) to 338 m (1,109 ft) above sea level (Figure 2). Major soil groups in the region are shown in Figure 3 using the State Soil Geographic (STATSGO) Data Base (STATSGO, 1994). Soils throughout the watershed fall into hydrologic group C, having slow infiltration rates, with layers impeding downward movement of water, or soils with moderately fine or fine textures.

Figure 2. Topography in the Great Run watershed

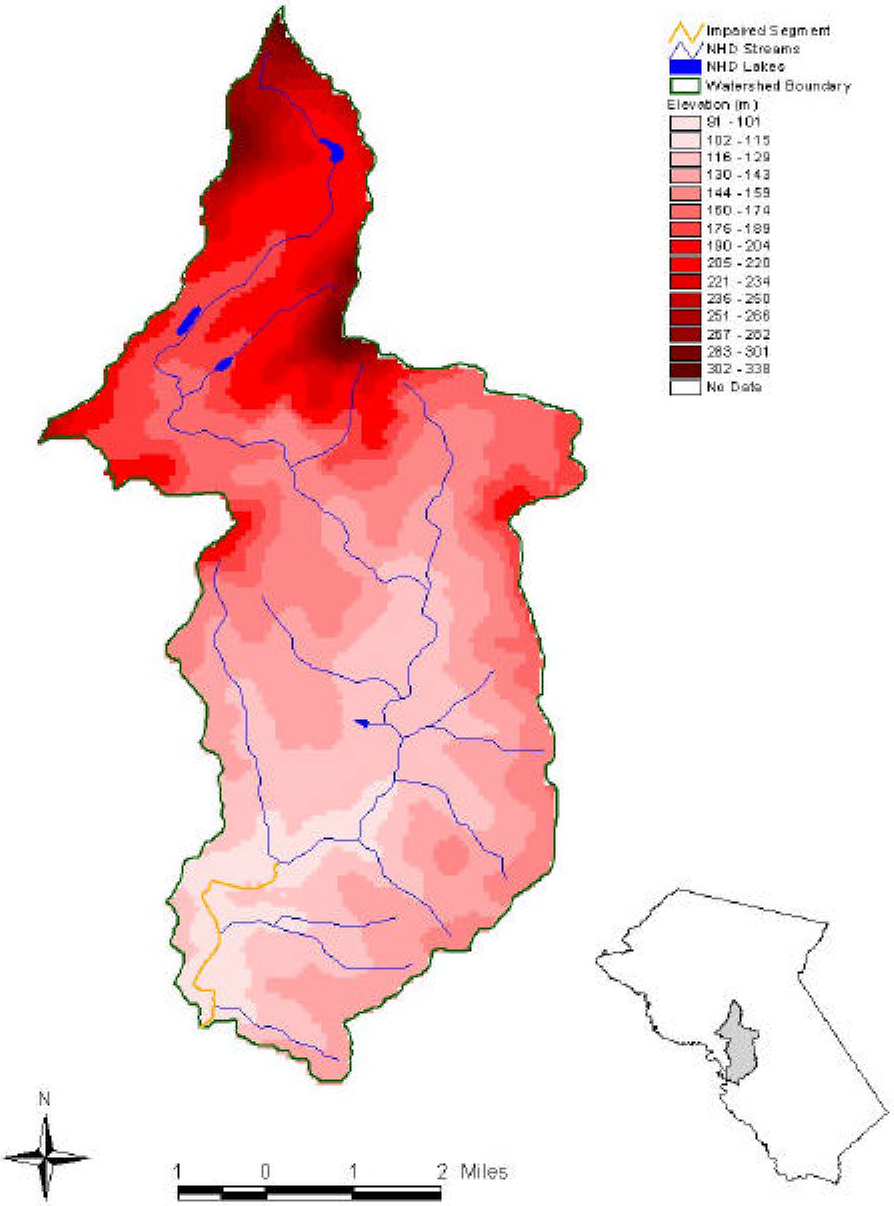
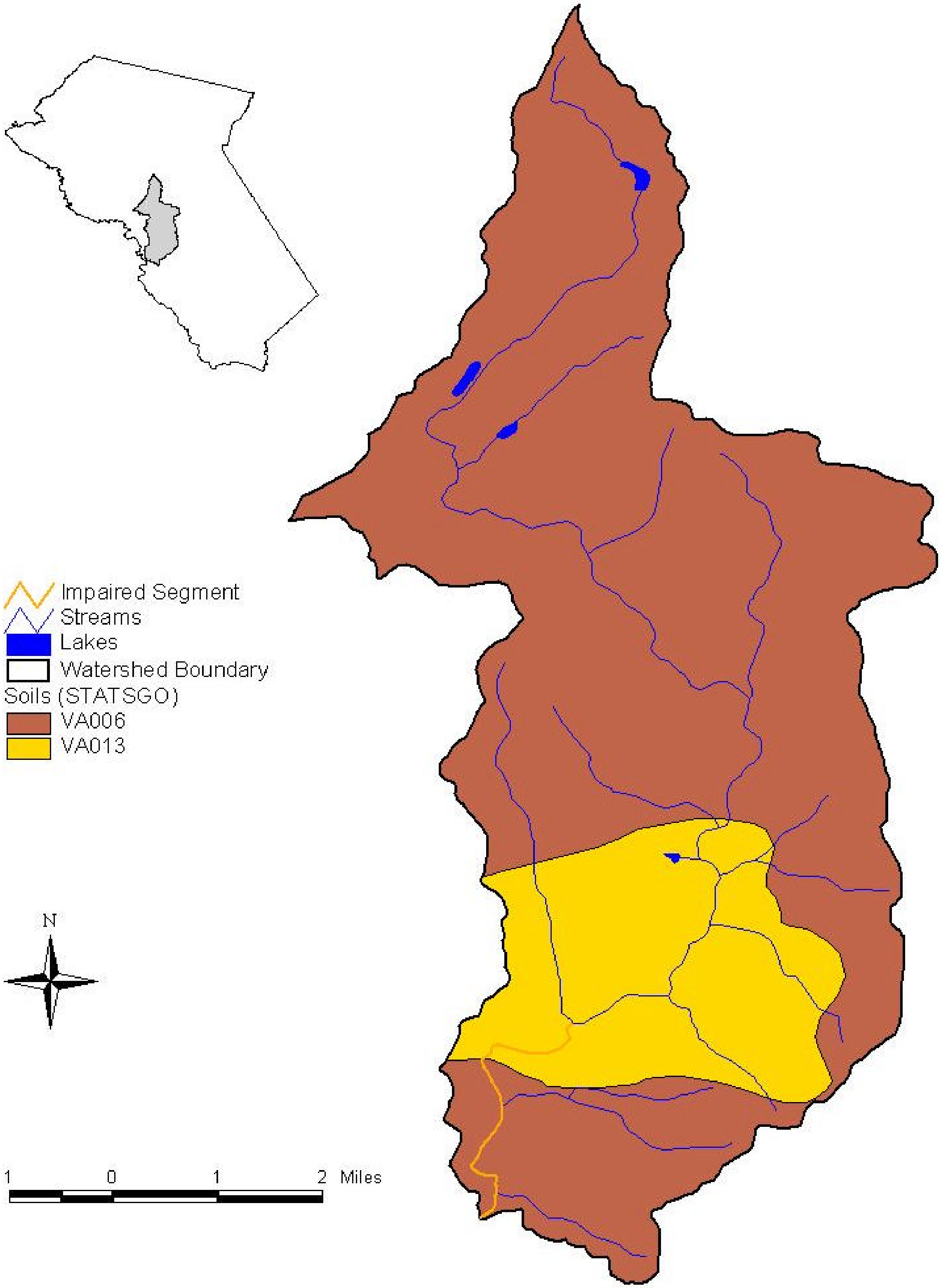


Figure 3. Major soil groups in the Great Run watershed



Climate

The drainage area of the Great Run watershed is approximately 28.3 square miles. The average annual rainfall as recorded at the Warrenton, Virginia (NCDC Station 448888 ~2 miles east of study area) is 41.17 inches. Table 2 presented below provides a summary of climate data for the Warrenton, Virginia weather station (Hydrodata 2001).

Table 2. Climate summary for Warrenton 3 SE, Virginia (448888)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Avg. Max. Temp. (F)	41.9	45.4	54.0	65.5	74.0	81.7	86.0	84.7	78.9	68.1	56.7	45.6	65.2
Avg. Min. Temp. (F)	22.7	25.1	32.4	42.3	51.5	60.0	64.7	63.0	56.3	44.4	36.0	26.9	43.8
Avg. Total Precip. (in.)	2.99	2.70	3.58	3.30	3.82	3.81	4.08	3.82	3.58	3.11	3.24	3.14	41.17

Land Use

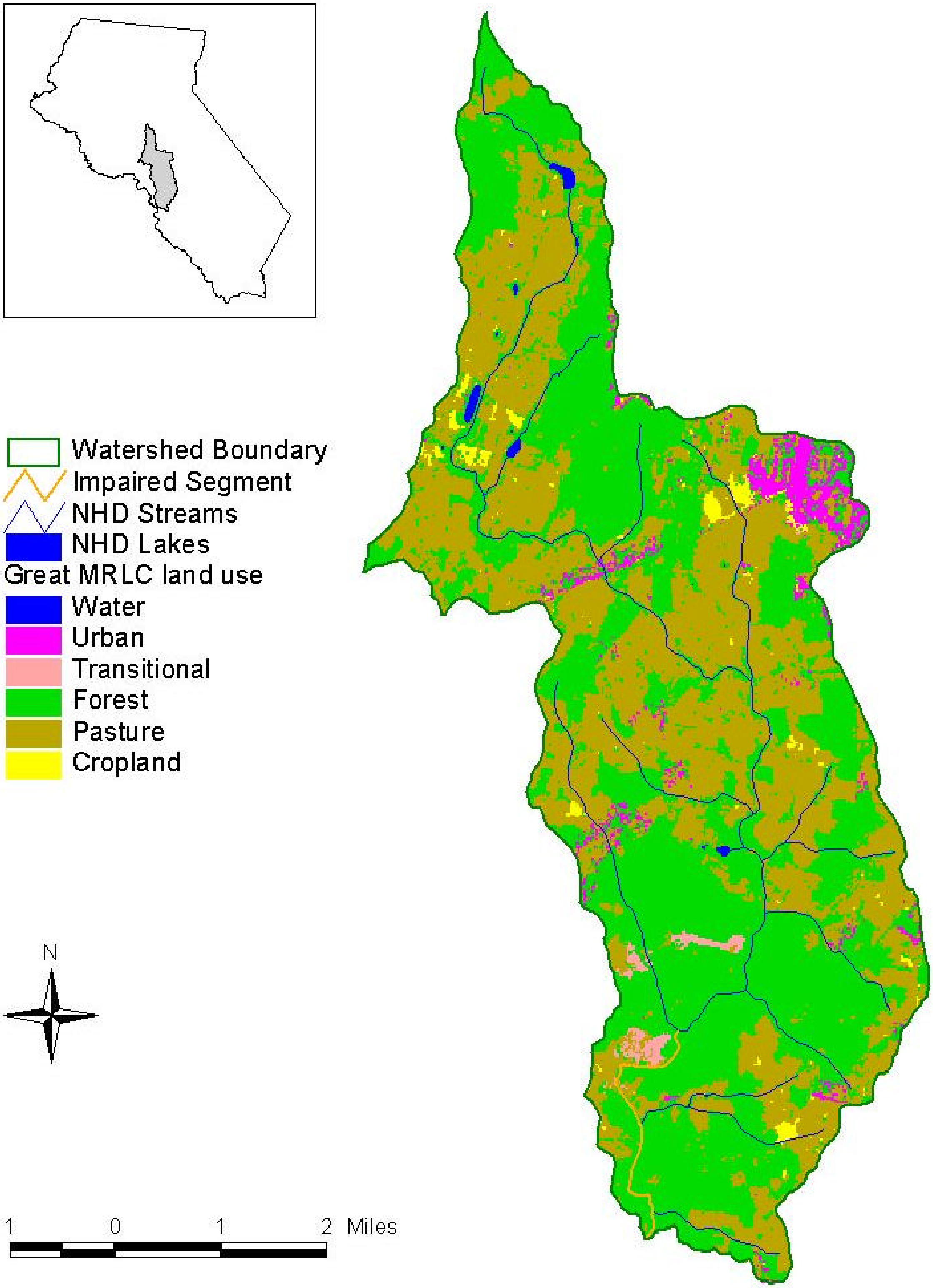
The Great Run watershed study area is approximately 18,100 acres, which is predominately forest land (50.6 percent), with the majority of the remaining area in pasture land (44.7 percent). The remaining 4.7 percent of the watershed consists of residential areas, crop land, and open water (Table 3). A map of the distribution of land use in the watershed (Figure 4) indicates that the pasture land tends to be located closer to the stream, while the forest land is farther from the stream. This is most likely due to the hilly topography of the watershed. The steeper slopes at the edges of the watershed have remained forested while the shallower slopes near the stream are used for agriculture.

Table 3. Land use in the Great Run watershed

Land Use	Area (acres)	Percentage
Agriculture - Cropland	211	1.2%
Agriculture - Pasture	8,078	44.7%
Forest	9,144	50.6%
Transitional	123	0.7%
Urban	501	2.8%
Water	28	0.2%
Grand Total	18,084	100.0%

Source: Virginia National Land Cover Data (NLCD) Version 05-27-99

Figure 4. Land Use in the Great Run Watershed



3. Description of Water Quality Problem/Impairment

Great Run was listed as impaired on Virginia's 1998 *303(d) Total Maximum Daily Load Priority List and Report*, the 2002 *303(d) Report on Impaired Waters*, and the 2004 *Virginia Water Quality Assessment 305(b)/303(d) Integrated Report* (VADEQ, 1998, 2002, and 2004) due to exceedances of the State's water quality standard for fecal coliform bacteria. Out of 18 samples collected during the 1998 assessment period, 5 exceeded the water quality standard for fecal coliform at station 3-GRT001.70 located at the Route 687 bridge. Three of 18 samples exceeded the water quality standard at station 3-GRT001.70 during the 2002 assessment period, and 4 of 18 samples exceeded the criterion during the 2004 assessment period. The length of impairment on Great Run was expanded in 2004 based on the water quality monitoring results from station 3-GRT007.72 at the Route 802 bridge. The bacteria impairment was also expanded to include exceedances of the water quality criterion for *E. coli*. During the 2004 assessment window, two of 4 samples exceeded the *E. coli* criteria at station 3-GRT001.70 and three of 4 samples exceeded the instantaneous *E. coli* criteria at station 3-GRT007.72.

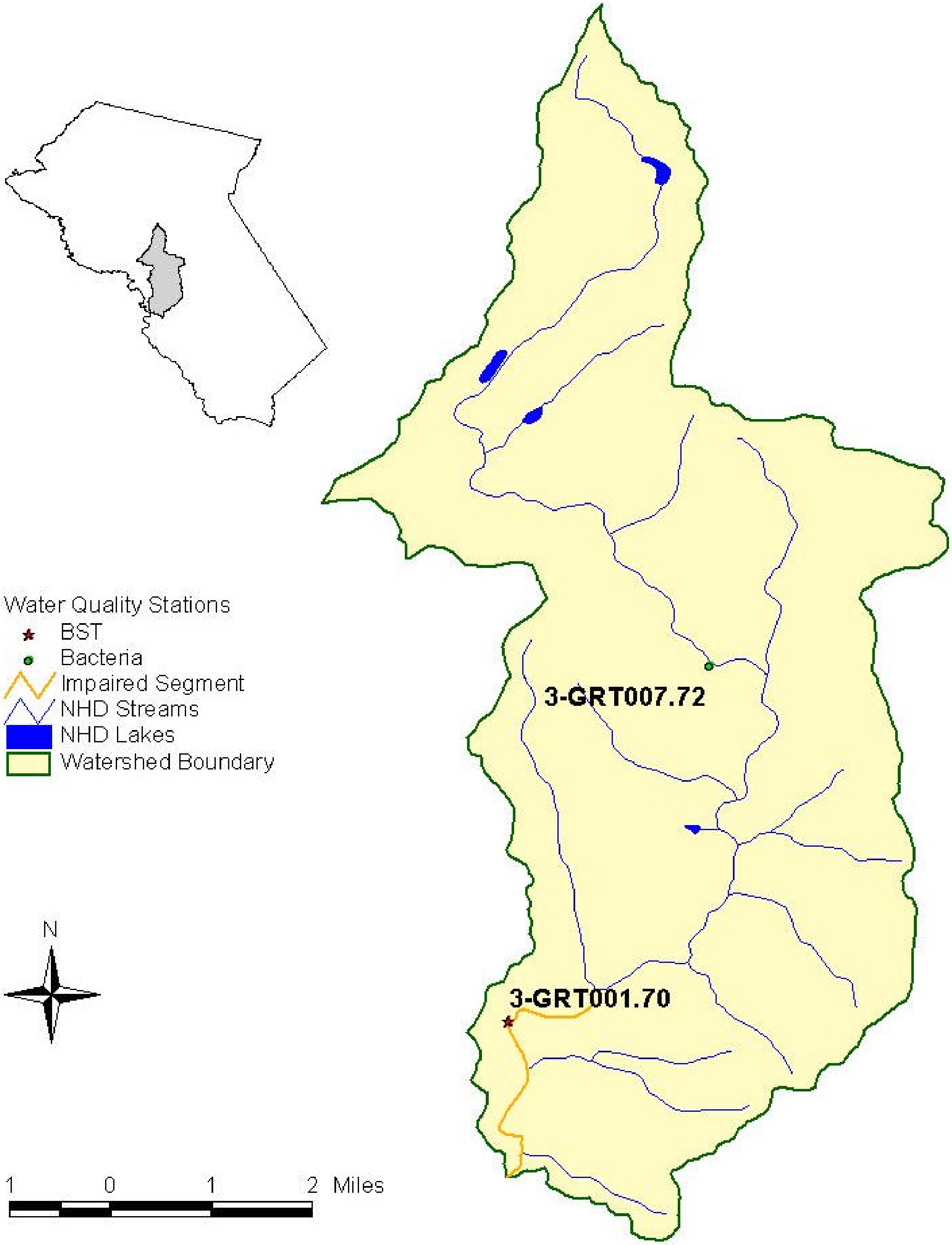
The sampling record at station 3-GRT001.70 is presented in Table 4 and the station location is presented in Figure 5. Time series fecal coliform data and seasonal fecal coliform data are presented in Figures 6 and 7, respectively.

Table 4. Fecal coliform data collected by DEQ on Great Run

Station	Date of First Sample	Date of Last Sample	Number of Samples	Average (cfu/100 ml)	Minimum (cfu/100 ml)	Maximum (cfu/100 ml)	Number of Exceed-ances*
3-GRT001.70	11/25/70	1/14/04	204	631	0	8,000	22
3-GRT007.72	11/12/74	1/14/04	20	751	25	6,000	4
1998 305(b) Data (July 1, 1992 to June 30, 1997)							
3-GRT001.70	9/14/92	6/30/97	18	1,802	100	8,000	5
2002 305(b) Data (January 1, 1996 to December 31, 2000)							
3-GRT001.70	3/19/96	10/5/00	18	833	100	8,000	3

* Exceedances of the then-applicable instantaneous standard of 1,000 cfu/100 mL

Figure 5. Map of DEQ Monitoring Stations in the Great Run watershed



A time series graph of the data collected at station 3-GRT001.70 from 1970 until 2004 is presented as Figure 6. The horizontal line at the 1000 cfu/100 ml mark represents the then-applicable instantaneous fecal coliform water quality standard. The data points above the 1000 cfu/100 ml line illustrate violations of the water quality standard.

Figure 6. Time series of fecal coliform concentrations at Station 3-GRT001.70

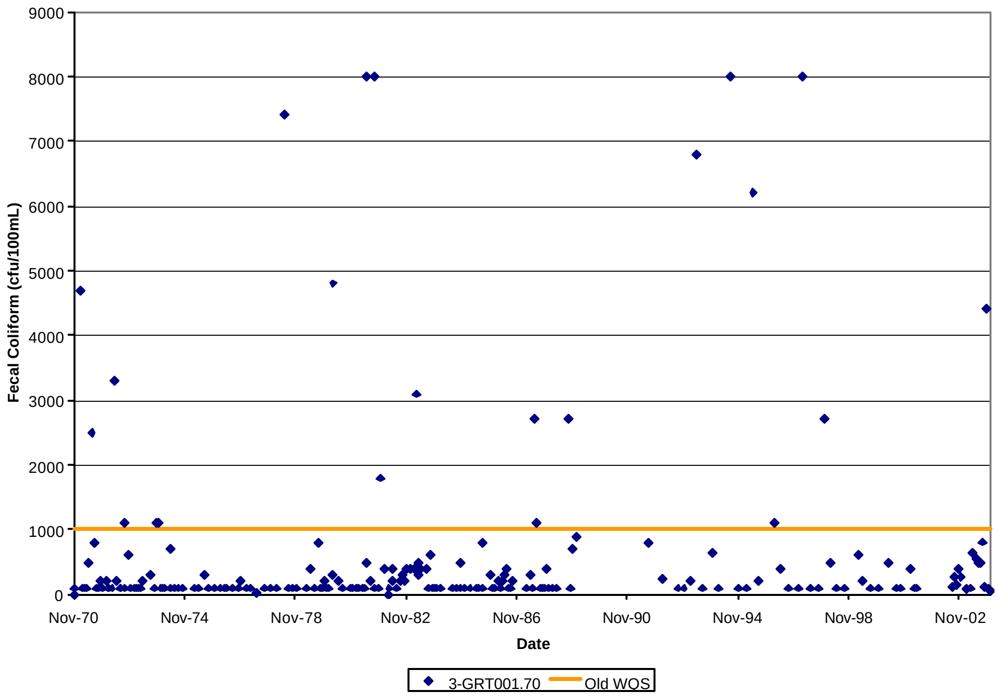
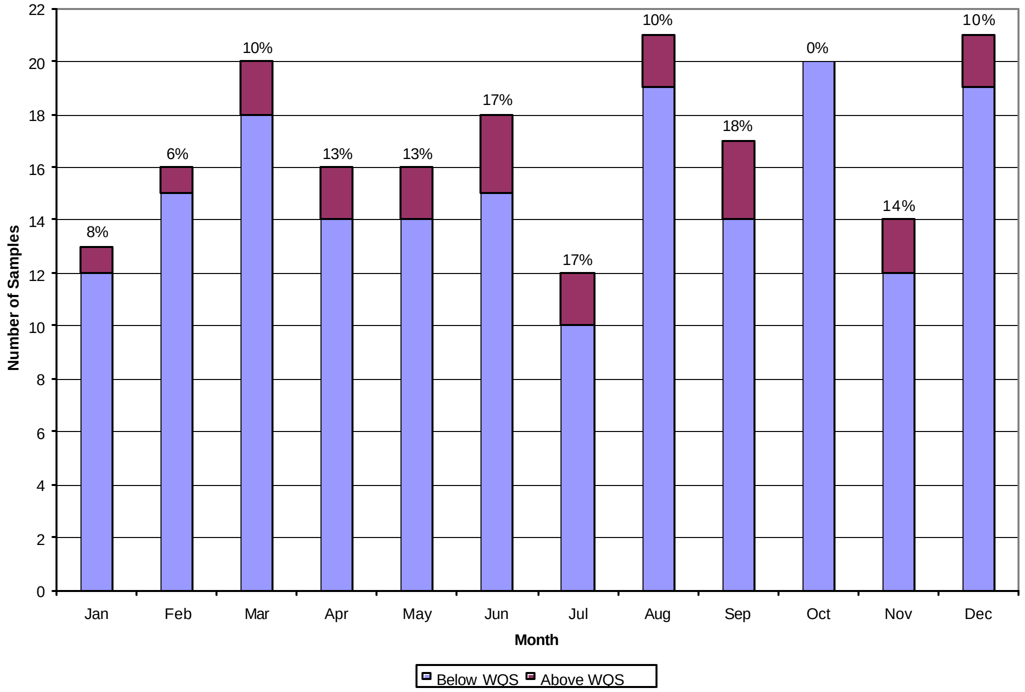


Figure 7 presents the distribution of water samples and exceedances (instantaneous fecal water quality standard - 1000 cfu/100mL) by month.

Figure 7. Seasonal distribution of fecal coliform samples and violations (station 3-GRT001.70)



4. Water Quality Standard

According to Virginia Water Quality Standards (9 VAC 25-260-5), the term *"water quality standards means provisions of state or federal law which consist of a designated use or uses for the waters of the Commonwealth and water quality criteria for such waters based upon such uses. Water quality standards are to protect the public health or welfare, enhance the quality of water and serve the purposes of the State Water Control Law (§62.1-44.2 et seq. of the Code of Virginia) and the federal Clean Water Act (33 USC §1251 et seq.)."*

As stated above, Virginia water quality standards consist of a designated use or uses and a water quality criteria. These two parts of the applicable water quality standard are presented in the sections that follow.

4.1. Designated Uses

According to Virginia Water Quality Standards (9 VAC 25-260-10A), *"all state waters 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 be reasonably expected to inhabit them; wildlife; and the production of edible and marketable natural resources (e.g., fish and shellfish)."*

As stated above, Great Run must support all designated uses and meet all applicable criteria.

4.2. Applicable Water Quality Criteria

The applicable water quality criteria for bacteria in the Great Run watershed have changed since the initial listing on the 303(d) report. Following EPA recommendations, the Virginia Department of Environmental Quality (DEQ) proposed more stringent fecal coliform bacteria standards as well as new standards for *Escherichia coli* (*E. coli*) bacteria. These new standards were adopted by the State Water Control Board in May 2002, public noticed in June 2002, approved by the USEPA in November 2002, and were effective January 15, 2003.

The EPA recommendation that states adopt *E. coli* and enterococci (saltwater) standards stems from a stronger correlation between the concentration of *E. coli* and enterococci organisms and the incidence of gastrointestinal illness. *E. coli* and enterococci are both bacteriological organisms that can be found in the intestinal tract of warm-blooded animals. *E. coli* is a subset of fecal coliform group; thus a waterbody listed as impaired for fecal coliform is considered to be listed for *E. coli* as well.

Great Run is listed as impaired due to exceedances of both the fecal coliform and *E. Coli* bacteria standards. The TMDL is developed to meet the new *E. coli* bacteria standard. The interim fecal coliform bacteria standard presented below will not apply to this TMDL since 12 *E. coli* bacteria samples were collected as part of the bacteria source tracking study of the source assessment.

New Bacteria Standards

For a non-shellfish supporting water body such as Great Run to be in compliance with Virginia bacteria standards for primary contact recreational use, the DEQ specifies the following criteria (9 VAC 25-260-170):

1. Fecal coliform bacteria shall not exceed a geometric mean of 200 fecal coliform bacteria per 100 ml of water for two or more samples over a calendar month nor shall more than 10% of the total samples taken during any calendar month exceed 400 fecal coliform bacteria per 100 ml of water. This criterion shall not apply for a sampling station after the bacterial indicators described in subdivision 2 of this subsection have a minimum of 12 data points or after June 30, 2008, whichever comes first.

2. E.coli and enterococci bacteria per 100 ml of water shall not exceed the following:

Table 5. Applicable water quality standards

Parameter	Geometric Mean[1] (cfu/100 ml)	Single Sample (cfu/100 ml)
E.coli (fresh water)	126	235
Enterococci (saltwater & Transition Zone 3)	35	104

[1] for two or more samples taken during a calendar month.

If the waterbody exceeded either criterion more than 10% of the time, the waterbody was classified as impaired and the development and implementation of a TMDL was indicated in order to bring the waterbody into compliance with the water quality criterion. Based on the sampling frequency, only one criterion was applied to a particular datum or data set (9 VAC 25-260-170). If the sampling frequency was one sample or less per 30 days, the instantaneous criterion was applied; for a higher sampling frequency, the geometric criterion was applied. These were the criteria used for listing the impairments included in this study. Sufficient fecal coliform bacteria standard violations were recorded at VADEQ water quality monitoring stations to indicate that the recreational use designations are not being supported.

For Great Run, the TMDL is required to meet the instantaneous criterion since the load-duration approach used to develop the TMDL for Great Run yields the maximum allowable bacteria concentration under any given flow condition. Unlike a continuous time series simulation, the flow duration approach does not yield daily bacteria concentrations which are needed to apply the geometric mean standard. Such an approach ensures that TMDLs, when implemented, do not result in violations under a wide variety of scenarios that affect bacteria loading.

5. Assessment of Bacteria Sources

The assessment of bacteria sources in traditional bacteria TMDL studies involves estimating loads from sources in the watershed and developing a computer model to establish the links between estimated loads and actual in-stream bacteria concentrations.

In a load-duration bacteria TMDL, source assessment is accomplished by determining the relative contribution by source of the fecal bacteria contained in a sample of stream water. This method of source identification is achieved through microbial source tracking (MST). MST methods that specifically use bacteria as the target organism are referred to collectively as bacteria source tracking (BST) methods. MST has been applied to study microbial ecology of environmental systems for years and is now being applied to help improve water quality by identifying problem sources and determining the effect of implemented remedial solutions. Management and remediation of water pollution would be more cost effective if the correct sources could be identified (Simpson, 2002).

To support BST analyses in load-duration TMDLs, bacteria loading in a watershed is also estimated. These load estimates are broken into point and non-point sources. It is important to note that the non-point source load estimates represent loading to the surface of the watershed; they are not estimates of in-stream loads.

The following sections present BST analysis and point- and non-point source load estimates.

5.1. Bacteria Source Tracking (BST)

Background

MST methods can be divided into three categories: molecular (genotype), biochemical (phenotype), and chemical. Molecular methods may offer the most precise identification of specific types of sources but are limited by high per-isolate costs and detailed and time-consuming procedures. They are not yet suitable for assaying large numbers of samples in a reasonable time frame. Biochemical methods (BST) may or may not be as precise, but are more simple, quicker, less costly, and allow large numbers of samples to be assayed in a short period of time (Hagedorn, 2002).

Several biochemical BST methods are in various stages of development. Among these are Antibiotic Resistance Analysis (ARA), F-Specific (F+ or FRNA) Coliphage, Sterols or Fatty Acid Analysis, Nutritional Patterns, and Fecal Bacteria Ratios. Of these, ARA has been chosen as the BST method for this TMDL report.

The ARA method uses fecal streptococcus (including the enterococci) and/or *E. coli* and patterns of antibiotic resistance for separation of sources. The premise is that human fecal bacteria will have the greatest resistance to antibiotics and that domestic and wildlife animal fecal bacteria will have significantly less resistance (but still different) to the battery of antibiotics and concentrations used. Most investigators are testing each isolate on 30 to 70+ antibiotic concentrations (Hagedorn, 2002). A more detailed description of the ARA method used by MapTech, Inc. in support of this TMDL is presented in Appendix B.

BST Sampling and Results

A total of 12 ambient water quality samples were collected by DEQ staff and submitted to MapTech, Inc. (MapTech) for BST analysis. The BST analyses performed by MapTech determined the relative contribution of overall bacteria by human, pet, livestock, and wildlife sources. Fecal and *E.coli* bacteria were also enumerated as part of the analyses performed by MapTech. Results of the Great Run BST sampling program are presented in Table 6.

Table 6. Great Run bacteria source tracking results (3-GRT001.70)

Sample Date	Fecal Coliform (cfu/100mL)	*E. coli* (cfu/100mL)	BST Distribution			
			Wildlife	Human	Livestock	Pet
12/17/02	270	70	13%	0%	87%	0%
3/5/03	80	60	17%	25%	17%	41%
4/16/03	100	78	33%	0%	29%	38%
5/20/03	650	410	20%	4%	38%	38%
6/23/03	550	140	25%	8%	25%	42%
7/21/03	500	230	33%	4%	13%	50%
8/19/03	490	170	38%	0%	13%	49%
9/9/03	810	210	33%	0%	38%	29%
10/14/03	120	30	50%	0%	50%	0%
11/6/03	4,400	1,350	55%	4%	29%	12%
12/3/03	90	50	25%	4%	38%	33%
1/14/04	50	28	59%	4%	12%	25%
Average			33%	4%	32%	30%
Standard Deviation			15%	7%	21%	17%

The BST data results indicate that the majority bacteria are coming from anthropogenic sources. Approximately 67% of the bacteria found in the Great Run study comes from human, pet, or livestock sources.

5.2. Point Sources

Bacteria loading from point sources such as sewage treatment plants, small commercial establishments, schools, homes and businesses require permits under the Virginia Pollution Discharge Elimination System (VPDES) permit program. In order to consider all such point-source discharges in the Great Run watershed, the DEQ comprehensive environmental database and regional DEQ permit staff were queried. One bacteria point source discharge was identified in the Great Run watershed.

The point source is covered under a VPDES individual permit and is presented in Table 7.

Table 7. VPDES point source facilities and loads

VPDES Permit Number	Facility Name	Receiving Stream	Watershed ID	Design Flow (MGD)	Effluent Limit (cfu/100 ml)	Wasteload Allocation (cfu/year)
VA0021172	Warrenton Town Sewage Treatment Plant	Great Run, UT	VAN-E02R	2.5	126	4.35×10^{12}
Existing WLA				2.5	126	4.35×10^{12}
Expansion Matrix						
Total x 2						8.70×10^{12}
Total x 5						2.18×10^{13}

Permitted loads were calculated by multiplying the permitted discharge concentration (126 cfu/100 ml) times the design flow times the appropriate unit conversions.

5.3. Non-Point Sources

In order to gain an understanding of non-point source loading in the Great Run watershed, bacteria loads for typical non-point sources were estimated. These estimates were based upon animal and human population data sets, typical waste production rates and typical bacteria densities in waste products.

Currently published values for fecal bacteria production rates are primarily in terms of fecal coliform. There is little data on *E. coli* production; however, studies have shown that though minor variability will exist between sources, *E. coli* represents roughly 90-95% of fecal coliforms contained in "as-excreted" fecal material (Yagow, 2002). This implies that the relative bacteria contribution by source should remain constant.

It is important to note that the bacteria loads presented in the following sections on non-point sources represent "as-produced" loads. This is to say that some portion of an estimated load may not be available to be transported to Great Run in runoff.

5.3.1. Humans and Pets

Bacteria loading from human sources can come from straight pipes, failing septic systems, and land-applied biosolids. Failing septic systems are typically manifested by effluent discharging to the ground surface where the bacteria laden effluent is then available to be washed into a stream as runoff during a precipitation event. In contrast, discharges from straight pipes are typically directly deposited to streams.

All biosolids can contain a certain concentration of fecal bacteria. When biosolids are applied to the land surface, the potential exists for a portion of these fecal bacteria to be transported to a stream as runoff during storm events.

Straight Pipes

There are no known straight pipes in the Great Run Watershed. An estimate of the potential number of straight pipes in the watershed was made using best professional judgement. It is estimated that there are potentially 14 straight pipes in the Great Run watershed.

Based on 2000 U.S. Census data, the Great Run watershed is populated by approximately 3,580 residents living in approximately 1,350 households. Based on these estimates, there are an average of 2.7 people per household in the Great Run watershed. Assuming a fecal coliform production rate by humans of 2.00 x 10^9 cfu per day (Metcalf and Eddy, 1991), the potential fecal coliform load to Great Run from straight pipes is estimated to be 2.76 x 10^{13} cfu per year.

Septic Systems

An estimate of the potential number of failing septic systems in the watershed was made based on known drain field locations and age of structure. Using this method, it is estimated that there are potentially 34 failing septic systems in the Great Run watershed. Assuming an average of 2.7 people per household, a wastewater production rate of 75 gallons per day per person (Geldreich, 1978), and a fecal coliform density in septic tank waste of 1.04 x 10^6 cfu per 100 mL (MapTech, 2002), the potentially failing septic load in the Great Run watershed is estimated to be 9.89 x 10^{13} cfu per year.

Biosolids

In the Commonwealth of Virginia, the VDH and the DEQ regulate biosolids generation and application to the land surface. The DEQ regulates the generation of biosolids and the land application of those biosolids by the generator. The VDH regulates contractors who transport and spread biosolids; the biosolids can be from in-state or out-of-state sources. There were no records of biosolids applications in the Great Run watershed.

Pets

The number of pets in the watershed was estimated based on the number of households. Assuming an average of 1.7 dogs and 2.1 cats per household (National Pet Owner Survey, American Pet Products Manufacturers Association, 2001-2002), the estimated pet population in the Great Run watershed consists of 2,295 dogs and 2,835 cats. Using the waste production rates and fecal coliform densities from MapTech, 2002, the total bacteria loads from dogs and cats in the Great Run watershed are 1.81 x 10^{14} and 1.81 x 10^8 cfu per year, respectively. Table 8 presents the calculation of human and pet loads in the watershed. It should be noted that the numbers presented in Table 8 represent loads available for runoff and not in-stream loads.

Table 8. Estimated fecal coliform production from humans and pets in the Great Run watershed

Source	Population	Waste Production Rate	Waste Fecal Coliform Density	Total Est. Annual Fecal Production
Straight Pipes	14 households x 2.7 people/household = 37.8 people	2.00 x 10^9 cfu/day/person * x 365 days/yr = 7.30 x 10^{11} cfu/yr/person		2.76 x 10^{13} cfu/yr
Failing Septic Systems	34 systems x 2.7 people/system = 91.8 people	75 gal/day/person x 37.85412 100mL/gal x 365 days/yr = 1.04 x 10^6 100mL/yr/person **	1.04 x 10^6 cfu/100mL ***	9.89 x 10^{13} cfu/yr
			Total Human	1.26 x 10^{14} cfu/yr

Table 8. Estimated fecal coliform production from humans and pets in the Great Run watershed

Source	Population	Waste Production Rate	Waste Fecal Coliform Density	Total Est. Annual Fecal Production
Dogs	2,295 dogs	450 g/day/dog *** x 365 days = 1.64×10^5 g/yr/dog	4.8×10^5 cfu/g ***	1.81×10^{14} cfu/yr
Cats	2,835 cats	19.4 g/day/cat *** x 365 days = 7.08×10^3 g/yr/cat	9 cfu/g ***	1.81×10^8 cfu/yr
			Total Pets	1.81×10^{14} cfu/yr

* Metcalf and Eddy, 1991
** Geldreich, 1978 (A conversion factor of 37.85412 was used to convert gallons to 100mL)
*** MapTech, 2002 (Catoctin Creek TMDL Report)

5.3.2. Livestock

Fecal matter from livestock can be deposited directly to the stream in instances where livestock have stream access, or the fecal matter can be transported to the stream in surface runoff from grazing or pasture lands.

The predominant types of livestock in the Great Run watershed are cattle and horses, although all types of livestock were considered in developing the TMDL. The livestock population in the watershed was estimated based on 1997 Census of Agriculture data for Fauquier County (http://govinfo.library.orst.edu/php/agri/area.php) and input from the John Marshall Soil and Water Conservation District (JMSWCD, 2004). The Great Run watershed is located entirely within Fauquier County and contains approximately 4.5% of the total pasture land in the county as determined by GIS analysis. Table 9 presents the livestock population estimates, fecal production rates, and estimated annual fecal loads in the watershed. It should be noted that the numbers presented in Table 9 represent loads available for runoff and not in-stream loads.

Table 9. Estimated annual fecal coliform production from livestock in the Great Run watershed

Source	Population		Waste Production Rate** (lbs/animal/day)	Fecal Density** (cfu/g)	Total Fecal Production*** (cfu/yr)
	Fauquier County	Great Run			
Cattle and Calves	58,969	2,403	46.4	1.01×10^5	1.86×10^{15}
Beef Cows	23,703	1,071	46.4	1.01×10^5	8.31×10^{14}
Milk Cows	5,801	0	120.4	2.58×10^5	0
Hogs and Pigs	461	21	11.3	4.00×10^5	1.56×10^{13}
Sheep and Lambs	1,650	55	2.4	4.30×10^4	9.40×10^{11}
Layers	1,588	72	1.40×10^8 (cfu/animal/day) ****		3.67×10^{12}
Broilers	0	0	1.40×10^8 (cfu/animal/day) ****		0
Horses	13,700	619	51.0	9.40×10^4	4.91×10^{14}
				Total Livestock	3.21×10^{15}

* 2001 Virginia Equine Report
** MapTech, 2002
*** A conversion factor of 453.6 was used to convert pounds to grams
**** ASAE, 1998

5.3.3. Wildlife

Like livestock, fecal matter from wildlife can be either deposited directly to the stream, or it can be transported to the stream in surface runoff from woods, pastureland and cropland. Direct deposition to streams varies with species, e.g. beaver spend most of their time in water; therefore most of their fecal matter would be directly deposited to the stream.

Wildlife populations in the Great Run watershed were estimated based on wildlife densities used in developing the Thumb Run TMDL. The only exception to this was the density of geese in the watershed was increased in response to comments made at the final public meeting. Habitat was assigned as follows:

- deer: forest, cropland, pasture
- raccoon: forest, cropland, urban pervious within 400 m of streams
- muskrats: forest within 10 m of streams
- beaver: forest, cropland, pasture within 100 m of streams
- turkey: forest
- duck: forest, cropland, pasture within 400 m of streams
- goose: forest, cropland, pasture within 100 m of streams
- fox: forest, cropland, pasture
- bear: forest, cropland, pasture

Table 11. Estimated fecal coliform production from wildlife in the Great Run watershed

Source	Population Density (animals /acre) *	Habitat (acres)	Water-shed Popula-tion (animals)	Range of Waste Production Rate ** (cfu/animal/day)		Range of Fecal Coliform Production (cfu/yr)	
				Low	***High***	***Low***	***High***
Deer	0.0656	17,432	1,144	1.52×10^{8}	3.60×10^{8}	6.34×10^{13}	1.50×10^{14}
Raccoon	0.07692	6,146	473	2.05×10^{7}	9.45×10^{8}	3.54×10^{12}	1.63×10^{14}
Muskrat	5	91	457	2.50×10^{7}	1.90×10^{8}	4.17×10^{12}	3.17×10^{13}
Beaver	0.0317	1,743	55	3.00×10^{6}		6.05×10^{10}	
Turkey	0.01	9,144	91	9.3×10^{7}		3.10×10^{12}	
Duck	0.04	6,973	279	2.43×10^{9}		2.47×10^{14}	
Goose	0.455	1,743	793	5.87×10^{4}	2.25×10^{9}	1.70×10^{10}	6.51×10^{14}
Fox	0.0106	17,432	185	5.06×10^{6}		3.41×10^{11}	
Bear	0.00046	17,432	8	41.7×10^{9}		1.22×10^{14}	
Total Wildlife						4.44×10^{14}	1.37×10^{15}

* GKY, 2002
** VADCR, 2003

6. TMDL Development

One of the major obstacles to improving stream water quality is that the potential sources of bacteria are numerous and the dominant sources and/or pathways are generally unknown. This can make it difficult to direct effective cleanup efforts.

Typical pathogen TMDLs are completed by developing watershed-based computer simulations that establish links between sources and in-stream water quality. While effective, the effort required to develop modeled TMDLs can be costly. In an effort to complete pathogen TMDLs in a timely and cost-effective manner, the use of load-duration analyses has been investigated. It has been determined that the load-duration method of calculating a TMDL produces a result only slightly more conservative than if the TMDL had been determined through computer modeling.

The load duration method essentially uses an entire stream flow record to provide insight into the flow conditions under which exceedances of the water quality standard occur. Exceedances that occur under low flow conditions are generally attributed to loads delivered directly to the stream such as straight pipes and livestock with access to the stream. Exceedances that occur under high flow conditions are typically attributed to loads that are delivered to the stream in stormwater runoff. Exceedances occurring under during normal flows can be attributed to a combination of runoff and direct deposits.

The following sections detail the development of the load-duration TMDL and associated allocations.

6.1. Load-Duration Curve

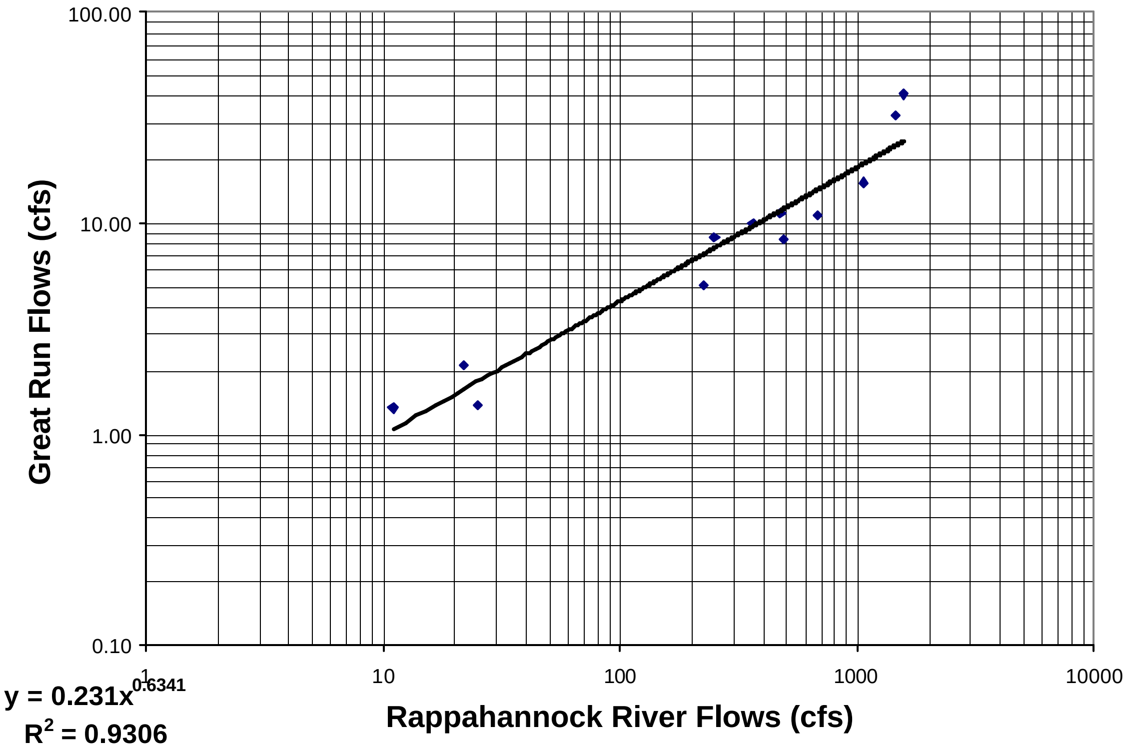
Development of a load-duration curve begins with a flow-duration curve, and in order to develop a meaningful flow-duration curve one must have several years of flow data for the target stream or river. Where very little flow data exists for a target stream, a reference stream with the requisite flow measurements must be used similar to the paired watershed approach used in watershed-based modeling. In the case of Great Run, a limited number of flow observations are available.

The following sections detail the flow data for Great Run, the development of a flow-duration curve for Great Run, and the creation of a load-duration curve for Great Run.

6.1.1. Flow Data

There is no flow gauge located on Great Run, but twelve flow measurements were made under a range of flow conditions between March 2002 and June 2004. In order to extend the period of flow record to span the 1998 and 2002 assessment periods, the Great Run flows were correlated with flows on Battle Run, and the Rappahannock and Rapidan Rivers. Great Run correlated best with the Rapidan River (USGS 01665500), however the regression between Great Run and the Rappahannock River River (USGS 01664000) had a substantially higher R^2 (0.9306 vs. 0.8532 for the Rapidan.) The regression presented in Figure 8 was developed using the Rappahannock flow record and used to extend the flow record from 1988 to the present.

Figure 8. Regression of Great Run and Battle Run flows



6.1.2. Flow-Duration Curves

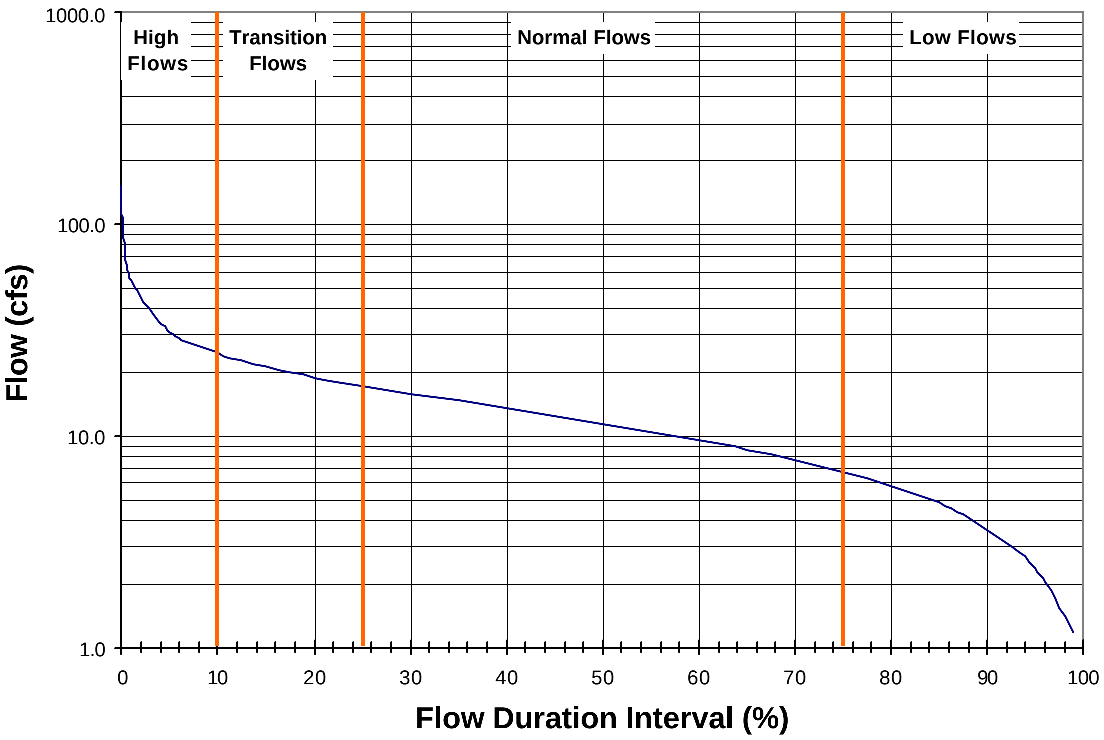
In order to use the load-duration method to develop a TMDL, a load-duration curve must be developed for the impaired stream. This is accomplished by first developing a flow-duration curve for the stream.

A flow-duration curve is a plot showing the flow magnitude (cfs) along the "y" axis and the frequency of daily average stream flow (%) along the "x" axis. For example, the flow value corresponding to “1%” is the flow that has been exceeded only 1% of the time for which measurements exist. Likewise, the flow value corresponding to “30%” is the flow that 30% of the historic record exceeds.

To plot the flow values for the period of record of the reference stream, the PERCENTILE statistic function of Excel was used. The resulting percentile of a given flow was then subtracted from 1 to yield the percent of time that a given flow is exceeded by the flows of record. The flow duration interval values were plotted with the corresponding flows to yield a log/normal flow duration curve. The flow-duration curve for Great Run is presented as Figure 9.

The flow-duration curve for Great Run has been divided into four sections to help illustrate flow conditions. These sections are titled "High Flows", "Transition Flows", "Normal Flows", and "Low Flows". Low flows can be roughly equated to near-drought or drought flows. High flows are near-flood or flood flows. Transition flows are, as implied, neither normal nor high.

Figure 9. Flow-duration curve for Great Run



6.1.3. Load-Duration Curve

As mentioned in Section 3, the violations of the bacteria water quality standards on the Great Run were collected primarily at Station 3-GRT001.70, which is also the location of the USGS flow station.

A load-duration curve is developed by multiplying each flow level along the flow-duration curve by the applicable water quality standard and required unit conversions. The resulting curve represents the maximum allowable load at each flow level, in other words, the Total Maximum Daily Load (TMDL). Since the TMDL and required reductions must be in terms of an average annual stream flow, the loads on the load-duration curve are multiplied by 365 days/year and presented as annual loads.

In order to plot existing fecal coliform (FC) data against the *E. coli* (EC) standard/TMDL line, it was necessary to translate the FC data to EC data. Translation of FC data to EC data was achieved by using a translator equation developed from a regression analysis of 493 paired FC/EC data sets from the DEQ's statewide monitoring network. The translator equation resulting from the regression analysis is presented below:

$$\mathbf{EC\ log_2 = -0.0172 + 0.91905 * FC\ log_2}$$

By plotting these observed loads on the load-duration curve, the number and pattern of exceedances of the water quality standard (TMDL) can be analyzed. The load duration curve and observed data for Great Run are shown in Figure 10. The TMDL line has been plotted for the instantaneous *E. coli* standard of 235 cfu/100mL.

Figure 10. Load duration curve and observed data for Great Run at station 3-GRT001.70

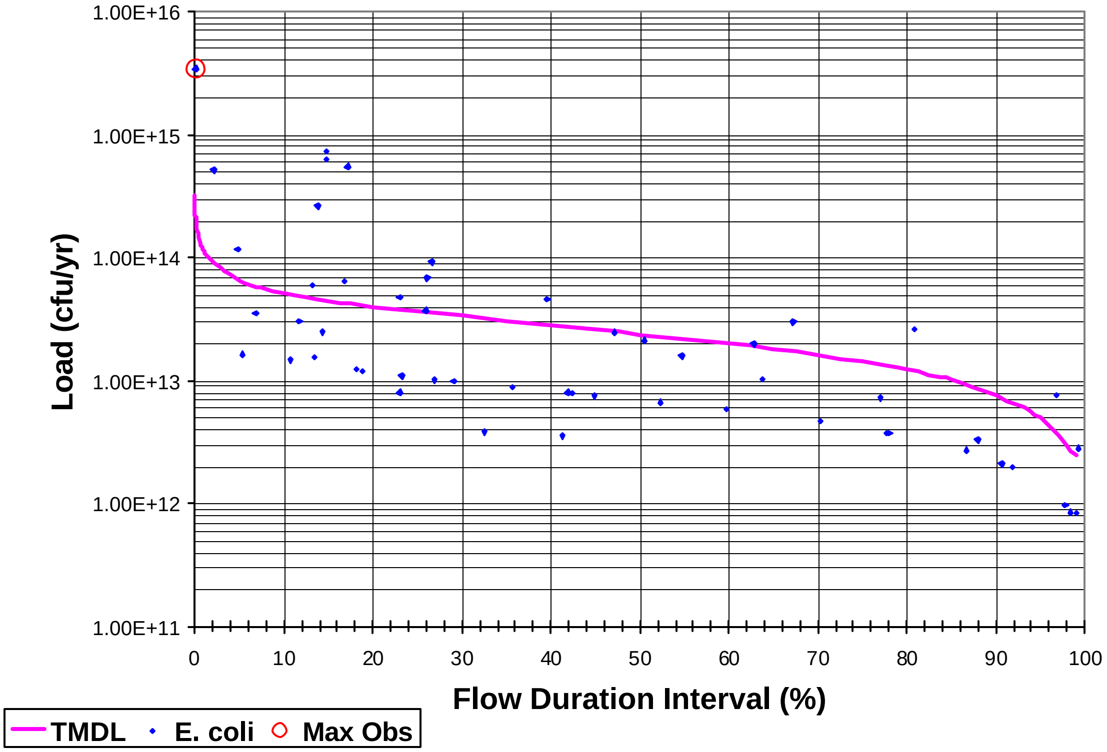
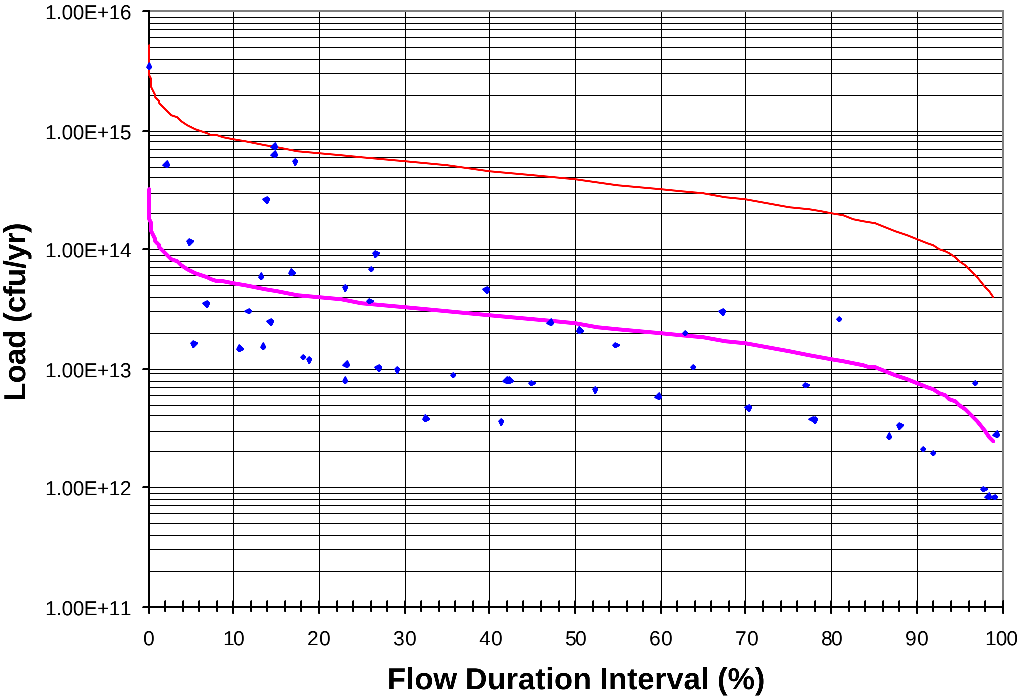


Figure 10 suggests that exceedances of the water quality standard occur under all flow conditions. The highest exceedance of the water quality standard (circled) occurs at a high flow that has virtually never been exceeded (approximately 100 cfs). This represents the flow condition under which the largest bacteria reduction is required in order to meet water quality standards. The translated load at this flow condition is 3.43 x 10^{15} cfu/yr. Under the instantaneous *E. coli* standard of 235 cfu/100mL, this load would have to be reduced by 94% to an allowable load of 2.11 x 10^{14} cfu/yr. The allowable load is simply the *E. coli* standard multiplied by the applicable flow condition and the proper unit conversions. The full calculation with unit conversions is presented in Appendix C.

In order to determine the necessary load reduction at the average annual flow condition, a second curve must be drawn through the highest exceedance described above. The second curve represents the magnitude of the highest observed exceedance if it were to occur over any flow condition. The graph of the load-duration curve with the max-exceedance curve is presented in Figure 11.

Figure 11. Load duration curve with maximum exceedance curve for Great Run at station 3-GRT001.70



6.2. TMDL

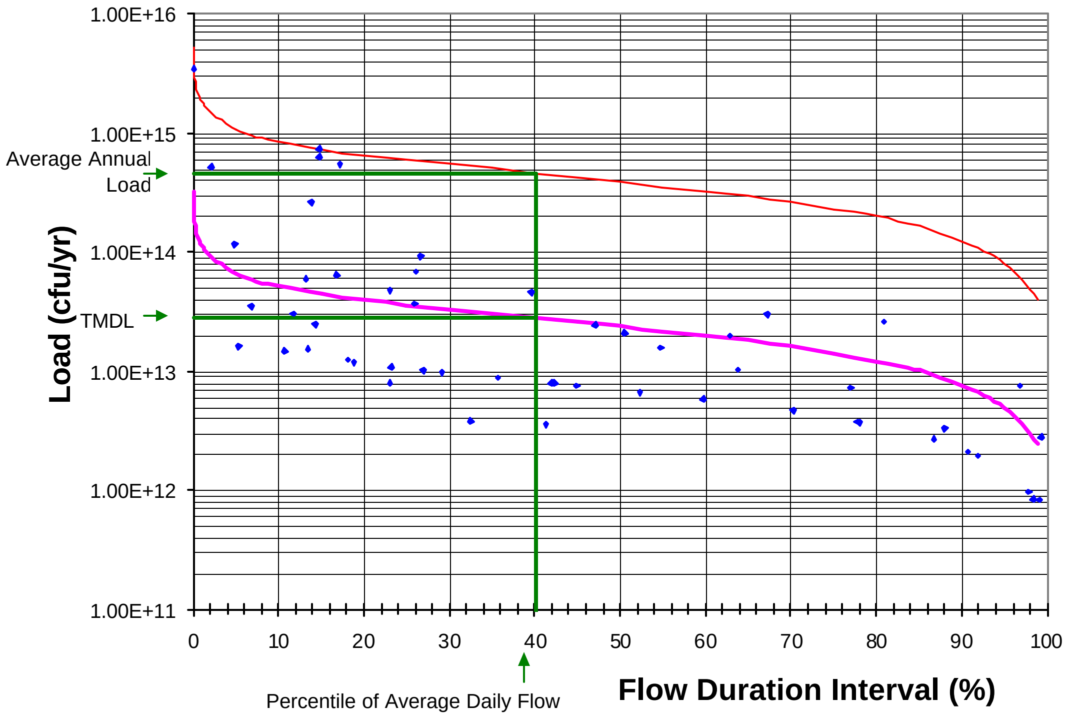
A Total Maximum Daily Load (TMDL) consists of 1) point source/waste load allocations (WLAs), 2) non-point sources/load allocations (LAs) where the non-point sources include natural/background levels, and 3) a margin of safety (MOS) where the margin of safety may be implicitly or explicitly defined. This TMDL definition is typically illustrated by the following equation:

TMDL = WLAs + LAs + MOS

Simply put, a TMDL is the amount of a pollutant that can be present in a waterbody where the waterbody will still meet water quality standards for that pollutant. In the case of load-duration bacteria TMDLs, the TMDL is expressed as the total number of colony forming units (cfu) per year as opposed to cfu/day. This is because the load-duration TMDL must be based on the average annual flow condition.

The estimated average annual flow for Great Run is 13.51 cfs. This flow value has an associated flow duration of 40.1%. From this information an average annual *E. coli* load and TMDL can be calculated from the max-exceedance and TMDL curves. This is represented graphically in Figure 12. The full calculation is presented in Appendix C.

Figure 12. Load duration curve illustrating the TMDL and estimated average annual *E. Coli* load for Great Run at station 3-GRT001.70



The average annual *E. coli* load is 4.61 x 10^{14} cfu/yr, and the TMDL under average annual flow conditions is 2.83 x 10^{13} cfu/yr. These values are used to calculate required reductions. By subtracting the waste load allocation (known value) from the TMDL (as determined above), the load allocation can be determined. These three values are presented in Table 12.

Table 12. Average annual *E. coli* loads and TMDL for Great Run watershed (cfu/yr)

WLA *	LA	MOS	TMDL
4.35 x 10^{12}	2.40 x 10^{13}	(implicit)	2.83 x 10^{13}

* The point sources permitted to discharge in the Great Run watershed are presented in section 5.2.

7. Allocations

Reduction

The annual average TMDL and *E. coli* load values from section 6.2, together with the waste load allocation from the permitted bacteria sources in section 5.2, were plugged into Table 13 to determine the required reduction. Since the required reduction will only apply to the non-point sources, the LA value was used to calculate the required percent reduction. The full calculations are presented in Appendix C.

Table 13. TMDL and required reduction for Great Run

Load Category (annual average)	Allowable Loads (cfu/yr)	Average Annual EC Load (cfu/yr)	Required Reduction
Waste Load Allocation (WLA)	4.35×10^{12}	4.35×10^{12}	0%
Load Allocation (LA)	2.40×10^{13}	4.56×10^{14}	95%
MOS	0 (implicit)		
TMDL	2.83×10^{13}	4.61×10^{14}	94%

As illustrated in Table 12 and 13, the WLA for the Great Run watershed has an effect on the LA reduction calculations. The WLA represents 15% of the TMDL load. An additional TMDL scenario where the WLA has been increased by a factor of five was developed and is presented in Appendix E. This scenario gives flexibility to accommodate future expansion and/or additional discharges in the watershed. However, given the substantial portion of the TMDL already allocated to point sources, any expansion of existing or addition of new sources should be studied carefully prior to approval.

Margin of Safety

This requirement is intended to add a level of safety to account for any inherent uncertainty in the TMDL development process and the data used in the development. The MOS may be either implicit or explicit. An implicit margin of safety relies on the conservative nature of the assumptions, values, and methods used to calculate a TMDL whereas an explicit margin of safety is a value (typically a percentage) applied at some point during the TMDL calculation.

In Great Run TMDL, an implicit MOS was incorporated through the use of conservative analytical assumptions. These include: (1) the use of the single-most extreme observed water quality violation event which was used to develop the maximum exceedance curve over the entire range of flow conditions, and (2) the computation of average annual load using the average flow conditions. Additionally, the load duration method of TMDL development has been evaluated against TMDLs that were developed using computer modeling. The results showed the load duration method to be slightly more conservative.

Allocations

In order to apply the reduction calculated above, the average annual *E. coli* load had to be allocated to each of the four non-point sources identified in the BST analysis. Table 14 shows the distribution of the average annual *E. coli* load among sources, the reduction applied to each source, and the allowable loading for each source.

Table 14. Average annual load distribution, reduction, and allowable load by source

	Total (cfu/yr)	Human: 4% (cfu/yr)	Pet: 30% (cfu/yr)	Livestock: 32% (cfu/yr)	Wildlife: 33% (cfu/yr)
Average Annual Load	4.56×10^{14}	2.02×10^{13}	1.36×10^{14}	1.48×10^{14}	1.52×10^{14}
Reduction	95%	95%	95%	95%	95%
Allowable Annual Load	2.40×10^{13}	1.06×10^{12}	7.14×10^{12}	7.78×10^{12}	8.02×10^{12}

7.1. Consideration of Critical Conditions

EPA regulations at 40 CFR 130.7 (c)(1) require TMDLs to take into account critical conditions for stream flow, loading, and water quality parameters. The intent of this requirement is to ensure that the water quality of Great Run is protected during times when it is most vulnerable.

Critical conditions are important because they describe the factors that combine to cause a violation of water quality standards and will help in identifying the actions that may have to be undertaken to meet water quality standards. The sources of bacteria for Great Run are a mixture of dry and wet weather driven sources. TMDL development utilizing the load-duration approach applies to the full range of flow conditions; therefore, the critical conditions for Great Run were addressed during TMDL development.

7.2. Consideration of Seasonal Variations

Seasonal variations involve changes in stream flow and water quality as a result of hydrologic and climatological patterns. The load-duration approach allows the pattern of water quality exceedances to be examined for seasonal variations. The load-duration method used to develop this TMDL implicitly incorporates the seasonal variations of precipitation and runoff by looking at the highest water quality violation and applying it to the entire stream flow record when calculating the TMDL.

8. Implementation and Reasonable Assurance

The goal of the TMDL program is to establish a three-step path that will lead to attainment of water quality standards. The first step in the process is to develop TMDLs that will result in meeting water quality standards. This report represents the culmination of that effort for the bacteria impairments on the Great Run. The second step is to develop a TMDL implementation plan. The final step is to implement the TMDL implementation plan, and to monitor stream water quality to determine if water quality standards are being attained.

Once a TMDL has been approved by EPA, measures must be taken to reduce pollution levels in the stream. These measures, which can include the use of better treatment technology and the installation of best management practices (BMPs), are implemented in an iterative process that is described along with specific BMPs in the implementation plan. The process for developing an implementation plan has been described in the recent "TMDL Implementation Plan Guidance Manual", published in July 2003 and available upon request from the DEQ and DCR TMDL project staff or at http://www.deq.state.va.us/tmdl/implans/ipguide.pdf. With successful completion of implementation plans, Virginia will be well on the way to restoring impaired waters and enhancing the value of this important resource. Additionally, development of an approved implementation plan will improve a locality's chances for obtaining financial and technical assistance during implementation.

8.1. TMDL Implementation Process

In general, Virginia intends for the required reductions to be implemented in an iterative process that first addresses those sources with the largest impact on water quality. For example, in agricultural areas of the watershed, the most promising management practice is livestock exclusion from streams. This has been shown to be very effective in lowering bacteria concentrations in streams, both by reducing the cattle deposits themselves and by providing additional riparian buffers.

Additionally, in both urban and rural areas, reducing the human bacteria loading from failing septic systems should be a primary implementation focus because of its health implications. This component could be implemented through education on septic tank pump-outs as well as a septic system repair/replacement program and the use of alternative waste treatment systems.

In urban areas, reducing the human bacteria loading from leaking sewer lines could be accomplished through a sanitary sewer inspection and management program. Other BMPs that might be appropriate for controlling urban wash-off from parking lots and roads and that could be readily implemented may include more restrictive ordinances to reduce fecal loads from pets, improved garbage collection and control, and improved street cleaning.

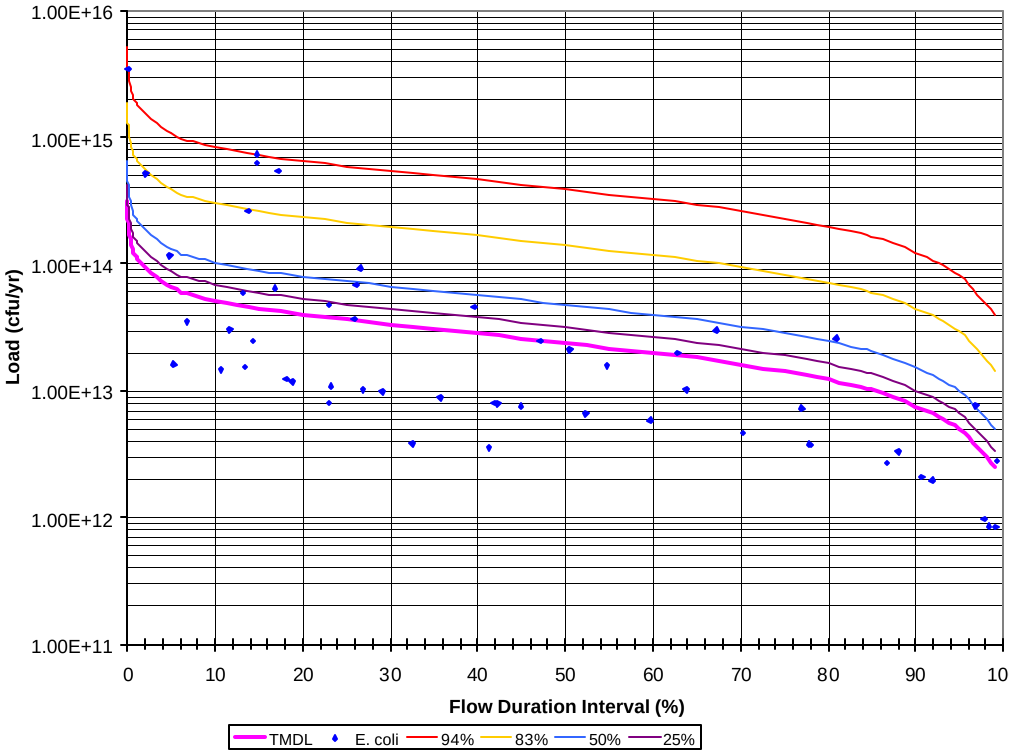
The iterative implementation of BMPs in the watershed has several benefits:

1. It enables tracking of water quality improvements following BMP implementation through follow-up stream monitoring;
2. It provides a measure of quality control, given the uncertainties inherent in computer simulation modeling;
3. It provides a mechanism for developing public support through periodic updates on BMP implementation and water quality improvements;
4. It helps ensure that the most cost effective practices are implemented first; and
5. It allows for the evaluation of the adequacy of the TMDL in achieving water quality standards.

8.2. *Stage I Implementation Goal*

As stated in Section 7.0 the TMDL requires a 95% reduction in non-point source loading in order to attain a 0% violation of water quality standards. In order to evaluate interim reduction goals for a phased implementation plan, several reduction levels and their associated violation rates were assessed. Reduction curves similar to the max exceedance/reduction curve of Figure 11 were plotted on the Great Run load-duration curve. These reduction curves are presented in Figure 13.

Figure 13. Load duration curve illustrating the TMDL and reduction curves for Great Run at station 3-GRT001.70



The theoretical violation rates for the various load reductions presented in Figure 13 are presented below in Table 15.

Table 15. Load Reductions and WQS Violation Rates

Load Reduction	94%	83%	50%	25%	0% (Current Load)
Violation Rate	0%	7%	16%	25%	35%

Based on the reduction analysis presented above and a goal of measurable water quality improvement, a suitable Phase I reduction level would be 83%. Table 16 presents the Phase I load allocations based on an 83% reduction of in-stream loads. Table 17 presents the overall reduction attained by eliminating anthropogenic contributions and making no reductions to wildlife contributions.

Table 16. Phase I Load Allocations (based on an 83% overall reduction and 0% Waste Load Allocation reduction)

	Total (cfu/yr)	Human (cfu/yr)	Pet (cfu/yr)	Livestock (cfu/yr)	Wildlife (cfu/yr)
Average Annual Load	4.56×10^{14}	2.02×10^{13}	1.36×10^{14}	1.48×10^{14}	1.52×10^{14}
Reduction	84%	95%	95%	95%	62%
Target Annual Load	7.39×10^{13}	1.06×10^{12}	7.14×10^{12}	7.78×10^{12}	5.79×10^{13}

Table 17. Reduction Attained by Eliminating from Nonpoint Source Anthropogenic Contributions

	Total (cfu/yr)	Human (cfu/yr)	Pet (cfu/yr)	Livestock (cfu/yr)	Wildlife (cfu/yr)
Average Annual Load	4.56×10^{14}	2.02×10^{13}	1.36×10^{14}	1.48×10^{14}	1.52×10^{14}
Reduction	67%	100%	100%	100%	0%
Target Annual Load	1.52×10^{14}	0.00	0.00	0.00	1.52×10^{14}

In order to provide some insight into the nature of the Great Run water quality violations and to better target possible BMPs, the correlation between violations, stream flow change, and local precipitation was examined.

Results indicate that the violations are approximately evenly distributed between times of precipitation and increasing stream flow or times of no precipitation with decreasing stream flow. This suggests that the violations could be related to both runoff events and direct loads delivered to the stream. The complete analysis is presented in Appendix D.

BMPs effective in correcting dry weather/low-flow violations of the bacteria water quality standard typically include: streamside fencing for cattle exclusion, straight pipe replacement, and septic system repair. Among some of the BMPs effective in reducing bacteria runoff from precipitation events include: riparian buffers zone, retention ponds/basins, range and pasture management, and animal waste management. Detailed lists of BMPs and their relative effectiveness will be presented in the eventual TMDL implementation plan for the Great Run watershed.

8.3. Link to Ongoing Restoration Efforts

The local John Marshall Virginia Soil and Water Conservation District (JMSWCD), in recent years, has made significant progress in implementing Best Management Practices (BMPs) in the Great Run watershed. However, current available BMP monies are limited in the watershed. VADEQ and JMSWCD believe additional grant monies available through the TMDL program would be greatly beneficial in reaching members of the community that have not yet participated in BMP programs.

8.4. Reasonable Assurance for Implementation

8.4.1. Follow-Up Monitoring

VADEQ will continue to monitor Great Run in accordance with its ambient monitoring program. Watershed stations will continue to be monitored bi-monthly on a 6 year rotational schedule in the future and trend stations will be monitored continuously. VADEQ and VADCR will continue to use data from the monitoring station on Great Run to evaluate reductions in bacteria counts and the effectiveness of the TMDL in attainment of water quality standards. Watershed sampling includes field parameters (temperature, pH, dissolved oxygen, conductivity), bacteria, nutrients and solids. Future bacteria sampling will consist of *E. coli* sampling only, since the interim fecal coliform bacteria will be phased out after twelve *E. coli* samples have been collected.

8.4.2. Regulatory Framework

While section 303(d) of the Clean Water Act and current EPA regulations do not require the development of TMDL implementation plans as part of the TMDL process, they do require reasonable assurance that the load and wasteload allocations can and will be implemented. Additionally, Virginia's 1997 Water Quality Monitoring, Information and Restoration Act (the "Act") directs the State Water Control Board to "develop and implement a plan to achieve fully supporting status for impaired waters" (Section 62.1-44.19.7). The Act also establishes that the implementation plan shall include the date of expected achievement of water quality objectives, measurable goals, corrective actions necessary and the associated costs, benefits and environmental impacts of addressing the impairments. EPA outlines the minimum elements of an approvable implementation plan in its 1999 "Guidance for Water Quality-Based Decisions: The TMDL Process." The listed elements include implementation actions/management measures, timelines, legal or regulatory controls, time required to attain water quality standards, monitoring plans and milestones for attaining water quality standards.

Watershed stakeholders will have opportunities to provide input and to participate in the development of the implementation plan, which will also be supported by regional and local offices of DEQ, DCR, and other cooperating agencies.

Once developed, DEQ intends to incorporate the TMDL implementation plan into the appropriate Water Quality Management Plan (WQMP), in accordance with the Clean Water Act's Section 303(e). In response to a Memorandum of Understanding (MOU) between EPA and DEQ, DEQ also submitted a draft Continuous Planning Process to EPA in which DEQ commits to regularly updating the WQMPs. Thus, the WQMPs will be, among other things, the repository for all TMDLs and TMDL implementation plans developed within a river basin.

8.4.3. Implementation Funding Sources

A key factor in implementing TMDLs is funding. One potential source of funding for TMDL implementation is Section 319 of the Clean Water Act. Section 319 funding is a major source of funds for

Virginia’s Nonpoint Source Management Program. Watershed restoration activities, such as TMDL implementation, are eligible for Section 319 funding. Other funding sources for implementation include the U.S. Department of Agriculture’s Conservation Reserve Enhancement Program (CREP) and Environmental Quality Incentive Programs (EQIP), the Virginia State Revolving Loan Program, and the VA Water Quality Improvement Fund (WQIP). The TMDL Implementation Plan Guidance Manual contains additional information on funding sources, as well as government agencies that might support implementation efforts and suggestions for integrating TMDL implementation with other watershed planning efforts.

8.4.4. Wildlife Contributions and Water Quality Standards

In some streams for which TMDLs have been developed, water quality modeling indicates that even after removal of all bacteria sources (other than wildlife), the stream will not attain standards under all flow regimes at all times. Virginia and EPA are not proposing the elimination of wildlife to allow for the attainment of water quality standards. While managing overpopulations of wildlife remains as an option to local stakeholders, the reduction of wildlife or changing a natural background condition is not the intended goal of a TMDL.

To address this issue, Virginia has proposed (during its recent triennial water quality standards review) a new “secondary contact” category for protecting the recreational use in state waters. On March 25, 2003, the Virginia State Water Control Board adopted criteria for “secondary contact recreation” which means “a water-based form of recreation, the practice of which has a low probability for total body immersion or ingestion of waters (examples include but are not limited to wading, boating and fishing)”. These new criteria will become effective pending EPA approval and can be found at http://www.deq.state.va.us/wqs/rule.html.

In order for the new criteria to apply to a specific stream segment, the primary contact recreational use must be removed. To remove a designated use, the state must demonstrate 1) that the use is not an existing use, 2) that downstream uses are protected, and 3) that the source of bacterial contamination is natural and uncontrollable by effluent limitations and by implementing cost-effective and reasonable best management practices for nonpoint source control (9 VAC 25-260-10). This and other information is collected through a special study called a Use Attainability Analysis (UAA). All site-specific criteria or designated use changes must be adopted as amendments to the water quality standards regulations. Watershed stakeholders and EPA will be able to provide comment during this process. Additional information can be obtained at http://www.deq.state.va.us/wqs/WQS03AUG.pdf

Based on the above, EPA and Virginia have developed a process to address the wildlife issue. First in this process is the development of a stage 1 scenario such as those presented previously in this chapter. The pollutant reductions in the stage 1 scenario are targeted only at the controllable, anthropogenic bacteria sources identified in the TMDL, setting aside control strategies for wildlife except for cases of overpopulations. During the implementation of the stage 1 scenario, all controllable sources would be reduced to the maximum extent practicable using the iterative approach described in Section 8.1 above. DEQ will re-assess water quality in the stream during and subsequent to the implementation of the stage 1 scenario to determine if the water quality standard is attained. This effort will also evaluate if the modeling assumptions were correct. If water quality standards are not being met, a UAA may be initiated to reflect the presence of naturally high bacteria levels due to uncontrollable sources. In some cases, the effort may never have to go to the UAA phase because the water quality standard exceedances attributed to wildlife in the model may have been very small and infrequent and within the margin of error.

9. Public Participation

Public participation in the Great Run TMDL process plays a vital role in developing a TMDL that is accurate, reflecting actual conditions in the watershed, and can be supported by local stakeholders through implementation measures to achieve improvements in water quality. A first public meeting was held in Marshall, Virginia on January 28, 2004 to discuss the process for TMDL development and the source assessment input. Five people attended. Copies of the presentation materials were available at the meeting and on the DEQ website. The meeting was public noticed in the Virginia Register and an announcement was included in the community calendars of the Fauquier Times Democrat newspaper. There was a 30 day-public comment period following the first public meeting during which no written comments were received.

A second and final public meeting was held in Warrenton, Virginia on November 16, 2004, to present the draft TMDL report. Twenty-one people attended. Copies of the presentation materials and draft report were available at the meeting and on the DEQ website. The meeting was public noticed in the Virginia Register and an announcement was included in the community calendars of the Fauquier Times Democrat and The Times Citizen newspapers. Flyers announcing the meeting were sent to all members on the technical advisory committee for distribution, and a mailing was sent from the John Marshall Soil and Water Conservation District announcing the meeting. There was a 30 day-public comment period following the final public meeting during which no written comments were received.

A Technical Advisory Committee (TAC) was also established and met on January 20, 2004 and October 21, 2004. The TAC included representatives of several branches of Fauquier County Government, the John Marshall Soil and Water Conservation District, the Department of Conservation and Recreation, the Rappahannock/Rapidan Health District of the Virginia Department of Health, the local agricultural extension agent, and the Piedmont Environmental Council.

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Appendix A

Glossary

GLOSSARY

Note: All entries in italics are taken from USEPA (1998). All non-italicized entries are taken from MapTech (2002).

303(d). A section of the Clean Water Act of 1972 requiring states to identify and list water bodies that do not meet the states' water quality standards.

Allocations. *That portion of a receiving water's loading capacity attributed to one of its existing or future pollution sources (nonpoint or point) or to natural background sources. (A wasteload allocation [WLA] is that portion of the loading capacity allocated to an existing or future point source, and a load allocation [LA] is that portion allocated to an existing or future nonpoint source or to natural background levels. Load allocations are best estimates of the loading, which can range from reasonably accurate estimates to gross allotments, depending on the availability of data and appropriate techniques for predicting loading.)*

Ambient water quality. *Natural concentration of water quality constituents prior to mixing of either point or nonpoint source load of contaminants. Reference ambient concentration is used to indicate the concentration of a chemical that will not cause adverse impact on human health.*

Anthropogenic. *Pertains to the [environmental] influence of human activities.*

Antidegradation Policies. *Policies that are part of each states water quality standards. These policies are designed to protect water quality and provide a method of assessing activities that might affect the integrity of waterbodies.*

Background levels. *Levels representing the chemical, physical, and biological conditions that would result from natural geomorphological processes such as weathering or dissolution.*

Bacteria. *Single-celled microorganisms. Bacteria of the coliform group are considered the primary indicators of fecal contamination and are often used to assess water quality.*

Bacterial source tracking (BST). A collection of scientific methods used to track sources of fecal contamination.

Best management practices (BMPs). *Methods, measures, or practices determined to be reasonable and cost-effective means for a landowner to meet certain, generally nonpoint source, pollution control needs. BMPs include structural and nonstructural controls and operation and maintenance procedures.*

Biosolids. Biologically treated solids originating from municipal wastewater treatment plants.

Clean Water Act (CWA). *The Clean Water Act (formerly referred to as the Federal Water Pollution Control Act or Federal Water Pollution Control Act Amendments of*

1972), Public Law 92-500, as amended by Public Law 96-483 and Public Law 97-117, 33 U.S.C. 1251 et seq. The Clean Water Act (CWA) contains a number of provisions to restore and maintain the quality of the nation's water resources. One of these provisions is section 303(d), which establishes the TMDL program.

Concentration. *Amount of a substance or material in a given unit volume of solution; usually measured in milligrams per liter (mg/L) or parts per million (ppm).*

Concentration-based limit. *A limit based on the relative strength of a pollutant in a waste stream, usually expressed in milligrams per liter (mg/L).*

Confluence. The point at which a river and its tributary flow together.

Contamination. *The act of polluting or making impure; any indication of chemical, sediment, or biological impurities.*

Cost-share program. *A program that allocates project funds to pay a percentage of the cost of constructing or implementing a best management practice. The remainder of the costs is paid by the producer(s).*

Critical condition. *The critical condition can be thought of as the "worst case" scenario of environmental conditions in the waterbody in which the loading expressed in the TMDL for the pollutant of concern will continue to meet water quality standards. Critical conditions are the combination of environmental factors (e.g., flow, temperature, etc.) that results in attaining and maintaining the water quality criterion and has an acceptably low frequency of occurrence.*

Designated uses. *Those uses specified in water quality standards for each waterbody or segment whether or not they are being attained.*

Dilution. *The addition of some quantity of less-concentrated liquid (water) that results in a decrease in the original concentration.*

Direct runoff. *Water that flows over the ground surface or through the ground directly into streams, rivers, and lakes.*

Discharge. *Flow of surface water in a stream or canal, or the outflow of groundwater from a flowing artesian well, ditch, or spring. Can also apply to discharge of liquid effluent from a facility or to chemical emissions into the air through designated venting mechanisms.*

Discharge permits (under NPDES). *A permit issued by the U.S. EPA or a state regulatory agency that sets specific limits on the type and amount of pollutants that a municipality or industry can discharge to a receiving water; it also includes a compliance schedule for achieving those limits. The permit process was established under the National Pollutant Discharge Elimination System, under provisions of the Federal Clean Water Act.*

DNA. Deoxyribonucleic acid. The genetic material of cells and some viruses.

Domestic wastewater. *Also called sanitary wastewater, consists of wastewater discharged from residences and from commercial, institutional, and similar facilities.*

Drainage basin. *A part of a land area enclosed by a topographic divide from which direct surface runoff from precipitation normally drains by gravity into a receiving water. Also referred to as a watershed, river basin, or hydrologic unit.*

Effluent. *Municipal sewage or industrial liquid waste (untreated, partially treated, or completely treated) that flows out of a treatment plant, septic system, pipe, etc.*

Effluent limitation. *Restrictions established by a state or EPA on quantities, rates, and concentrations in pollutant discharges.*

Endpoint. *An endpoint (or indicator/target) is a characteristic of an ecosystem that may be affected by exposure to a stressor. Assessment endpoints and measurement endpoints are two distinct types of endpoints commonly used by resource managers. An assessment endpoint is the formal expression of a valued environmental characteristic and should have societal relevance (an indicator). A measurement endpoint is the expression of an observed or measured response to a stress or disturbance. It is a measurable environmental characteristic that is related to the valued environmental characteristic chosen as the assessment endpoint. The numeric criteria that are part of traditional water quality standards are good examples of measurement endpoints (targets).*

Existing use. *Use actually attained in the waterbody on or after November 28, 1975, whether or not it is included in the water quality standards (40 CFR 131.3).*

Fecal Coliform. Indicator organisms (organisms indicating presence of pathogens) associated with the digestive tract.

Feedlot. *A confined area for the controlled feeding of animals. Tends to concentrate large amounts of animal waste that cannot be absorbed by the soil and, hence, may be carried to nearby streams or lakes by rainfall runoff.*

Geometric mean. A measure of the central tendency of a data set that minimizes the effects of extreme values.

GIS. Geographic Information System. A system of hardware, software, data, people, organizations and institutional arrangements for collecting, storing, analyzing and disseminating information about areas of the earth. (Dueker and Kjerne, 1989)

Ground water. *The supply of fresh water found beneath the earths surface, usually in aquifers, which supply wells and springs. Because ground water is a major source of drinking water, there is growing concern over contamination from leaching agricultural or industrial pollutants and leaking underground storage tanks.*

Hydrograph. *A graph showing variation of stage (depth) or discharge in a stream over a* *period of time.*

Hydrologic cycle. *The circuit of water movement from the atmosphere to the earth and its return to the atmosphere through various stages or processes, such as precipitation, interception, runoff, infiltration, storage, evaporation, and transpiration.*

Hydrology. *The study of the distribution, properties, and effects of water on the earth's surface, in the soil and underlying rocks, and in the atmosphere.*

Indicator. *A measurable quantity that can be used to evaluate the relationship between pollutant sources and their impact on water quality.*

Indicator organism. *An organism used to indicate the potential presence of other (usually pathogenic) organisms. Indicator organisms are usually associated with the other organisms, but are usually more easily sampled and measured.*

In situ. *In place; in situ measurements consist of measurements of components or processes in a full-scale system or a field, rather than in a laboratory.*

Isolate. An inbreeding biological population that is isolated from similar populations by physical or other means.

Limits (upper and lower). The lower limit equals the lower quartile – 1.5x(upper quartile – lower quartile), and the upper limit equals the upper quartile + 1.5x(upper quartile – lower quartile). Values outside these limits are referred to as outliers.

Loading, Load, Loading rate. *The total amount of material (pollutants) entering the system from one or multiple sources; measured as a rate in weight per unit time.*

Load allocation (LA). *The portion of a receiving waters loading capacity attributed either to one of its existing or future nonpoint sources of pollution or to natural background sources. Load allocations are best estimates of the loading, which can range from reasonably accurate estimates to gross allotments, depending on the availability of data and appropriate techniques for predicting the loading. Wherever possible, natural and nonpoint source loads should be distinguished (40 CFR 130.2(g)).*

Loading capacity (LC). *The greatest amount of loading a water can receive without violating water quality standards.*

Margin of safety (MOS). *A required component of the TMDL that accounts for the uncertainty about the relationship between the pollutant loads and the quality of the receiving waterbody (CWA section 303(d)(1)(C)). The MOS is normally incorporated into the conservative assumptions used to develop TMDLs (generally within the calculations or models) and approved by EPA either individually or in state/EPA agreements. If the MOS needs to be larger than that which is allowed through the conservative assumptions, additional MOS can be added as a separate component of the TMDL (in this case, quantitatively, a TMDL = LC = WLA + LA + MOS).*

Mathematical model. *A system of mathematical expressions that describe the spatial and temporal distribution of water quality constituents resulting from fluid transport and the one or more individual processes and interactions within some prototype aquatic ecosystem. A mathematical water quality model is used as the basis for waste load allocation evaluations.*

Mean. The sum of the values in a data set divided by the number of values in the data set.
MGD. Million gallons per day. A unit of water flow, whether discharge or withdraw.

Monitoring. *Periodic or continuous surveillance or testing to determine the level of compliance with statutory requirements and/or pollutant levels in various media or in humans, plants, and animals.*

Narrative criteria. *Nonquantitative guidelines that describe the desired water quality goals.*

National Pollutant Discharge Elimination System (NPDES). *The national program for issuing, modifying, revoking and re-issuing, terminating, monitoring, and enforcing permits, and imposing and enforcing pretreatment requirements, under sections 307, 402, 318, and 405 of the Clean Water Act.*

Natural waters. *Flowing water within a physical system that has developed without human intervention, in which natural processes continue to take place.*

Non-point source. *Pollution that originates from multiple sources over a relatively large area. Nonpoint sources can be divided into source activities related to either land or water use including failing septic tanks, improper animal-keeping practices, forest practices, and urban and rural runoff.*

Numeric targets. *A measurable value determined for the pollutant of concern, which, if achieved, is expected to result in the attainment of water quality standards in the listed waterbody.*

Organic matter. *The organic fraction that includes plant and animal residue at various stages of decomposition, cells and tissues of soil organisms, and substances synthesized by the soil population. Commonly determined as the amount of organic material contained in a soil or water sample.*

Peak runoff. *The highest value of the stage or discharge attained by a flood or storm event; also referred to as flood peak or peak discharge.*

Permit. *An authorization, license, or equivalent control document issued by EPA or an approved federal, state, or local agency to implement the requirements of an environmental regulation; e.g., a permit to operate a wastewater treatment plant or to operate a facility that may generate harmful emissions.*

Phased approach. *Under the phased approach to TMDL development, load allocations and wasteload allocations are calculated using the best available data and information* *recognizing the need for additional monitoring data to accurately characterize sources and loadings. The phased approach is typically employed when nonpoint sources dominate. It provides for the implementation of load reduction strategies while collecting additional data.*

Point source. *Pollutant loads discharged at a specific location from pipes, outfalls, and conveyance channels from either municipal wastewater treatment plants or industrial waste treatment facilities. Point sources can also include pollutant loads contributed by tributaries to the main receiving water stream or river.*

Pollutant. *Dredged spoil, solid waste, incinerator residue, sewage, garbage, sewage sludge, munitions, chemical wastes, biological materials, radioactive materials, heat, wrecked or discarded equipment, rock, sand, cellar dirt, and industrial, municipal, and agricultural waste discharged into water. (CWA section 502(6)).*

Pollution. *Generally, the presence of matter or energy whose nature, location, or quantity produces undesired environmental effects. Under the Clean Water Act, for example, the term is defined as the man-made or man-induced alteration of the physical, biological, chemical, and radiological integrity of water.*

Privately owned treatment works. *Any device or system that is (a) used to treat wastes from any facility whose operator is not the operator of the treatment works and (b) not a publicly owned treatment works.*

Public comment period. *The time allowed for the public to express its views and concerns regarding action by EPA or states (e.g., a Federal Register notice of a proposed rule-making, a public notice of a draft permit, or a Notice of Intent to Deny).*

Publicly owned treatment works (POTW). *Any device or system used in the treatment (including recycling and reclamation) of municipal sewage or industrial wastes of a liquid nature that is owned by a state or municipality. This definition includes sewers, pipes, or other conveyances only if they convey wastewater to a POTW providing treatment.*

Raw sewage. *Untreated municipal sewage.*

Receiving waters. *Creeks, streams, rivers, lakes, estuaries, ground-water formations, or other bodies of water into which surface water and/or treated or untreated waste are discharged, either naturally or in man-made systems.*

Restoration. *Return of an ecosystem to a close approximation of its presumed condition prior to disturbance.*

Riparian areas. *Areas bordering streams, lakes, rivers, and other watercourses. These areas have high water tables and support plants that require saturated soils during all or part of the year. Riparian areas include both wetland and upland zones.*

Riparian zone. *The border or banks of a stream. Although this term is sometimes used interchangeably with floodplain, the riparian zone is generally regarded as relatively narrow compared to a floodplain. The duration of flooding is generally much shorter, and the timing less predictable, in a riparian zone than in a river floodplain.*

Runoff. *That part of precipitation, snowmelt, or irrigation water that runs off the land into streams or other surface water. It can carry pollutants from the air and land into receiving waters.*

Septic system. *An on-site system designed to treat and dispose of domestic sewage. A typical septic system consists of a tank that receives waste from a residence or business and a drain field or subsurface absorption system consisting of a series of percolation lines for the disposal of the liquid effluent. Solids (sludge) that remain after decomposition by bacteria in the tank must be pumped out periodically.*

Sewer. *A channel or conduit that carries wastewater and storm water runoff from the source to a treatment plant or receiving stream. Sanitary sewers carry household, industrial, and commercial waste. Storm sewers carry runoff from rain or snow. Combined sewers handle both.*

Slope. *The degree of inclination to the horizontal. Usually expressed as a ratio, such as 1:25 or 1 on 25, indicating one unit vertical rise in 25 units of horizontal distance, or in a decimal fraction (0.04), degrees (2 degrees 18 minutes), or percent (4 percent).*

Stakeholder. Any person with a vested interest in the TMDL development.

Standard. In reference to water quality (e.g. 200 cfu/100 ml geometric mean limit).

Storm runoff. *Storm water runoff, snowmelt runoff, and surface runoff and drainage; rainfall that does not evaporate or infiltrate the ground because of impervious land surfaces or a soil infiltration rate lower than rainfall intensity, but instead flows onto adjacent land or into waterbodies or is routed into a drain or sewer system.*

Streamflow. *Discharge that occurs in a natural channel. Although the term "discharge" can be applied to the flow of a canal, the word "streamflow" uniquely describes the discharge in a surface stream course. The term "streamflow" is more general than "runoff" since streamflow may be applied to discharge whether or not it is affected by diversion or regulation.*

Stream restoration. *Various techniques used to replicate the hydrological, morphological, and ecological features that have been lost in a stream because of urbanization, farming, or other disturbance.*

Surface area. *The area of the surface of a waterbody; best measured by planimetry or the use of a geographic information system.*

Surface runoff. *Precipitation, snowmelt, or irrigation water in excess of what can infiltrate the soil surface and be stored in small surface depressions; a major transporter* *of nonpoint source pollutants.*

Surface water. *All water naturally open to the atmosphere (rivers, lakes, reservoirs, ponds, streams, impoundments, seas, estuaries, etc.) and all springs, wells, or other collectors directly influenced by surface water.*

Topography. *The physical features of a geographic surface area including relative elevations and the positions of natural and man-made features.*

Total Maximum Daily Load (TMDL). *The sum of the individual wasteload allocations (WLAs) for point sources, load allocations (LAs) for nonpoint sources and natural background, plus a margin of safety (MOS). TMDLs can be expressed in terms of mass per time, toxicity, or other appropriate measures that relate to a state's water quality standard.*

Transport of pollutants (in water). *Transport of pollutants in water involves two main processes: (1) advection, resulting from the flow of water, and (2) dispersion, or transport due to turbulence in the water.*

Tributary. *A lower order-stream compared to a receiving waterbody. "Tributary to" indicates the largest stream into which the reported stream or tributary flows.*

Variance. A measure of the variability of a data set. The sum of the squared deviations (observation – mean) divided by (number of observations) – 1.

DACS. Department of Agriculture and Consumer Services.

DCR. Department of Conservation and Recreation.

DEQ. Virginia Department of Environmental Quality.

VDH. Virginia Department of Health.

Wasteload allocation (WLA). *The portion of a receiving waters' loading capacity that is allocated to one of its existing or future point sources of pollution. WLAs constitute a type of water quality-based effluent limitation (40 CFR 130.2(h)).*

Wastewater. *Usually refers to effluent from a sewage treatment plant. See also* ***Domestic wastewater****.*

Wastewater treatment. *Chemical, biological, and mechanical procedures applied to an industrial or municipal discharge or to any other sources of contaminated water to remove, reduce, or neutralize contaminants.*

Water quality. *The biological, chemical, and physical conditions of a waterbody. It is a measure of a waterbody's ability to support beneficial uses.*

Water quality criteria. *Levels of water quality expected to render a body of water* *suitable for its designated use, composed of numeric and narrative criteria. Numeric criteria are scientifically derived ambient concentrations developed by EPA or states for various pollutants of concern to protect human health and aquatic life. Narrative criteria are statements that describe the desired water quality goal. Criteria are based on specific levels of pollutants that would make the water harmful if used for drinking, swimming, farming, fish production, or industrial processes.*

Water quality standard. *Law or regulation that consists of the beneficial designated use or uses of a waterbody, the numeric and narrative water quality criteria that are necessary to protect the use or uses of that particular waterbody, and an antidegradation statement.*

Watershed. *A drainage area or basin in which all land and water areas drain or flow toward a central collector such as a stream, river, or lake at a lower elevation.*

WQIA. Water Quality Improvement Act.

Appendix B

Antibiotic Resistance Analysis
(MapTech)

When performing ARA, isolates (colonies picked from membrane filtration plates) of *E. coli* or *Enterococcus* are transferred to a 96-well tissue culture plate (one isolate per well) containing a selective liquid medium. The 96-well plates are incubated and confirmed as *E. coli* or *Enterococcus* by color changes in the liquid after incubation (Figure 1). Antibiotic stock solutions are prepared and each of twenty-eight or more antibiotic/concentrations is added separately to flasks of autoclaved and cooled Trypticase Soy Agar (TSA) from the stock solutions to achieve the desired concentration, and then poured into sterile 15x100mm petri dishes.

Figure 1. 96-well plate after incubation.

Control plates (no antibiotics) are included with each set. Isolates are transferred from the 96-well plate using a stainless steel 48-prong replica plater (Sigma). The replicator is flame-sterilized (95% ethanol) after inoculation of each TSA plate. Resistance to an antibiotic is determined by comparing each isolate to the growth of that isolate on the control plate. A one (1) is recorded for growth and a zero (0) is recorded for no growth (Figure 2). This is repeated for each isolate on each of the 30 antibiotic plates to develop a profile.

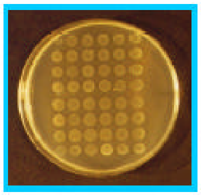

Figure 2. TSA control plate (with no antibiotics) showing growth of all 48 isolates.

The profile is then compared against the known source library to determine the source of the isolate (see data analysis section). The basic process is the same for all approaches, that is, a data base of known sources analyzed using the BST method of choice must be developed and samples of unknown bacterial origin are collected, analyzed and compared to the known source database. For studies, such as Total Maximum Daily Loads (TMDL), we recommend the ARA procedure due to typical cost constraints. Typically we analyze 24 isolates per unknown source (e.g. stream or well water) sample. This provides measurements of the proportion of a given source that are in increments of approximately 4%. If more precision is required, 48 isolates can be analyzed, resulting in resolution of approximately 2%. If the sampling is to be done in a geographical area where a database of known sources has not been developed, we will need to collect samples from known sources (i.e. human, livestock, wildlife) and compare them to our existing databases to determine if one of our existing databases is compatible with the study area. Twenty-four isolates from each of these samples will be analyzed. If no existing database is compatible, we will need to develop a database for the study area. The number of samples needed depend on variability of source samples. We have had a good deal of success in the past by using existing databases through obtaining known source samples from each group (i.e. human, livestock, wildlife) in the study area and comparing them to existing databases.

Appendix C

Calculations

Calculations

Allowable Load Calculation from Section 6.

TMDL cfu/yr = Q ft^3/s * 7.48 gal/ft^3 * 3.785 l/gal * 1000 ml/l * 235 cfu/100 ml * 60 s/min * 60 min/day * 24 hrs/day * 365 days/yr

Where:

TMDL cfu/yr = Allowable load in cfu/yr
235 cfu/100 ml = Instantaneous *E. coli* standard
Q ft^3/ s = Flow in cubic feet per second
cfu = *E. coli* colony forming units.
l = liters
ml = milliliters
s = seconds
min = minutes
yr = year
gal = gallons

Required Reduction Calculation from Section 7.

TMDL cfu/yr = LA cfu/yr + WLA cfu/yr + MOS (cfu/yr)

OL = LA cfu/yr + WLA cfu/yr

% reduction = [(OL - TMDL)/OL] * 100

Where:

TMDL = total maximum daily load
LA = load allocation
WLA = waste load allocation
MOS = margin of safety
OL = observed load (average annual load)

Appendix D

Flow Change and Precipitation Analysis

In the interest of better-targeted BMPs for the Great Run watershed, the correlation between water quality violations, stream flow changes and precipitation was investigated. The goal was to determine which violations might be related to runoff and which might be related to direct deposition.

As stated in Section 6.1 on flow data, there is no continuous stream gage in the Great Run watershed. To assess the link between flow changes and precipitation events recorded at the Warrenton, VA weather station (COOP ID 44888) located approximately 7 miles southeast of the Great Run watershed, were examined. Precipitation events on the day before and on the day of each violation were examined. Precipitation events on the day before the violation were examined to see if decreasing flows on violation days were the result of a precipitation event within the preceding 24 hours.

Results of the study are presented in tabular format below.

Water Quality Standard Violations, Stream Flow Change, and Precipitation in Great Run

Sampling Date	Fecal Coliform (cfu/100 mL)	Translated *E. coli* Value (cfu/100 mL)	Duration Interval	*E. coli* Load (cfu/yr)	Change in Flow From Prior Day (cfs)	Same Day Rain (inches)	Prior Day Rain (inches)
11/29/88	700	407	67	3.00E+13	0.92	#N/A	#N/A
1/30/89	900	513	81	2.60E+13	-0.07	0.03	0.00
8/29/91	790	455	97	7.59E+12	0.04	0.00	0.00
5/19/93	6,800	3,289	15	6.27E+14	5.41	0.61	0.00
12/13/93	640	375	40	4.56E+13	-1.10	0.00	0.00
8/18/94	8,000	3,819	0	3.43E+15	62.97	3.17	1.80
6/12/95	6,200	3,021	17	5.44E+14	11.70	1.12	0.20
3/19/96	1100	617	27	9.23E+13	1.38	0.00	0.00
5/22/96	400	243	26	3.68E+13	0.77	0.44	0.00
3/31/97	8,000	3,819	15	7.28E+14	3.25	0.67	0.04
1/8/98	2,700	1,407	2	5.16E+14	25.91	0.57	0.19
3/30/98	500	299	13	5.90E+13	-1.04	0.00	0.00
3/22/99	600	353	17	6.43E+13	4.04	0.00	0.41
4/25/00	500	299	23	4.76E+13	0.92	0.52	0.00
2/13/01	400	243	63	1.97E+13	-0.04	0.06	0.00
8/13/02	125	280	99	2.79E+12	-0.11	0.00	0.00
11/14/02	380	450	26	6.80E+13	-5.51	0.00	0.54
5/20/03	650	410	5	1.16E+14	-10.72	0.00	0.14
11/6/03	4400	1350	14	2.63E+14	7.01	0.70	0.00

🟦 Positive flow change with same day or prior day precipitation event.

🟩 Negative or stable flow change with prior day precipitation event.

🟨 *E. Coli* Data (not transformed)

The results of the study suggest that 11 of the 19 violations with precipitation data (58%) could be related to runoff events.

Additional information regarding the nature of the violation can be gleaned from looking at the flow conditions under which the violations occur. Ten of the exceedances occurred during high or transitional flows, including the violation requiring the highest load reduction. Six exceedances occurred during normal flows. Three exceedances occurred in the range of low flows.

Appendix E

(TMDL scenario with WLA increased by a factor of 5)

The following tables represent a TMDL scenario where the WLA has been increased by a factor of five. This scenario was presented to the public and is intended to be appended to the originally submitted TMDL report. Because the discharge currently represents 15% of the TMDL, any expandion of the WLA will increase nonpoint source reductions needed to meet water quality standards. The expanded WLA would represent 77% of the entire TMDL. Any expansion of existing or addition of new sources should be studied carefully prior to approval.

Table E-1. Average annual *E. coli* loads and TMDL for Great Run watershed (cfu/yr)

WLA *	LA	MOS	TMDL
2.18×10^{13}	6.59×10^{12}	(implicit)	2.83×10^{13}

* The point sources permitted to discharge in the Great Run watershed are presented in section 5.2. The WLA presented here is five times the existing WLA.

Table E-2. TMDL and required reduction for Great Run

Load Category (annual average)	Allowable Loads (cfu/yr)	Average Annual EC Load (cfu/yr)	Required Reduction
Waste Load Allocation (WLA)	2.18×10^{13}	2.18×10^{13}	0%
Load Allocation (LA)	6.59×10^{12}	4.39×10^{14}	98%
MOS	0 (implicit)		
TMDL	2.83×10^{13}	4.61×10^{14}	94%

Table E-3. Average annual load distribution, reduction, and allowable load by source

	Total (cfu/yr)	Human: 4% (cfu/yr)	Pet: 30% (cfu/yr)	Livestock: 32% (cfu/yr)	Wildlife: 33% (cfu/yr)
Average Annual Load	4.39×10^{14}	1.94×10^{13}	1.31×10^{14}	1.42×10^{14}	1.47×10^{14}
Reduction	98%	98%	98%	98%	98%
Allowable Annual Load	6.59×10^{12}	2.91×10^{11}	1.96×10^{12}	2.13×10^{12}	2.20×10^{12}