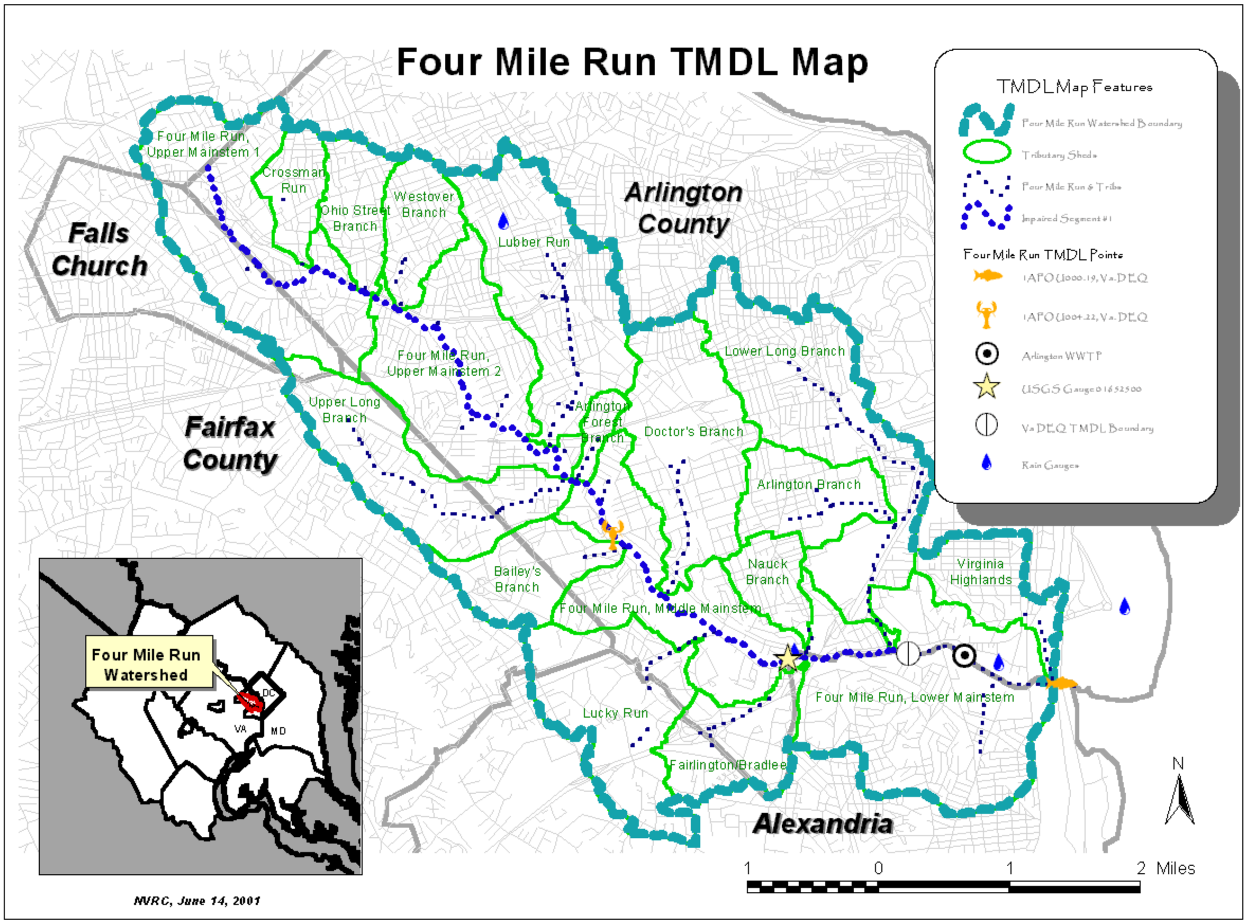
Fecal Coliform TMDL (Total Maximum Daily Load) Development for Four Mile Run, Virginia



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First Submission: March 21, 2002

Revised: April 25, 2002

Accepted: May 31, 2002

The Northern Virginia Regional Commission (NVRC) developed this TMDL for the Commonwealth of Virginia. NVRC's project manager and primary author of this report is Don Waye, who was assisted by Judy Buchino. This TMDL has been strengthened by contributions from numerous sources, many of which are cited in the acknowledgements below and in the reference section.

ACKNOWLEDGEMENTS

Jutta Schneider, Virginia Department of Environmental Quality (VADEQ)
David Lazarus, VADEQ
Katherine Bennett, VADEQ
William Keeling, Virginia Department of Conservation and Recreation (VADCR)
Dr. George Simmons, Virginia Tech
Dr. Adil Godrej, Virginia Tech
Jason Papacosma, Arlington County Department of Environmental Services (DES)
Jeff Harn, Arlington County DES
Greg Zell, Arlington County Parks, Recreation and Community Resources (DPRCR)
Scott Deibler, Arlington County DPRCR
Bill Hicks, City of Alexandria Transportation and Environmental Services
Fred Rose, Fairfax County Department of Public Works and Environmental Services (DPWES)
Dipmani Kumar, Fairfax County DPWES
Matt Meyers, Fairfax County DPWES
Moe Wadda, Falls Church Department of Public Works
Helen Reinecke-Wilt, Falls Church Department of Planning
Timothy J. Murphy, Metropolitan Washington Council of Governments

Funding for this study was generously provided by the Virginia Department of Environmental Quality through federal CWA 604(b) funds administered by the Environmental Protection Agency.

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1. Introduction

1.1 Background

Section 303(d) of the Federal Clean Water Act and the United States Environmental Protection Agency's (USEPA) Water Quality Planning and Management Regulations (40 CFR Part 130), requires states to identify water bodies that are in violation of the water quality standards for any given pollutant. Under this rule, states are also required to develop a Total Maximum Daily Load (TMDL) for the impaired water body. A TMDL determines the maximum amount of pollutant that a water body is capable of receiving while continuing to meet the existing water quality standards. TMDLs provide the framework that allows states to establish water quality controls to reduce sources of pollution with the ultimate goal of water quality restoration and the maintenance of water resources.

The Virginia Department of Environmental Quality (VADEQ) listed the Four Mile Run watershed on the Commonwealth's 1998 303(d) TMDL Priority List of Impaired Waters (VADEQ, 1998). Four Mile Run is a direct tributary of the Potomac River and is located in Virginia River Segment VAN-A12R, which is a portion of the Shenandoah-Potomac River Basin that drains into the Chesapeake Bay.

1.1.1 Study Area Description

Four Mile Run is an urban stream that spans most of Arlington County and parts of three other localities: Fairfax County, the City of Alexandria, and the City of Falls Church. The stream flows from west to east, with a slight southerly tilt. This TMDL addresses a fecal coliform bacteria impairment identified by VADEQ that begins at the headwaters of Four Mile Run just over nine miles upstream of its confluence with the Potomac River to the tidal/non-tidal boundary approximately 1.5 miles upstream from the Potomac. Figure 1.1 shows the location of the Four Mile Run watershed. While the entire watershed is 19.7 square miles, the nontidal portion of the watershed covered in this TMDL is 17.0 square miles.

There is no agricultural runoff in the watershed, which is home to 183,000 people, or just over 9,000 per square mile (NVRC staff analysis of 2000 U.S. Census data). The dominant land use in the watershed is medium to high density residential housing. Within this 19.7 square mile (12,600 acre) watershed are no less than seven central business districts (CBDs), including Ballston, Seven Corners, Baileys Crossroads, Skyline, Shirlington, Crystal City, and East Falls Church. Not surprisingly, Four Mile Run has a higher daytime population during the workweek than its 183,000 permanent residents. Two interstate highways, I-66 and I-395, pass through the watershed as well as numerous primary and secondary roadways. The watershed is approximately 40% impervious. Aside from a crowded human populous, there is a large pet population in the watershed. In addition to these two sources, the 1998-2001 study of bacteria sources in Four Mile Run by the Northern Virginia Regional Commission (NVRC) and Virginia Tech illustrate the influence of waterfowl (Canada Geese and mallards, in particular) and raccoons as sources of E. coli. Figure 1-2 provides a summary pie chart of this study's findings. Because of its central relevance to this TMDL, the report is attached in its entirety as Appendix A.

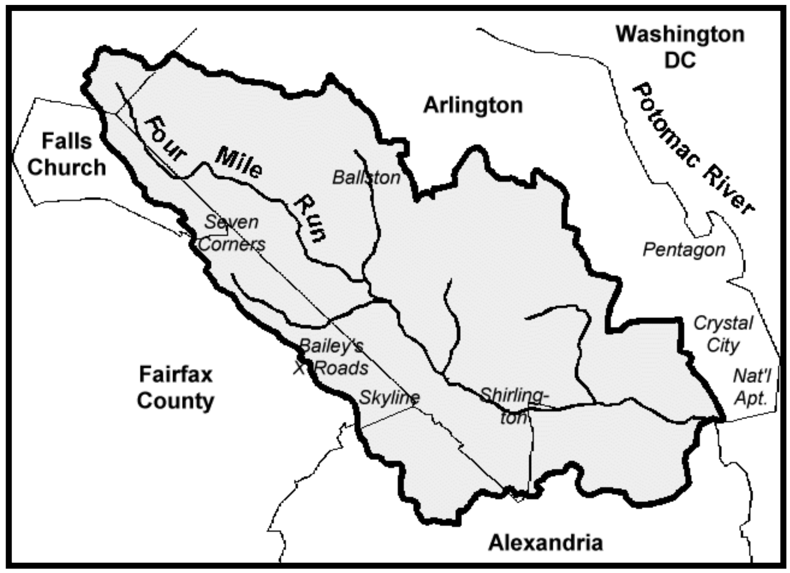


Figure 1-1. The Four Mile Run Watershed in Northern Virginia

In recent years, five groups have performed fecal coliform monitoring of Four Mile Run—VADEQ, NVRC, the Fairfax County Health Department, the Arlington County Parks Division, and the Arlington Chapter of the League of Women Voters. All have found elevated levels of fecal coliform bacteria in the Four Mile Run watershed. Since 1990, over 700 fecal coliform samples have been taken from Four Mile Run and its tributaries. Nearly half of these samples have been determined to be over the 1,000 most probable number (MPN) Virginia water quality standard for fecal coliform bacteria.

Importantly, there is little manufacturing industry to generate point source discharges. While there are two regulated point source discharges in the watershed, one is a small concrete

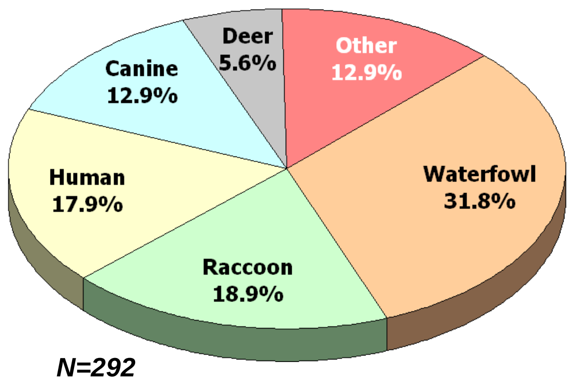


Figure 1-2. Isolate matches from NVRC's BST investigation in Four Mile Run with Virginia Tech, 1998 - 2001

batch plant with a pH discharge regulation only and the other is Arlington's modern sewage treatment plant (STP), which provides tertiary treatment and easily complies with its 200 colony forming units (cfu) per 100 milliliters (mL) permit limit for fecal coliform bacteria (NVRC analysis of Arlington ST daily discharge monitoring records, 1998 – 2001). This plant discharges in the tidal portion of Four Mile Run near the Potomac River, and is thus outside the study area of this TMDL.

There are no combined sewers in the vast majority of the watershed. While a small portion of the watershed in Alexandria is served by sewers that combine sanitary sewage with stormwater, there are no combined sewer outfalls in the watershed—only a single pumping station that seldom surcharges (estimated at a 10 year recurrence interval). This pumping station is downstream of the nontidal impaired segment of the watershed. Sanitary sewer serves more than 99.9% of the watershed's population, and the number of septic systems in the watershed is believed to be less than 50.

In the summers of 1999, 2000, and 2001, NVRC performed optical brightener monitoring (OBM) on each of the 297 outfalls in the watershed, many of which were monitored more than once. OBM is a technique that has been used in rural watersheds and the caves of the Ozarks to successfully trace human sewage to its source. The Four Mile Run watershed is the first urban application of this technique, and it has proven to be successful here, as well. (See www.novaregion.org/4MileRun/obm.html for more information.) The results revealed two isolated problems of moderate severity, which were corrected quickly, and eight outfalls with possible low-level contamination of human sewage for which investigations are ongoing.

While conducting monitoring for its municipal separate storm sewer system (MS4) permit in 1998, Arlington County staff discovered an illegal cross-connection from a condominium complex in Fairfax County that discharged to a stream in Arlington, and a repair was quickly made. Fieldwork for OBM and MS4 monitoring has also revealed intermittent problems typical of heavily urbanized watersheds, such as improper dumping of wastes. While OBM monitoring is limited by its ability to detect only human sewage that contains laundry waste, its findings, along with visual and "sniff" observations at every outfall in the watershed reveal a stream with little obvious direct human sewage component.

1.2 Impaired Water Quality Status

VADEQ determined that Four Mile Run exceeded one of the existing instream fecal coliform water quality standards and identified the source of impairment as being urban nonpoint source runoff. Fecal coliform bacteria are the primary resident bacteria in the feces of all warm-blooded animals. Although it is not usually pathogenic, fecal coliform bacteria is commonly used as an indicator for potential health risks resulting from pathogenic organisms that are also known to reside in feces. The Four Mile Run watershed has been given a TMDL status of "medium priority" resulting from the Virginia Water Quality Assessment for 1996 and a high NPS ranking in VADEQ's 1998 305(b) report to Congress and EPA.

1.3 Applicable Water Quality Standard

According to Virginia Water Quality Standards (9 VAC 25-260-5),

> "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.)."

1.3.1 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)."

1.3.2 Applicable Water Quality Criteria

For a non-shellfish supporting waterbody to be in compliance with Virginia fecal coliform standards for contact recreational use, VADEQ specifies the following criteria (9 VAC 25-260-170):

> "…the 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 30-day period, or a fecal coliform bacteria level of 1,000 per 100 mL at any time."

If the waterbody exceeds either criterion more than 10% of the time, the waterbody is classified as impaired and a TMDL must be developed and implemented to bring the waterbody into compliance with the water quality criterion. Based on the sampling frequency, only one criterion is applied to a particular datum or data set (9 VAC 25-260-170). If the sampling frequency is one sample or less per 30 days, the instantaneous criterion is applied; for a higher sampling frequency, the geometric criterion is applied. The fecal coliform instream water quality data used in the development of the Four Mile Run TMDL consists of quarterly-to-bimonthly VADEQ samples, as well as samples taken by NVRC and Arlington County, for a total of 25 samples from January 1, 1999 to May 31, 2001 (the study period for this TMDL). Eleven of these 25 samples were collected by VADEQ.

However, since the computer simulation used to develop the TMDL provides daily fecal coliform concentrations (which is analogous to daily sample collection), the Four Mile Run fecal coliform TMDL is required to meet the 30-day geometric mean criterion. The TMDL development process also must account for seasonal and annual variations in precipitation, flow, land-use, and pollutant contributions. Such an approach ensures that TMDLs, when implemented, do not result in violations under a wide variety of scenarios that affect fecal coliform loading.

1.3.3 Water Quality Standards Review

Two regulatory actions related to the fecal coliform water quality standard are currently under way in Virginia. The first rulemaking pertains to the indicator species used to measure bacteria pollution. The second rulemaking is an evaluation of the designated uses as part of the state's triennial review of its water quality standards.

Indicator Species

EPA has recommended that all States adopt an E. coli or enterococci standard for fresh water and enterococci criteria for marine waters by 2003. EPA is pursuing the States' adoption of these standards because there is a stronger correlation between the concentration of these organisms (E. coli and enterococci) and the incidence of gastrointestinal illness than with fecal coliform. E. coli and enterococci are both bacteriological organisms that can be found in the intestinal tract of warm-blooded animals. Like fecal coliform bacteria, these organisms indicate the presence of fecal contamination. In Virginia, the adoption of the E. coli and enterococci standard is scheduled for 2002.

Designated Uses

All waters in the Commonwealth have been designated as "primary contact" for the swimming use regardless of size, depth, location, water quality or actual use. The fecal coliform bacteria standard as described in 9 VAC 25-260-170 and in Section 1.3.2 is to be met during all stream flow levels and was established to protect bathers from ingestion of potentially harmful bacteria. However, many headwater streams are small and shallow during base flow conditions when surface runoff has minimal influence on stream flow. Even in pools, these shallow streams do not allow full body immersion during periods of base flow. In larger streams, lack of public access often precludes the swimming use.

In the TMDL public participation process, the residents in these watersheds often report that "people do not swim in this stream." It is obvious that many streams within the state are not used for primary contact recreation.

Additionally, the VADEQ and VADCR have developed fecal coliform TMDLs for a number of impaired waters in the State. In some of the streams, fecal coliform bacteria counts contributed by wildlife result in standards violations, particularly during base flow conditions. Examples include TMDLs for Mountain Run (Yagow, 2001) and Holmans Creek (SAIC, 2001). Wildlife densities obtained from the Department of Game and Inland Fisheries and analysis or "typing" of the fecal coliform bacteria show that the high densities of muskrat, beaver, and waterfowl are responsible for the elevated fecal bacteria counts in these streams.

Recognizing that all waters in the Commonwealth are not used extensively for swimming, Virginia is considering re-designation of the swimming use for secondary contact in cases of: 1) natural contamination by wildlife, 2) small stream size and 3) lack of accessibility to children. The widespread socio-economic impacts resulting from the cost of improving a stream to a "swimmable" status are also being considered.

The re-designation of the current swimming use in a stream to a secondary use will require the completion of a Use Attainability Analysis (UAA). A UAA is a structured scientific assessment of the factors affecting the attainment of the use which may include physical, chemical, biological, and economic factors as described in the Federal Regulations. The stakeholders in the watershed, Virginia, and EPA will have an opportunity to comment on these special studies.

1.4 Goal and Objectives

The goal of the Four Mile Run TMDL is to allocate the sources of fecal coliform contamination and to incorporate practices that will reduce fecal coliform loads and allow Four Mile Run to meet Virginia state water quality standards. The following objectives must be completed in order to achieve this goal:

- ***Objective 1*—**Assess the water quality and identify the potential sources of fecal coliform
- ***Objective 2*—**Quantify current fecal coliform loads and estimate the magnitude of each source
- ***Objective 3*—**Model and predict the current fecal coliform loads being deposited from each source
- ***Objective 4*—**Develop allocation scenarios that will reduce fecal coliform loads
- ***Objective 5*—**Determine the most feasible reduction plan that can realistically be implemented and incorporate it into the TMDL.

2. Watershed Characterization

2.1 Climate

The Four Mile Run watershed straddles the Mid-Atlantic piedmont and coastal plain physiographic provinces approximately 50 miles east of the Blue Ridge Mountains, and 35 miles west of the Chesapeake Bay. Watershed elevations range from sea level to 425 feet above mean sea level. Four Mile Run is a tributary of the Potomac River, and enters the river on its western shore at the southern end of Ronald Reagan National Airport (formerly Washington National Airport). The primary sources for information presented throughout this section are documents and records from the National Weather Service (NWS).

Climate data for this area have been kept continuously since November 1870. Official observations have been recorded since June 1941 at Reagan National Airport. This airport is at the center of the urban heat island associated with the greater Washington, D.C. area. Consequently, low temperatures recorded at the airport are approximately 10 to 15 degrees higher than the surrounding suburban areas (NWS, 2002). The recorded high temperatures are not as greatly affected by the urban heat island effect, so there is less variation in high temperature readings between urban and suburban locations.

Winters are usually mild, with an average temperature in the mid 20's (ºF). Spring and fall are generally mild climates, with very pleasant weather. Summers can be hot and humid, with temperatures averaging about 80ºF. The average date of the last freeze in spring is April 1, and the average date for the first freeze in the fall is November 10.

Precipitation is generally evenly distributed throughout the year, with an annual rainfall of 39 inches per year. Snowfalls average 18 inches per year, with perhaps only one or two major snowfalls in a season. It is unusual to have a snowstorm of 10 inches or more within any one particular day. However, there have been rare occurrences of 25-inch snowstorms.

Late spring and summer afternoons can bring locally intense thunderstorms with occasionally significant local flooding. Late summer can bring tropical storms or hurricanes, with their accompanying heavy rains, high winds, and flooding. Winds of up to 100 mph and rainfall exceeding seven inches have occurred with these types of storms. The greater

Washington, DC metropolitan area is also subject to rare tornadoes and springtime hailstorms, both of which can result in significant damage.

Frost (1998) analyzed the historical rainfall record around Washington, D.C. over a 96-year period and identified four distinct types of precipitation events: trace, convective, frontal and cyclonic. An analysis of each rainfall event from 1972 through 1976 revealed that frontal systems accounted for 37% of the total number of storms and 39% of the total volume of precipitation over the five-year period. Trace events were the second-most common type of precipitation, accounting for 28% of the events, but only 3% of the volume. 25% of the events were generated by warm weather convective cell atmospheric disturbances, which accounted for 24% of the volume. Finally, cyclonic systems produced only 10% of the storm, but 34% of the volume.

2.2 Land Use

Land use is a predominant determining factor for source of fecal coliform deposition. For example, wildlife is more common in open space and parkland than highway corridors and high-density development. Likewise, pet populations are associated with residential lands more so than commercial or industrial areas.

Land use information was obtained from NVRC's own Northern Virginia regional land use GIS layer with a multi-jurisdictional 15-key land use classification. A sixteenth land use category was culled from this GIS layer by parsing major highways from the "Public Open Space" category they shared with open parkland. Other minor cleaning of this layer was performed to ensure the final accuracy of this important model input. It should be noted that two land uses in this regional GIS layer are absent from the watershed—open water and rural residential/agricultural. Thus, the model uses 14 land uses. The determination and distribution of watershed imperviousness is derived from this supplied land use information. Thus, attention to the quality of this land use information is a large reason the hydrology calibration, described later, has an exceptionally good fit. Specific land use locations are shown in Figure 2-1.

The nontidal portion of the Four Mile Run watershed is 10,874 acres, or 17.0 square miles. Table 2-1 shows the acreage of each existing land use in the impaired portion of the watershed and the average estimated impervious land use. Land use acreage is also broken down for each of the three segments delineated for the Four Mile Run TMDL computer model (presented in Chapter 4). Using Table 2-1 yields an overall imperviousness for the impaired portion of the watershed of 41.5%. This value is consistent with other estimates from watershed localities and NVRC's Four Mile Run SWMM Model, which place the watershed within the 35 to 45 percent impervious range.

Table 2-1. Land Use Classification by Model Segments in Acres

Land Use	*Impervious*	Seg1	Seg2	Seg3	*Total*
Open Space/Parks	*2%*	390	180	40	*610*
Highway	*90%*	213	126	130	*469*
Medium to High Density Mixed Use	*65%*	241	80	96	*417*
Medium to High Density Industrial	*80%*	24	110	20	*154*
Public/Conservation/Golf	*8%*	148	102	309	*559*
High Density Residential	*75%*	20	179	101	*300*
Medium Density Residential	*40%*	2,692	755	804	*4,251*
Medium to High Density Residential	*50%*	392	930	414	*1,736*
Medium to High Density Commercial	*70%*	86	69	100	*255*
Low to Medium Density Residential	*20%*	767	243	33	*1,043*
Low Density Commercial	*40%*	260	274	7	*541*
Low Density Industrial	*65%*	9	46	5	*60*
Low Density Mixed Use	*30%*	12	189	0	*201*
Federal	*50%*	0	100	178	*278*
Total		***5,254***	***3,383***	***2,237***	***10,874***

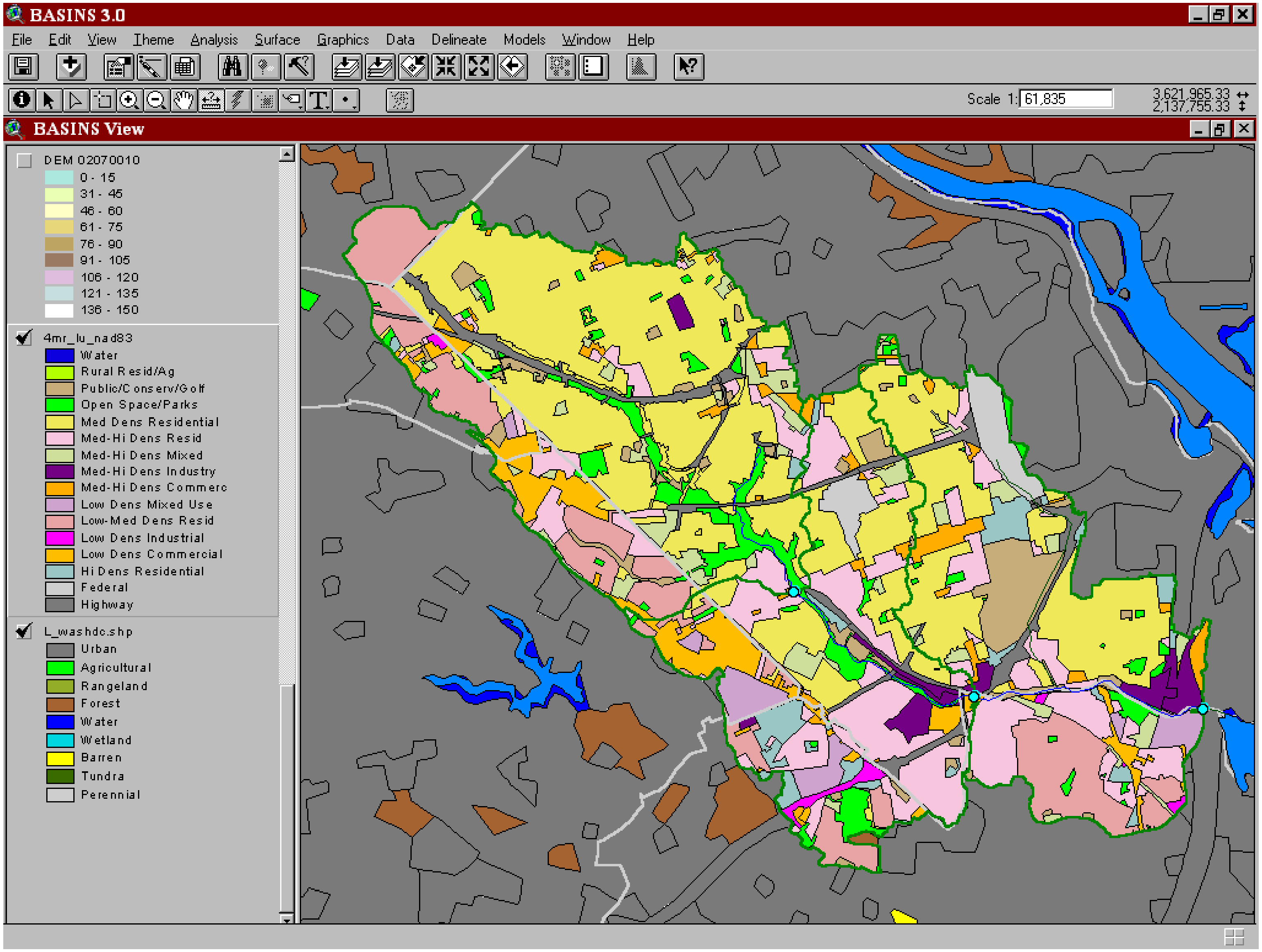


Figure 2-1. Modeled Land Use Categories within the Four Mile Run Watershed

2.3 Water Quality Data

Four Mile Run water quality data used for the development of this TMDL was compiled from the following sources:

- Virginia Department of Environmental Quality (VADEQ)
- Arlington County Department of Parks, Recreation, and Community Resources (DPRCR)
- Northern Virginia Regional Commission (NVRC).

The VADEQ data has been collected at least quarterly and at most semi-monthly at a single station in the nontidal portion of Four Mile Run since 1991. Prior to this, some sampling by VADEQ was performed during the 1970s, but this sampling was discontinued by 1980. VADEQ's identifier for this station is 1AFOU004.22, and it is located along the Four Mile Run mainstem directly under the Columbia Pike (Virginia Route 244) bridge. Throughout this report, this station is referred to as Four Mile Run at Columbia Pike. Data from 1999 through 2001 is plotted in Figure 2-2. Except for a single value of 25 on January 29, 2001, this dataset is constrained by a minimum detection limit of 100 cfu/100 mL. Similarly, except for a solitary value of 9,200 from October 16, 1991, the dataset is constrained by a maximum detection limit of 8,000 cfu/100 mL.

Data collected by the Arlington County DPRCR supports its annual put-and-take trout stocking program in Four Mile Run. County park naturalists collect fecal coliform bacteria data, along with dissolved oxygen and pH, to gauge stream conditions leading up to opening day of trout season, which is usually in late March. As a result, a variable number of samples are collected from early February to mid-March most years at four locations along Arlington's greenway park system that straddles the middle section of Four Mile Run's mainstem. Unfortunately, however, no data was collected by DPRCR during calendar year 2000, and only one value was obtained for calendar year 2001. One of the DPRCR stations, designated as FMR3, is located approximately 800 feet upstream Four Mile Run from Columbia Pike. As there are no tributaries or other significant drainage between FMR3 and Columbia Pike, and the reach is reasonably uniform along this section, data collected at this location was deemed appropriate to include with the other observed data collected at Four Mile Run and Columbia

Pike. All data collected at Columbia Pike and FMR3 during the period simulated by the TMDL model (January 1, 1999 through May 31, 2001) was used for calibration and verification.

Five fecal coliform values were collected by NVRC and Virginia Tech at Columbia Pike and Four Mile Run during the period simulated by the TMDL model described in Chapter 4. This data was collected to support the NVRC/Virginia Tech BST study documented in Appendix A. The upper detection limit used for this dataset was 1,600 cfu/100 mL. While fecal coliform bacteria data was collected at 31 locations in the watershed to support the BST study, only the data collected at Columbia Pike was directly useful for calibrating and verifying the Four Mile Run TMDL computer model.

The combined dataset for Four Mile Run at Columbia Pike is shown graphically in Figure 2-3. The period from July 1998 to May 2001 is plotted. This data is also presented in tabular form in Appendix D, and includes information about its source, date and time. All detection limits affecting this combined dataset are also disclosed.

These datasets can be characterized by the percent of the violations of Virginia's instantaneous standard of 1,000 cfu/100 mL. Table 2-2 shows the frequency of violation of the instantaneous fecal coliform standard by source and location from 1991 through the most recently available data.

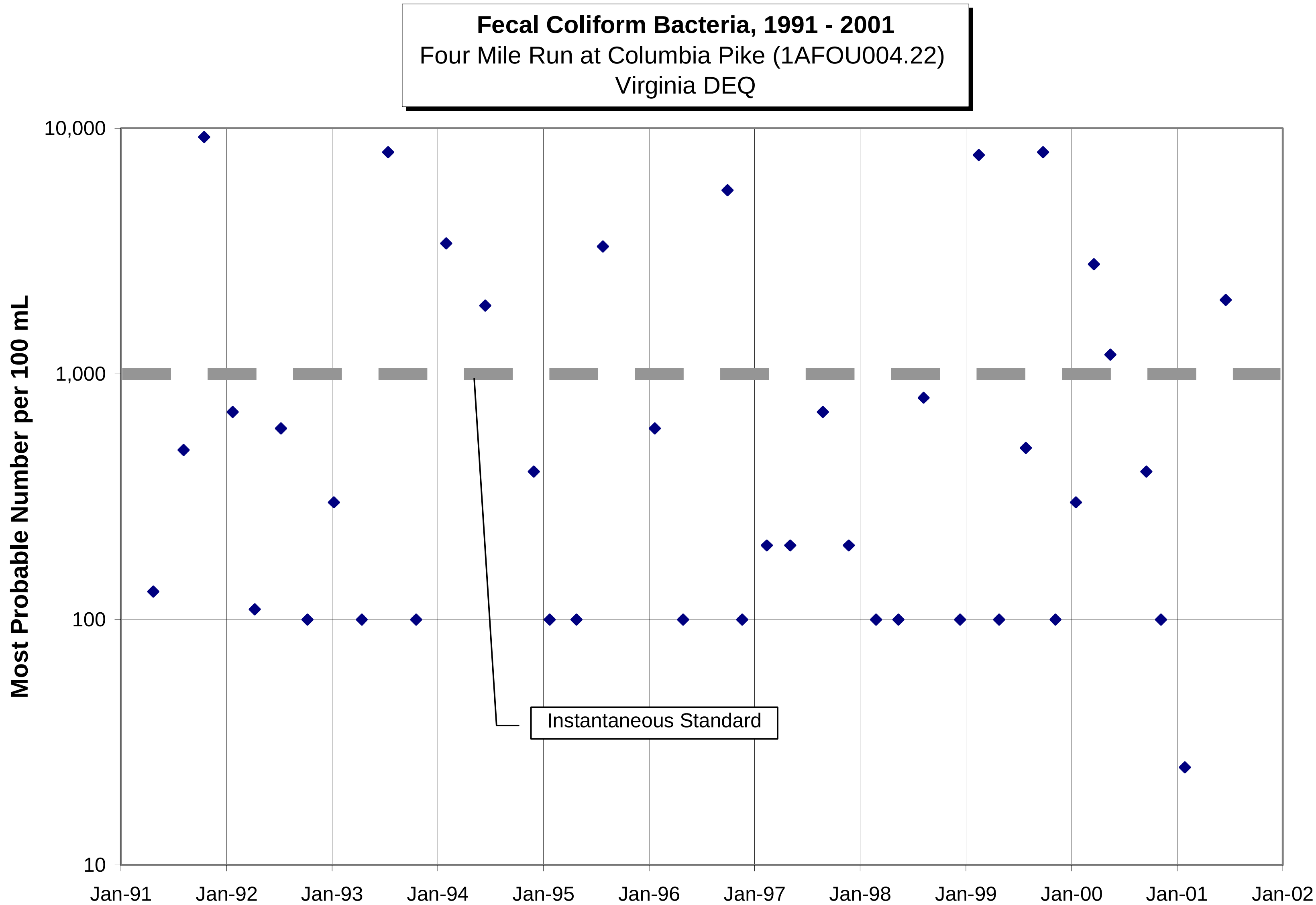


Figure 2-2. Fecal Coliform Densities in Four Mile Run at Columbia Pike, VADEQ Data Only, 1991 – 2001

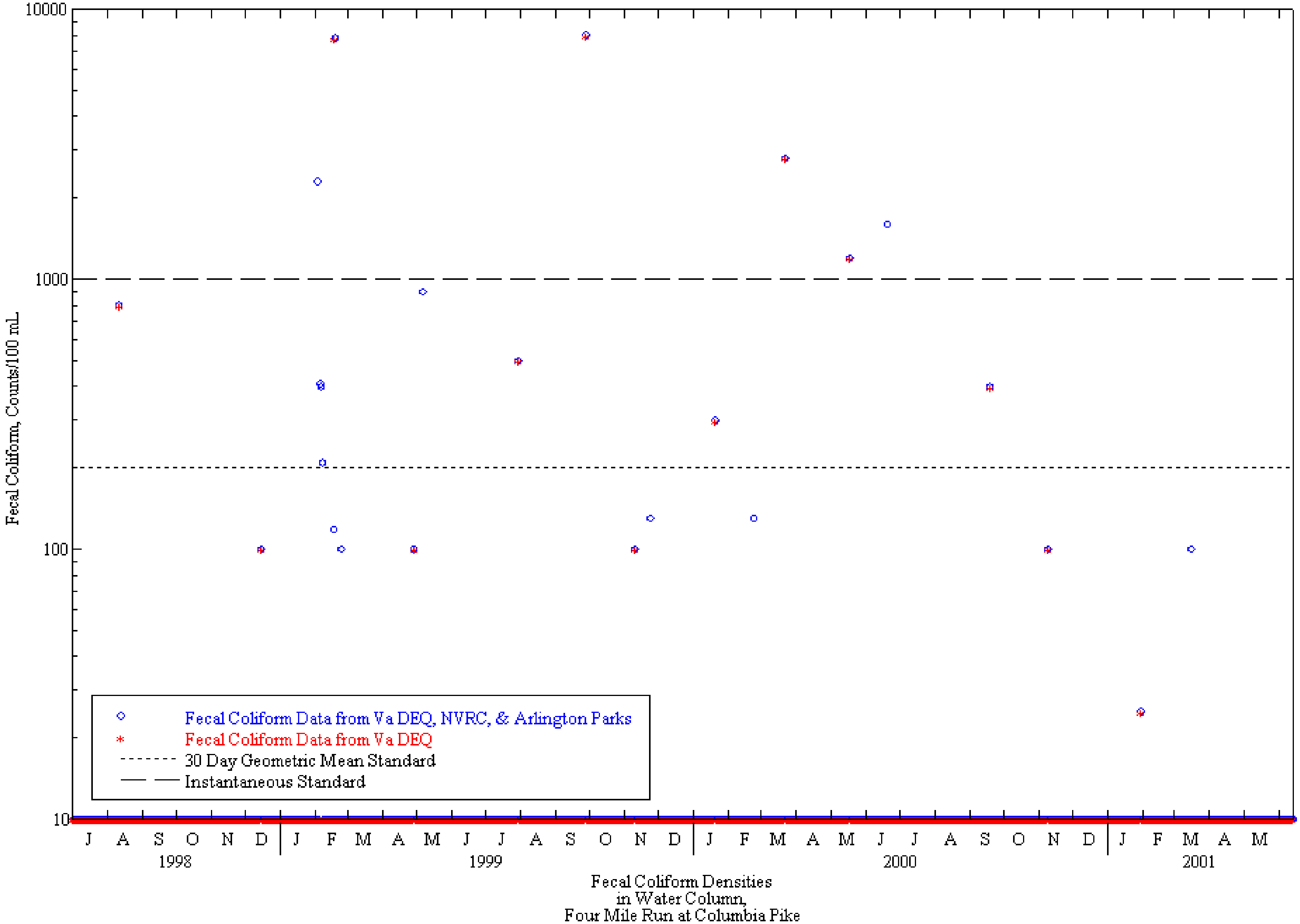


Figure 2-3. Observed Fecal Coliform Data, Four Mile Run at Columbia Pike, July 1998 – May 2001

Table 2-2. Fecal Coliform Standard Violation Frequency in the Four Mile Run Watershed

Source	Location(s)	Years	# of Observa-tions	Frequency of Violations for Instantaneous Standard*
VADEQ	Four Mile Run at Columbia Pike	1991 - 2001	41	27%
Arlington County Parks	4 sites along Four Mile Run mainstem from Bon Air Park to Barcroft Park	1998 - 2002	63	14%**
NVRC	29 sites throughout nontidal portion of watershed, including tributary streams	1998 - 2000	42	33%
All Sources	Combined	1991 - 2002	146	23%

* 1,000 counts (most probable number) per 100 mL of stream water

** Arlington limits data collection to late winter (February to mid-March) in association with its annual trout stocking program. See Table 2-3 for seasonal distributions.

2.3.1 Seasonal Analysis

Seasonal variation for instream fecal coliform concentration was performed for Four Mile Run. The seasonal cutoffs used in this analysis were the actual calendar dates for each season, and were not rounded by month. Thus, data collected on different days of a month that straddled two seasons was split between these seasons. Data from VADEQ and other sources were analyzed both separately and together. Figure 2-4 and Figure 2-5 present these seasonal mean values for the VADEQ station at Columbia Pike and the non-VADEQ data respectively. Figure 2-6 presents the seasonal mean values for all three sources at all nontidal stations.

Results show that the mean fecal coliform concentrations for the samples collected by the VADEQ are above the instantaneous standard for three seasons: winter, summer, and fall, with the highest mean values occurring during the fall season. The high winter mean fecal coliform concentration of 1,353 for the VADEQ data is attributable to a single reading of 7,800 MPN on February 17, 1999. Excluding this value results in a drop of the winter mean to 636.

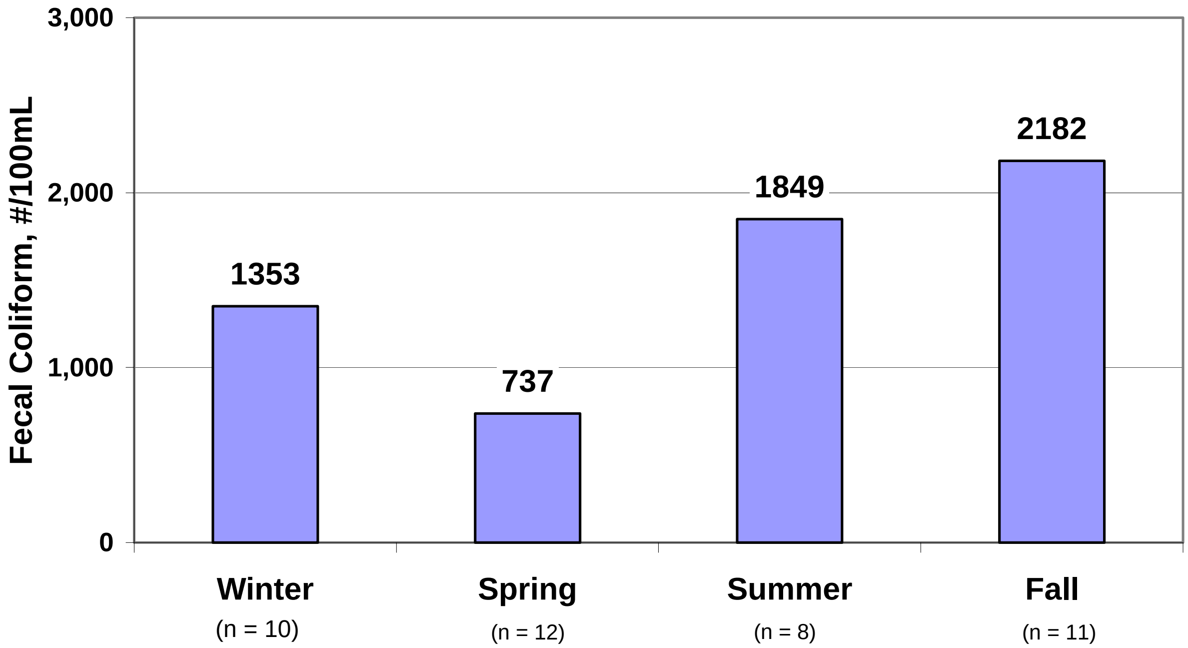


Figure 2-4. Mean Fecal Coliform Counts for the VADEQ Water Quality Monitoring Station at Columbia Pike by Season from 1991-2001

Figure 2-5 shows fecal coliform counts per 100 mL for nontidal NVRC stations, and indicates that this group of bacteria may be more plentiful in the impaired watershed during summer and fall than during winter and springtime. With the exception of the spring mean, the means in the NVRC dataset are much lower than they are for the VADEQ dataset. This is largely attributable to the differences in the upper and lower detection limits used in the two datasets.

For Figure 2-6, data from all three sources (VADEQ, NVRC and Arlington County Parks) were combined. As with Figure 2-4, this figure shows that bacteria counts are somewhat higher on average in the summer and fall than during winter and springtime.

While this simple analysis of the data shows a trend toward somewhat higher bacteria counts in the summer, this trend is not as strong as seasonal trends observed in less urbanized watersheds; for instance, the agricultural-dominated Pleasant Run watershed in Virginia's Shenandoah Valley (Virginia Tech, 2000). Caution should be used when interpreting these bar charts, as data values at the detection limits can influence the mean values in non-intuitive ways.

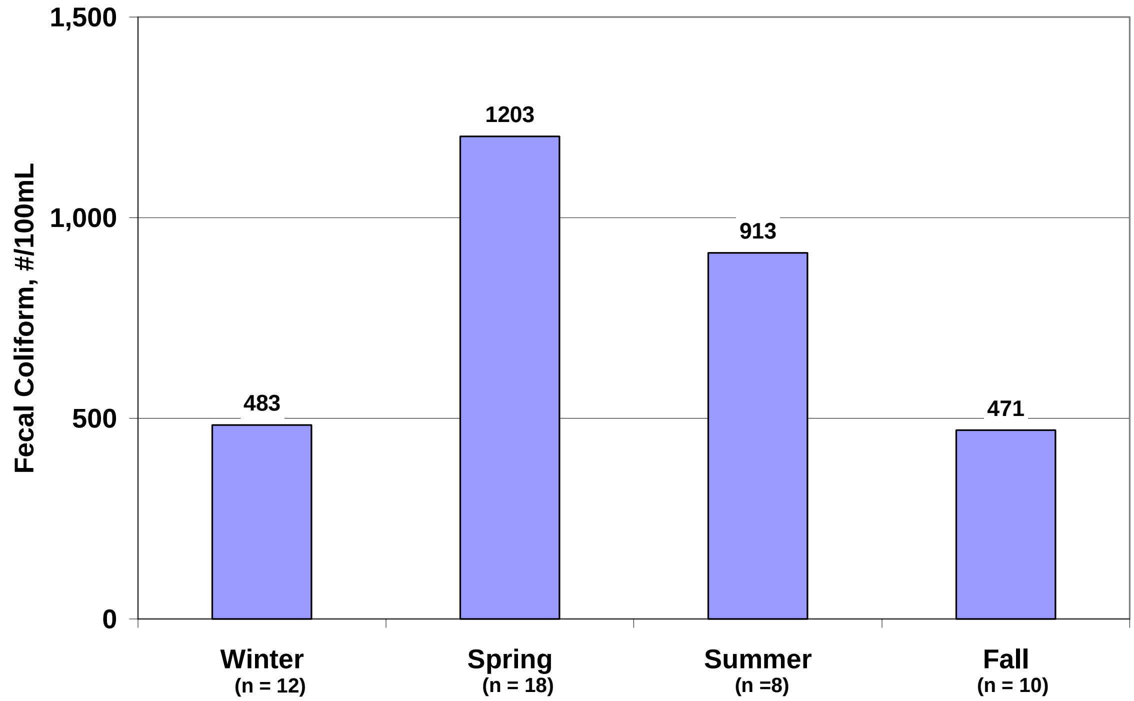


Figure 2-5. Mean E. Coli Counts for NVRC Water Quality Monitoring Stations by Season from 1998 – 2000

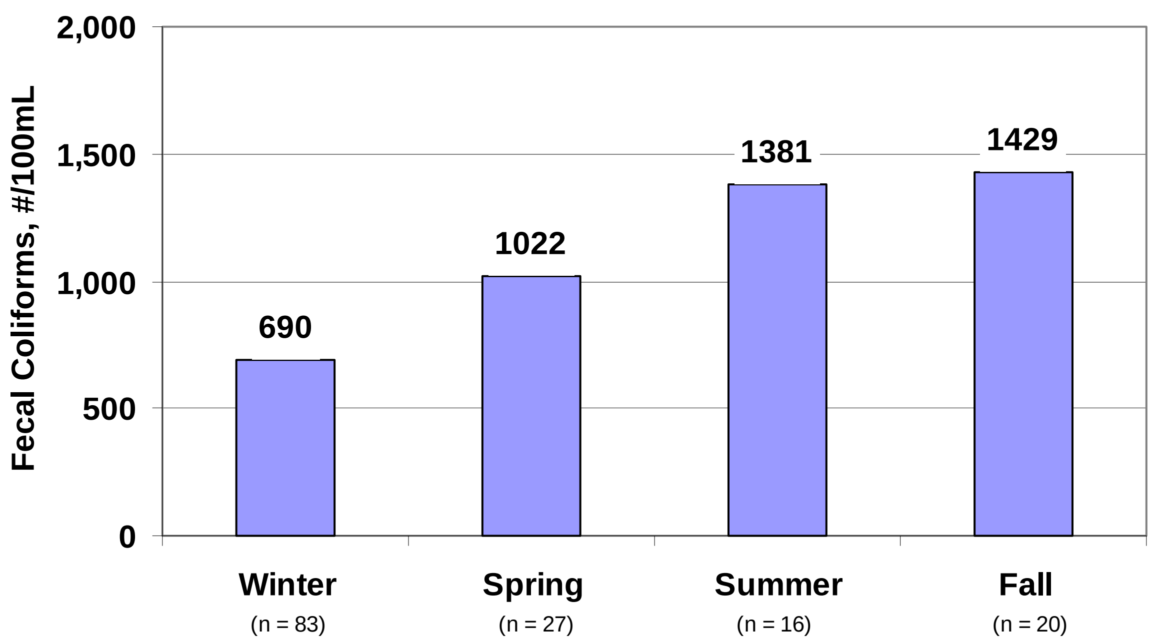


Figure 2-6. Mean Fecal Coliform Concentrations for Combined Stations (Nontidal) by Season from 1991 – 2001

The seasonal frequency of violation was evaluated for VADEQ and NVRC stations. Since Arlington County Parks data was collected entirely during the winter, it is evaluated only in combination with VADEQ and NVRC data (Column 3). Violations of the instantaneous standard were greatest in the springtime for both VADEQ and NVRC data (33% and 60% respectively).

Table 2-3. Fecal Coliform Standard Violation Frequency by Data Source and Season

	Frequency of Violations for Instantaneous Standard*					
	VADEQ		NVRC		VADEQ + NVRC + Arlington	
	%	*# of obs.*	**%**	*# of obs.*	**%**	*# of obs.*
Winter	**20%**	*10*	**20%**	*10*	**16%**	*83*
Spring	**33%**	*12*	**60%**	*15*	**46%**	*27*
Summer	**25%**	*8*	**25%**	*8*	**25%**	*16*
Fall	**27%**	*11*	**11%**	*9*	**20%**	*20*
Overall	**27%**	*41*	**33%**	*42*	**23%**	*146*

** 1,000 counts/100 mL*

3. Source Assessment

3.1 Nonpoint Sources

3.1.1 Bacteria Source Tracking (Genetic Fingerprinting)

The development of this TMDL greatly benefited from a significant genetic fingerprinting investigation on the DNA of E. coli in the Four Mile Run watershed performed by Dr. George Simmons of Virginia Tech's Biology Department from 1998 through 2000. Appendix A contains a technical paper on this study that was published in a peer-reviewed book titled *Advances in Water Monitoring Research*, released earlier this year (Simmons, 2001). Field data for this source tracking study was collected on five separate trips to the watershed at 31 different locations and across all four seasons. Some locations were visited on multiple occasions, and the number of DNA matches varied from site to site based on a number of different factors outlined in Appendix A.

It is important to note that genetic typing studies like this one are subject to the same statistical scrutiny and caveats that are appropriate for any population-based sampling survey. That is, there is a margin of error associated with each percentage shown in the tables and figures in this report and Appendix A. Further, because microbial communities are notoriously dynamic, and since relatively few genetic fingerprinting investigations have been performed to date, uncertainty ranges cannot be assigned in any meaningful way. The numbers are what they are, and are analogous to a series of half-blurred snapshots taken at a limited number of locations in the watershed at specific points in time. While the information from this study is the closest thing to hard evidence on bacteria sources in the watershed, the DNA matches are not at the 100% level—indeed, all matches were listed based on 80%-90% similarities with catalogued strains of known bacteria-to-host species associations. Appendix A provides information on why matches are listed as "probable" but not certain.

Genetic fecal typing, or BST, represents one line of evidence; long-term observations by trained naturalists working in the watershed represent another. Following the release of the BST results, NVRC performed in-depth interviews with five top naturalists working in and near the Four Mile Run watershed: two at Arlington's Long Branch Nature Center (Abugattas, 2001; Zell, 2001), two at Arlington's Gulf Branch Nature Center (Deibler, 2001; Chauvette, 2001), and one at the Northern Virginia Regional Park Authority's Potomac Overlook Regional Park located in Arlington County (Ogle, 2001). The purpose of these interviews was to ascertain the degree of overlap between bacteria sources suggested by the source tracking study and what the naturalists believed the sources should be. The interviews revealed near 100% agreement among the naturalists on which sources should be found in the watershed and their relative numbers and habitats, as well as which species were likely to be absent from the watershed, or in some cases, seasonally absent.

While information from these interviews revealed a large degree of overlap with the DNA evidence, some disparities emerged. For example, despite the relatively large percentages of deer matches found at several sites across the watershed, due to the extremely high levels of imperviousness in much of the watershed deer habitat is limited to only a few sites in the watershed, and with one notable exception, these do not align well with where the DNA evidence was found. Also, certain waterfowl species (e.g., least tern and black back gull) implicated by DNA evidence were believed by all five naturalists to be absent from the watershed year-round. Where these two lines of evidence contradicted each other, DNA matches were reclassified as “disputed” for the purposes of developing this TMDL. Figure 3-1 presents individual pie charts of the probable DNA matches by location in the watershed after the disputed matches were removed.

Fortunately, not only were the disputed cases limited to a few problem species, the overall DNA results track closely with a similar BST study (using RNA fingerprinting) in the Accotink Creek watershed performed in 2000. The centroids of these watersheds are approximately 10 miles apart, and their land uses are roughly similar. Figure 3-2 shows summary pie charts to facilitate an overall comparison of these two studies.

Table 3-1 reflects the resulting classifications after the disputed matches were removed. The percentages shown in Table 3-1 were used as a starting point and guide for modeling source contributions. DNA source tracking results from the portion of the watershed draining to the tidal reach of Four Mile Run are excluded from this table. As a practical matter, the percentages for each modeled segment could not be used directly in the model. For example, the number of isolate matches is so low for Segment 3 (lower nontidal Four Mile Run) that no matches were found for humans, raccoons or canines, despite their populations being in roughly the same proportions as found in Segments 1 and 2. There is considerably closer agreement in the proportion of waterfowl and raccoons between Segments 1 and 2, and the higher sample sizes of these segments make their percentages less suspect.

The slight difference in percentages among animal sources between Figure 3-2(a) and Table 3-1 is attributable to the way the Four Mile Run BST data is parsed. Table 3-1 is limited to data collected during baseflow periods and within the nontidal portion of the watershed, which is the subject of this TMDL. The Four Mile Run BST summary pie chart shown in Figure 3-2 includes all data in the watershed (for both tidal and nontidal portions) for all non-disputed matches, including BST matches from a storm event. While data from the only storm that was sampled for BST matches is not very statistically meaningful, it reflects a pattern of matches that is more or less similar to the BST dataset collected during baseflow periods. This storm data was collected at the Columbia Pike site during a brief summer squall on the evening of July 14, 2000, and is summarized in the pie chart in Figure 3-3.

While the human and canine percentages show much more variability across Segments 1 and 2, the genetic tools applied in this study has difficulty distinguishing between bacteria strains from these two host species. However, because of the persistent nature of human matches found at one particular storm drain outfall at the upper end of Doctors Run in Model Segment 2, coupled with consistently high bacteria counts obtained at that location by NVRC in this study and its subsequent investigation, NVRC suspects this to be a hotspot for human bacteria sources. In short, percentages of sources derived from the DNA source tracking investigation served as a guide for model loadings, along with information from the naturalists and NVRC's own long track record of analysis from fieldwork and census and pet records for the watershed.

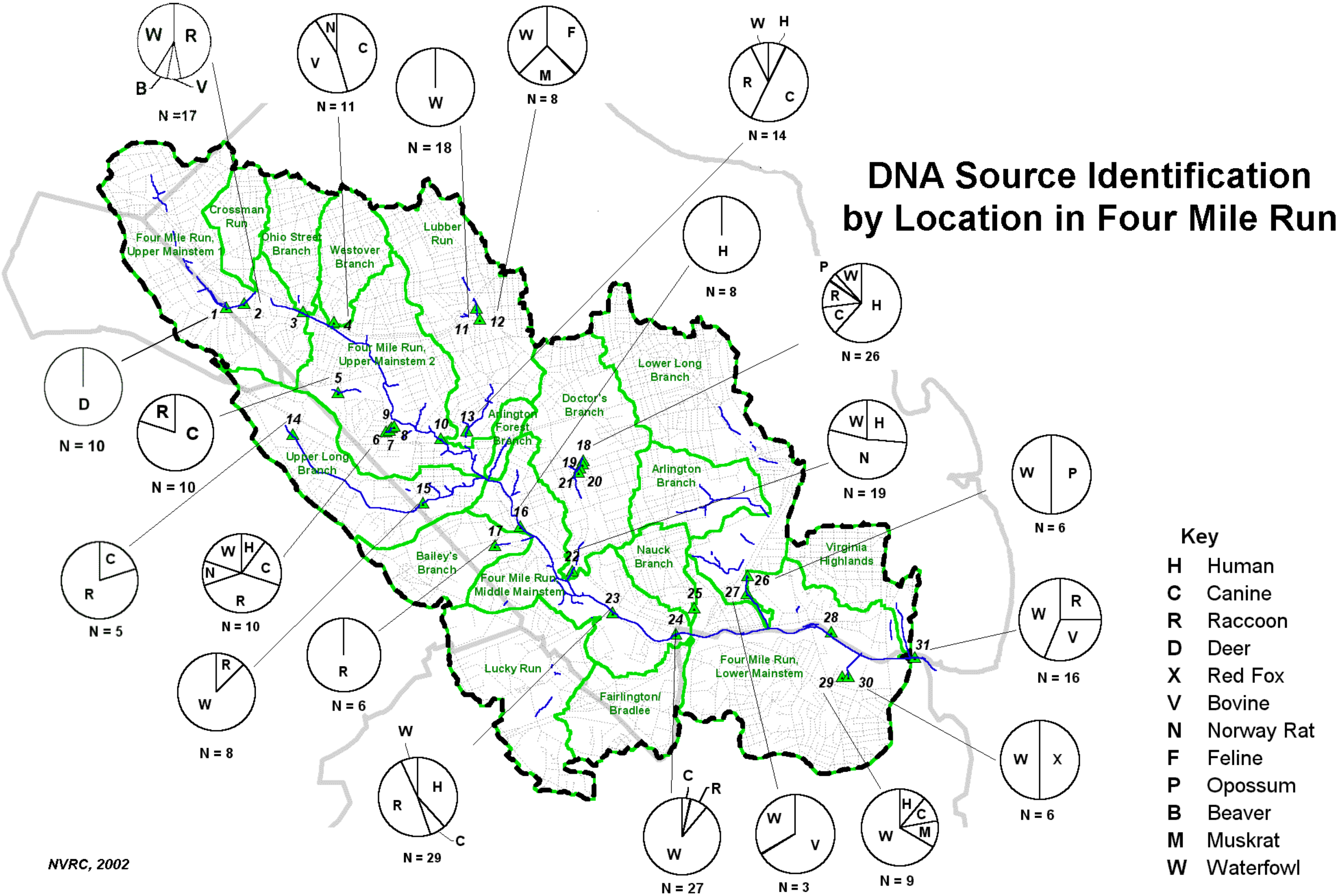
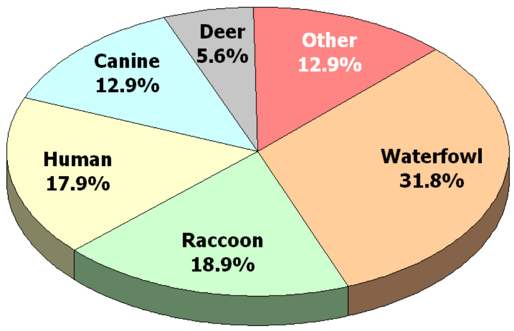
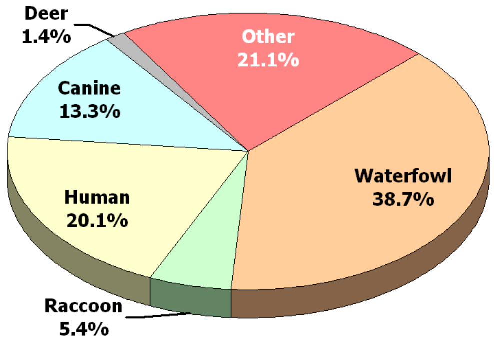


Figure 3-1. DNA Profiles by Location at 31 Sites in Four Mile Run

Figure 3-2. Comparison of BST Results in Four Mile Run and Accotink Creek



Four Mile Run BST Results, 1999-2001 (N=292)



Accotink Creek BST Results, 2000-2001 (N=278)

Table 3-1. Classification of E. coli Isolate Matches by Model Segment

Sub-watershed	# of Isolate Matches	Waterfowl %	Human %	Raccoon %	Canine %	Other %
Seg1: Upper Four Mile Run	119	32	8	20	19	20
Seg2: Middle Four Mile Run	107	31	30	23	6	10
Seg3: Lower Four Mile Run	9	44	0	0	0	56
Nontidal Overall	*235*	*32*	*18*	*21*	*12*	*17*

Totals may not sum to 100% due to rounding.

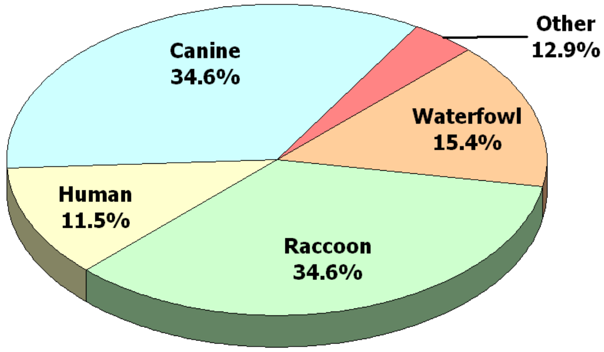


Figure 3-3. Summary of BST Results for July 14, 2000 Storm

3.2 Point Sources

There are no permitted or known point source discharges of bacteria in the watershed. Two of the four localities that share the watershed—Arlington and Fairfax counties—have municipal separate storm sewer system (MS4) permits. The other two localities—the cities of Alexandria and Falls Church—are expected to receive MS4 permits within the next few years. These permits are designed to compel awareness of the quality of water discharging from publicly owned storm sewer outfalls, and to reduce pollution from the MS4, although no numerical limits for bacteria or any other water quality parameter are stipulated in these permits. The permits blur the lines that have traditionally distinguished point and nonpoint sources of pollution. While the MS4 permits are regulated similarly to point source discharges, water quality discharging from the MS4s is nearly exclusively dictated by nonpoint source runoff (along with an unknown, but presumed small, amount of illicit connections). In the Four Mile Run watershed, the MS4s intercept groundwater flow during baseflow periods, and are dominated by runoff during and immediately after rainfall. This baseflow is controlled by pervious surface processes such as infiltration, while the storm flow is dominated by runoff from impervious surfaces. Optical Brightener Monitoring (OBM) conducted by NVRC staff from 1999 to 2001 at every outfall in the watershed lends evidence that storm sewer outfalls are largely free from illicit connections (NVRC, 2000; and various in-house OBM project documents, 1999-2001). This evidence is supported by Arlington County's MS4 monitoring results over the past three years on file with VADEQ.

4. Modeling Approach for Four Mile Run Total Maximum Daily Load

The most critical component of Total Maximum Daily Load (TMDL) development is to establish the relationship between the source loadings and the in-stream water quality. This relationship is essential for the evaluation and identification of management options that will achieve the desired source load reductions. Modeling the relationship between loads and water quality can be achieved through different techniques ranging from simple mass balance models to more sophisticated dynamic and fully integrated watershed scale modeling. However, when the fate and transport of a pollutant depends upon the changing responses to runoff flow and source loadings, it is important to use a model that simulates the loadings from various non-point sources and characterizes the resulting stream water quality for the different runoff and stream flows that may occur in the watershed.

This section describes the steps to select a model and to develop the information needed to apply the model to hydrologic and water quality simulations of Four Mile Run. It details the modeling tools used, the existing physical and hydrologic data, the hydrology approach used for the calibration, the development of direct and indirect source loadings used in the water quality model, and the approach used for the water quality calibration of the model.

4.1 Model Description

The model selected for Four Mile Run is HSPF—Hydrologic Simulation Program – Fortran. HSPF is a set of computer programs that simulate the hydrology of the watershed, nutrient and sediment nonpoint sources loads, and the transport of these loads in rivers and reservoirs. HSPF partitions the watershed into three smaller sub-watersheds (upper, middle and lower Four Mile Run). Data on land uses and nonpoint sources are entered into the model for each sub-watershed. The primary interface for this application of HSPF is WinHSPF and full advantage of EPA's BASINS modeling environment was taken in the development of key components of this model. However, the Four Mile Run HSPF model also benefited by moving beyond the somewhat limited data inputs and calibration options available through the interfaces offered by BASINS and WinHSPF.

In its production run configuration, the Four Mile Run HSPF model generates daily nonpoint source edge-of-stream pollutant loads for each land use and instream concentrations at each sub-watershed outlet. Each sub-watershed contains information generated by a specific component or submodel. Results from the three submodels (hydrologic submodel, non-point source submodel, and river submodel) combine to estimate the changes in load estimates to Four Mile Run. The hydrologic submodel uses rainfall and other meteorological data to calculate runoff and subsurface flow for all the watershed land uses. The runoff and subsurface flows, generated by the hydrologic sub-model, ultimately drive the nonpoint source sub-model. The nonpoint source sub-model (PERLND and IMPLND) simulates multiple pathway transport of pollutant loads from the land to the edge of the stream. The river sub-model (RCHRES) then routes flow and associated pollutant loads from the land through the stream network to the outlet of the watershed.

4.2 Model Sub-watershed Discretization and Land Use

The Four Mile Run watershed was divided into three sub-watersheds that are identified as Segment 1—upper Four Mile Run; Segment 2—middle Four Mile Run; and Segment 3—lower nontidal Four Mile Run. They are often referred to in tables by the shorthand “Seg1,” “Seg2,” and “Seg3.” Figure 4-1 illustrates this sub-watershed division and sampling station locations. The sampling station location between Seg1 and Seg2 on this map is the VADEQ monitoring site at Columbia Pike (1AFOU004.22). The sampling station between Seg2 and Seg3 is the USGS stream gauge at the Shirlington Road bridge crossing of Four Mile Run. The Shirlington station was used to calibrate the hydrologic response of the model, and the Columbia Pike station was used for bacteria calibration. The dot at the eastern edge of Seg3 is the tidal/nontidal downstream boundary of the TMDL model.

The locations of available flow and bacteria data to calibrate the model were the primary considerations for determining sub-watershed model boundaries. The sole acceptable stream gauge data set is from the U.S. Geological Survey (USGS) flow gauge on Four Mile Run at the Shirlington Road Bridge. High resolution flow data (at 5- to 15-minute intervals) was collected from October 1998 through the present, and is even available in near-real time online at <waterdata.usgs.gov/va/nwis/uv?01652500>. The only two long-term fecal coliform monitoring

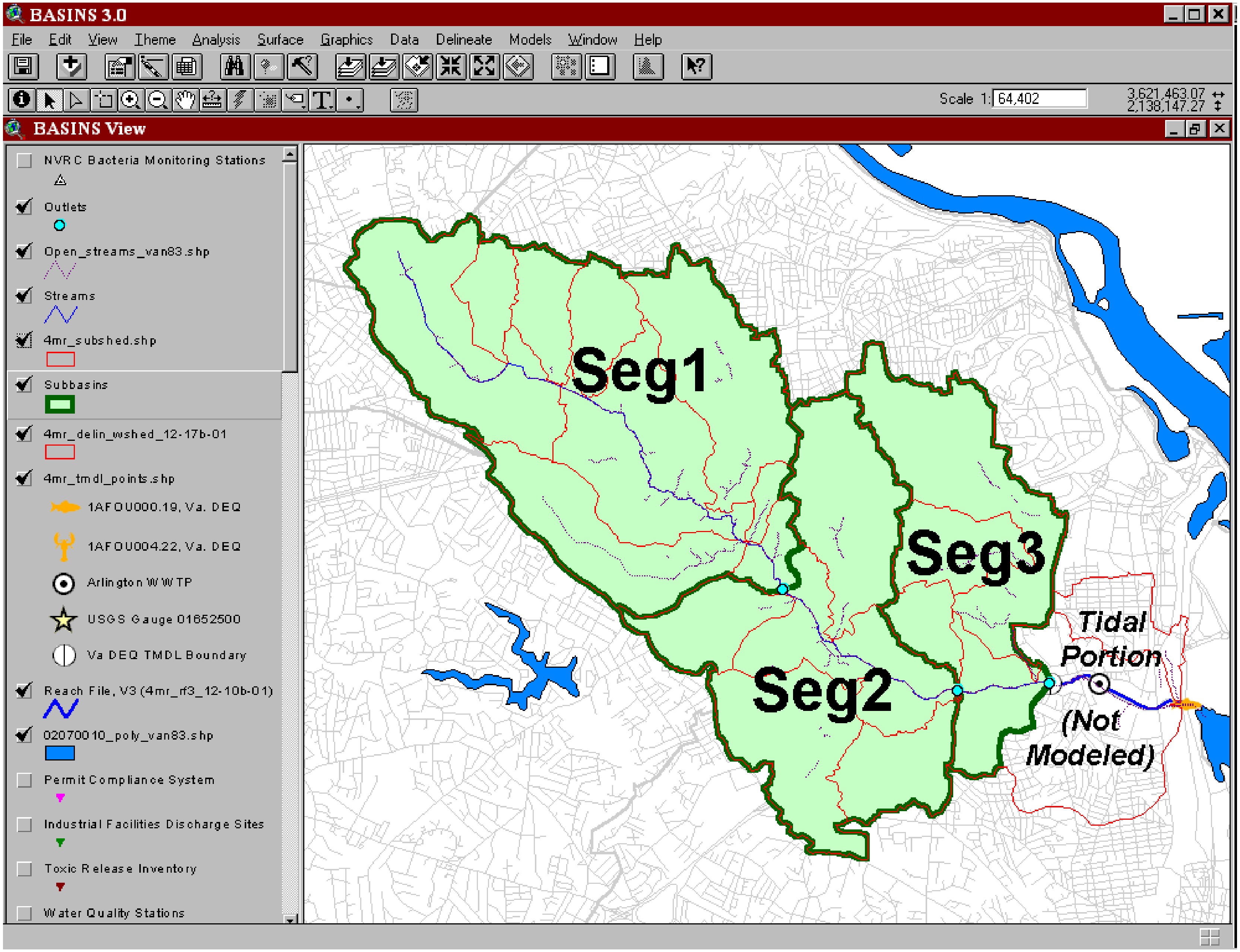


Figure 4-1. Subbasin Divisions for the Four Mile Run TMDL Model Segmentation

stations in the nontidal portion of the watershed are the one operated by the Virginia DEQ at Four Mile Run and Columbia Pike and one operated by the Fairfax County Health Department in the headwater portion of upper Long Branch—a tributary to Four Mile Run. The tributary site, located near the Fairfax/Arlington county line, was considered by NVRC to have too small of a drainage area to warrant its own HSPF model segment, and was therefore not useful for model calibration. The outlet for HSPF Model Segment 1 is the DEQ monitoring site at Columbia Pike and the outlet for Model Segment 2 is the USGS stream flow gauge in Shirlington.

High-resolution, ground-truthed land use information exists in standard digital GIS formats, and was generated by a previous NVRC project. This highly relevant land use data was improved upon by culling highway areas from the "public open space" category. Other minor updates and subdivisions were made to clean up the Four Mile Run portion of NVRC's land use GIS layer to maximize its value for development of the TMDL model. The automated land use and model segmentation capabilities of BASINS were used to automatically extract information from the land use layer and add them to the HSPF model for each sub-watershed segment in correct model input format. The segment-specific land use information was presented in Table 2-1.

4.3 Selection of Model Simulation Period

Because neither hourly nor daily flow data exists prior to October 1998, and because of the start-up period required by HSPF, the model calibration period was from January 1, 1999 through May 31, 2001. Continuous hourly time series inputs for precipitation, air temperature, dewpoint, potential evapotranspiration, and wind speed were added to the model input stream from July 1, 1998 to May 31, 2001. Most of these inputs exist for both Reagan National Airport at the lower end of the watershed and for a Fairfax County Health Department weather station in Seven Corners at the upper end of the watershed. All continuous record input datasets used in the TMDL model, and many more that were considered for use in the model, are documented in Appendix B.

Although a three-month start-up period was anticipated for this modeling effort, this application of HSPF ended up requiring a six month start-up period. Thus, although the model simulation began on July 1, 1998, when required hourly weather inputs were made available to the model, HSPF did not start generating acceptable calibration output until January 1, 1999. It is unknown if this was attributable to the near-drought conditions of late 1998, the three-to-six month start-up period typically required for HSPF to equilibrate, or some combination of both. Because insufficient data existed to test the model calibration parameter values against a separate verification period, the 29-month calibration period was subdivided into two periods for the purposes of providing a mini verification exercise. That is, while the final calibration parameter values were derived based on the period of January 1, 1999 through May 31, 2001, separate calibration statistics were also tracked for the periods January 1 – December 31, 1999 and January 1, 2000 – May 31, 2001. Calibration results for these two periods were very similar. Additionally, calibration statistics were tracked for seasonality—again with no evident seasonal bias in the final calibration results. Results of this calibration exercise are presented later in this chapter.

4.3.1 Availability of Precipitation Data

Precipitation is a particularly critical model input and serves as the primary driver for simulating stream flow and bacteria densities. Thus, a thorough search for precipitation data was conducted at the outset of model development. Figure 4-2 shows the locations of continuous rain gauge sites in and near the watershed, along with Thiessen polygons that indicate their areas of influence in the watershed. Not all these stations operated rain gauges continuously during the period of simulation. The Edison Center site was discontinued shortly before the simulated period began and the Arlington STP gauge was out-of-commission for much of this period. The rain gauge at Shirlington began operating midway through the simulation period. The Skyline Towers gauge appeared to be systematically under-representing precipitation, and a field visit confirmed that a line of overhanging trees could intercept a portion of most rainfalls, depending on the wind direction. Thus, only the gauges at Seven Corners and Reagan National Airport were used as model inputs. Small gaps in the Seven Corners dataset were filled with hourly precipitation records from a station approximately one mile northwest at Sisler's Stone (a store) in Falls Church.

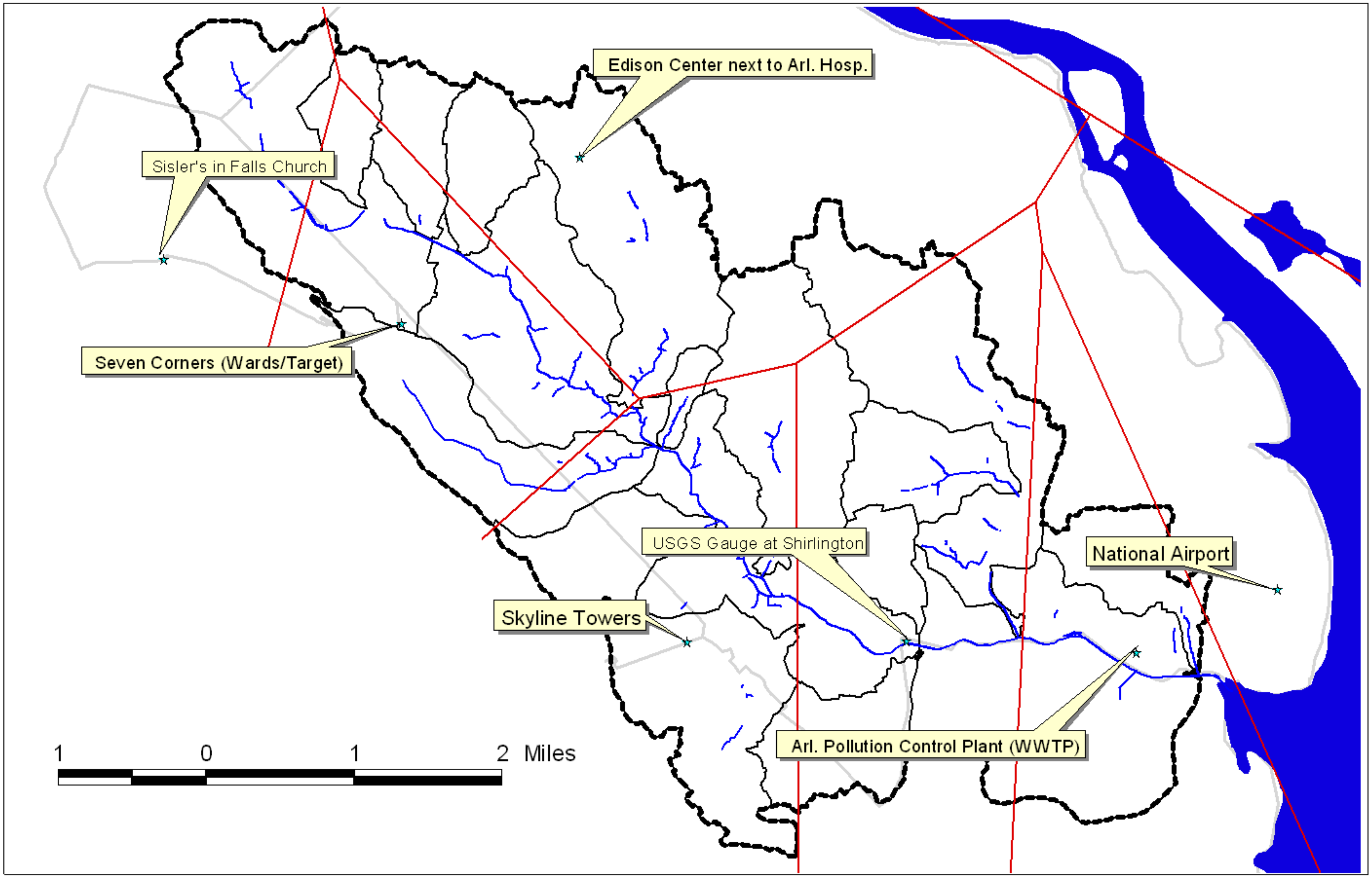


Figure 4-2. Rain Gauge Locations In and Near Four Mile Run

4.4 Hydrology Modeling Approach

This section describes the approach used for the hydrology model calibration in Four Mile Run. Simulating the long-term hydrologic response requires extensive information on the physical, meteorological, and hydrological characteristics of the watershed. Precipitation and other meteorological data are the primary driving functions in the HSPF model. Surface runoff, stream flows, nonpoint source loads, and kinetic reaction rates all primarily depend on the continuous hourly input of precipitation, air temperature, evaporation, and other meteorological inputs.

Model calibration involves comparing the model results with observed data and adjusting key parameters to improve the accuracy of the model results. An acceptable model calibration requires a period long enough (usually several years) to reproduce different hydrologic conditions.

4.5 Hydrology Calibration

Hydrology calibration of the model compares simulated stream flow data to observed data. The model assumptions for hydrology are adjusted within reasonable ranges to achieve a good agreement in the comparison.

A comparison of the simulated and observed flow data indicates that the model calibration is robust and adequately reproduces the hydrologic response of the Four Mile Run watershed. There is a very good agreement between observed and simulated flow as shown in Table 4-1 and Figures 4-3 through 4-6.

Figure 4-3 is a computer screenshot from the post-processing interface, called GenScn, which comes packaged with EPA's BASINS software. Mean daily flow in cubic feet per second (cfs) is represented on the Y-axis in a linear scale, which is useful for evaluating the model's ability to match peak storm flows. Because precipitation can vary across the watershed by 10 to 50 percent or more for any given storm, it is not realistic to expect simulated peak flows to match exactly with observed values. What is important is that the overall water balance is accurately reflected in total and seasonal flow volumes, and that error is minimized across the entire flow regime from drought conditions to infrequent storm events.

Figure 4-4 shows the same data as Figure 4-3, but the Y-axis displays flow data on a log scale. This allows a visual evaluation of baseflow response. The TMDL model simulated baseflow adequately overall, with certain periods matching against gauged flows better than others. Since baseflows in Four Mile Run typically range from 2 to 10 cfs (quite low when compared to most other streams for which TMDL models are developed), even a few cfs difference can cause a model to appear significantly out of line when the response is quite good. Also, the USGS gauge site in Shirlington is in a very broad, shallow channel with an uneven, and ever-shifting, bottom. This makes developing and maintaining a rating curve for low flow and drought conditions a challenge. Thus, gauge error can account for some of the discrepancy between observed and simulated values during dry periods.

Figure 4-5 is a scatter plot of mean daily flow. This plot shows a least-squares fit of a line with a slope of 1.007 and a Y-intercept of 0.035, with a 0.943 correlation coefficient. A model that exactly duplicates each observed flow value would have a line slope of 1.0, a Y-intercept of 0.0, and a correlation coefficient of 1.0.

The most meaningful visual assessment of a model's accuracy across the entire range of flow conditions is seen in Figure 4-6, the flow-duration curve. For this curve, hourly flows were selected to increase the size of the dataset being analyzed, which adds resolution and results in smoother data plots. For this reason, Figure 4-6 shows that some simulated and observed hourly flows were in excess of 1,000 cfs, whereas the mean daily flows presented in Figure 4-5 are all lower than 1,000 cfs. The X-axis in the flow-duration curve is deliberately stretched at the extremes of both low and high flows, to allow better assessment of the model's response to infrequent conditions. While simulated flows closely matched observed flows during storms of all sizes, as well as typical baseflow conditions, there is not a good agreement for the lowest half-percent of flows (about five days). This is an artifact of the model's start-up period. When the flow-duration curve is plotted for the period from January 7, 1999 to May 31, 2001, this outlier is removed. In reality, it is a difference of one to two cfs during the driest five days of the modeled period.

Figures 4-7 and 4-8 are close-ups of the model's hydrologic response for a single month (April 2000). Figure 4-7 shows hourly flows on a linear scale. While the timing and magnitude of the model's response during storm events appears very accurate, a discrepancy is evident between the 20th and the 22nd of April. For this period, Reagan National Airport (just downstream and outside of the nontidal portion of the watershed) received 0.84 inches of rain, while the gauge at Seven Corners at the upper end of the watershed only received 0.18 inches. In this case, the heaviest part of the storm skirted the watershed, and inaccurately influenced model response. Figure 4-8 shows the same hourly output detail, but with flows displayed on a log scale. This detail allows a visual assessment of the slope of the recession curves after each storm event, as well as an examination of baseflow response.

Table 4-1. Summary Statistics for Hydrology Calibration

21,376.9	Total Simulated Runoff, Avg. Daily Flow in cfs, 1/1/1999 - 5/31/2001
21,186.6	Total Observed Runoff, Avg. Daily Flow in cfs, 1/1/1999 - 5/31/2001
58.910	Total Simulated Runoff, inches, 1/1/1999 - 5/31/2001
58.386	Total Observed Runoff, inches, 1/1/1999 - 5/31/2001
0.90%	***Error in Total Volume***
38.367	Total of Highest 10% of Simulated Flow, inches, 1/1/1999 - 5/31/2001
37.142	Total of Highest 10% of Observed Flow, inches, 1/1/1999 - 5/31/2001
3.30%	***Error in Total of Highest 10% of Flows***
5.375	Total of Lowest 50% of Simulated Flow, inches, 1/1/1999 - 5/31/2001
5.024	Total of Lowest 50% of Observed Flow, inches, 1/1/1999 - 5/31/2001
6.98%	***Error in Total of Lowest 50% of Flows***
16.682	Simulated Summer Flow Volume, inches, 6/21-9/21/1999 + 6/21-9/21/2000
16.578	Observed Summer Flow Volume, inches, 6/21-9/21/1999 + 6/21-9/21/2000
0.62%	***Summer Flow Volume Error***
15.560	Simulated Winter Flow Volume, inches, 1/1-3/19/1999 + 12/22/1999-3/19/2000 + 12/22/2000-3/19/2001
15.120	Observed Winter Flow Volume, inches, 1/1-3/19/1999 + 12/22/1999-3/19/2000 + 12/22/2000-3/19/2001
2.91%	***Winter Flow Volume Error***
138.5	**Observed Avg. Daily Peak Flow, cfs**
142.3	**Simulated Avg. Daily Peak Flow, cfs**

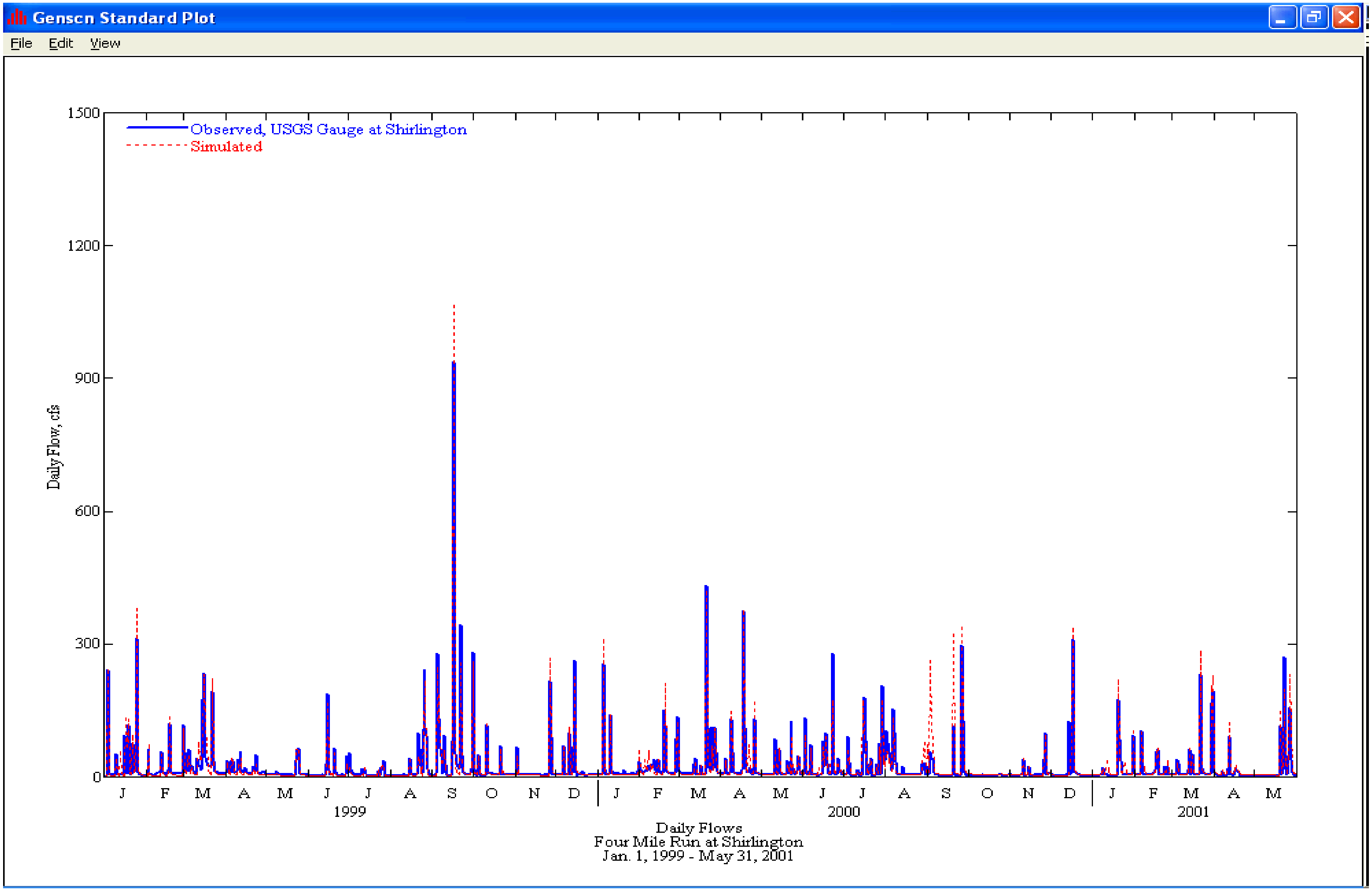


Figure 4-3. Simulated and Observed Daily Flow at Shirlington, 1/1999 – 5/2001

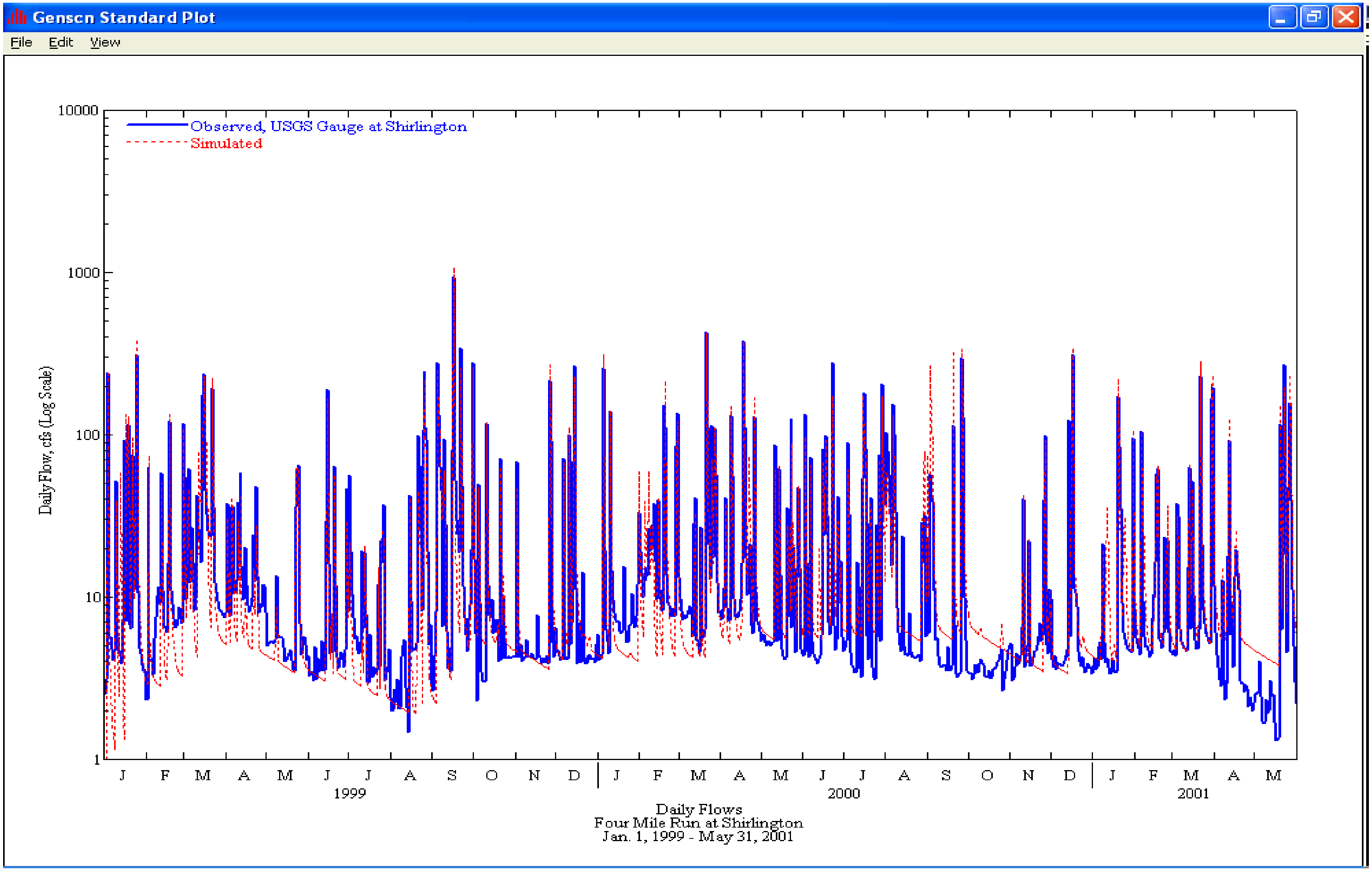


Figure 4-4. Simulated and Observed Daily Flow at Shirlington, Log Scale

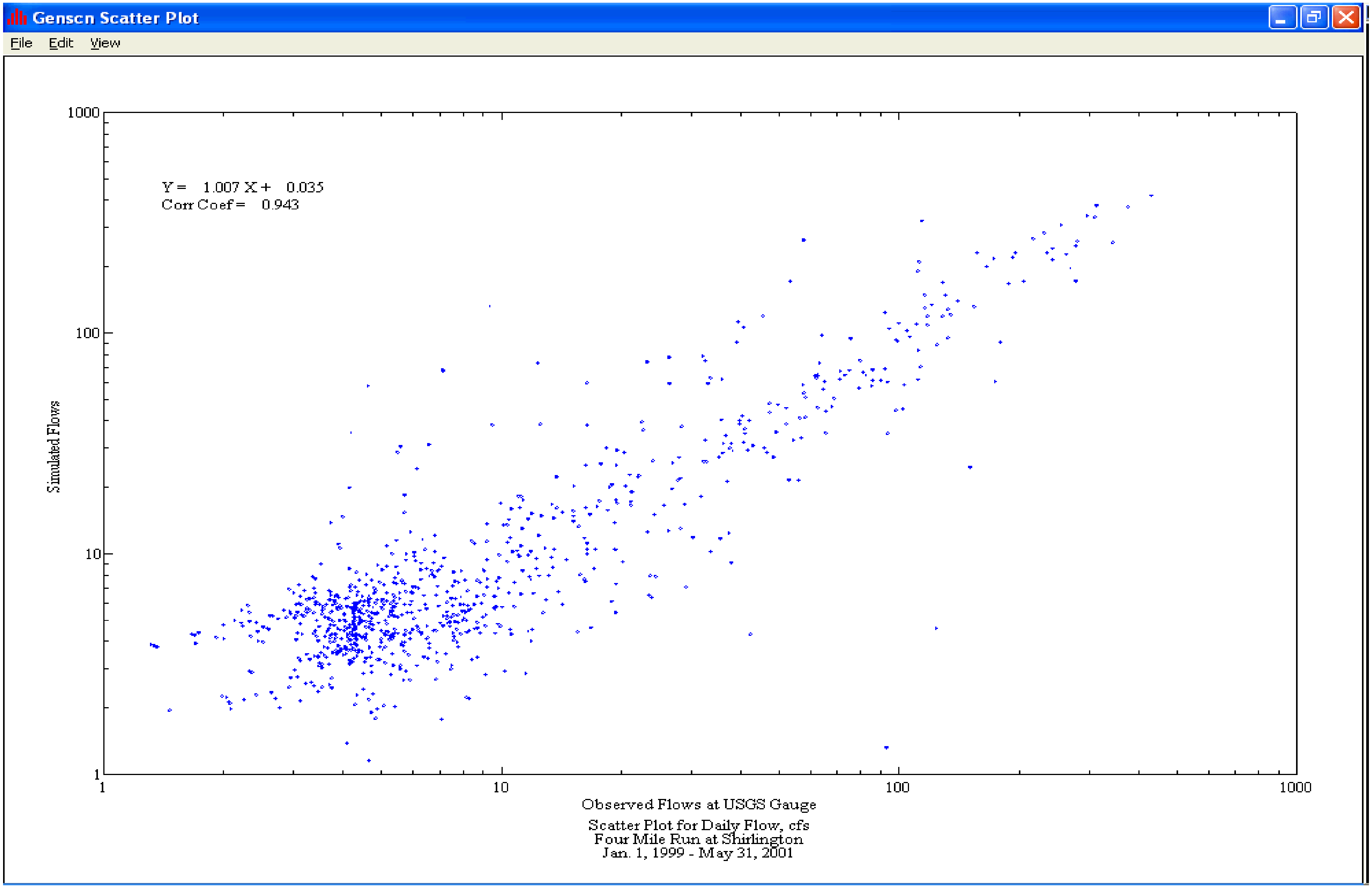


Figure 4-5. Scatter Plot for Simulated and Observed Daily Flow at Shirlington

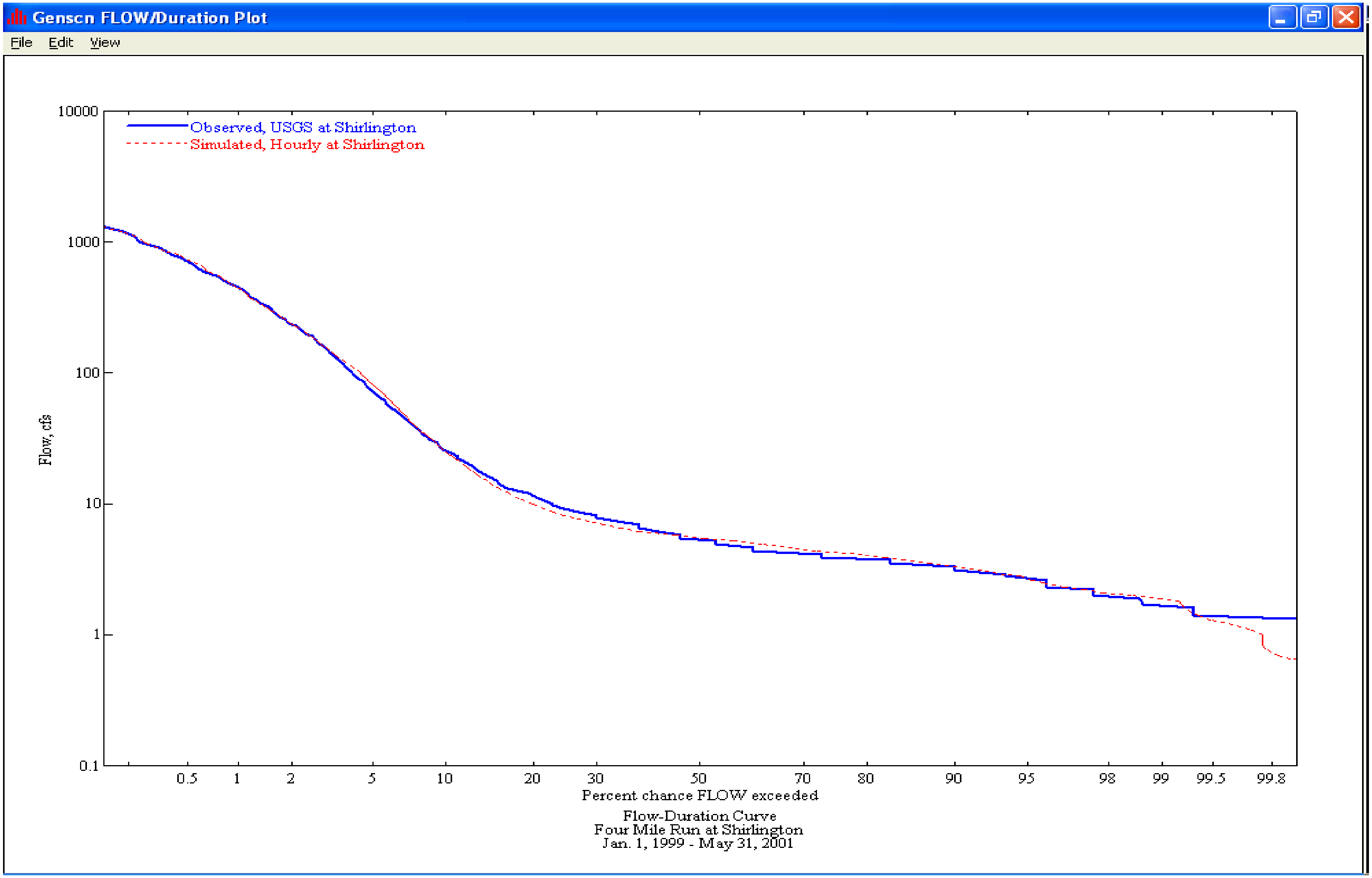


Figure 4-6. Flow Duration Curve for Simulated and Observed Hourly Flow at Shirlington

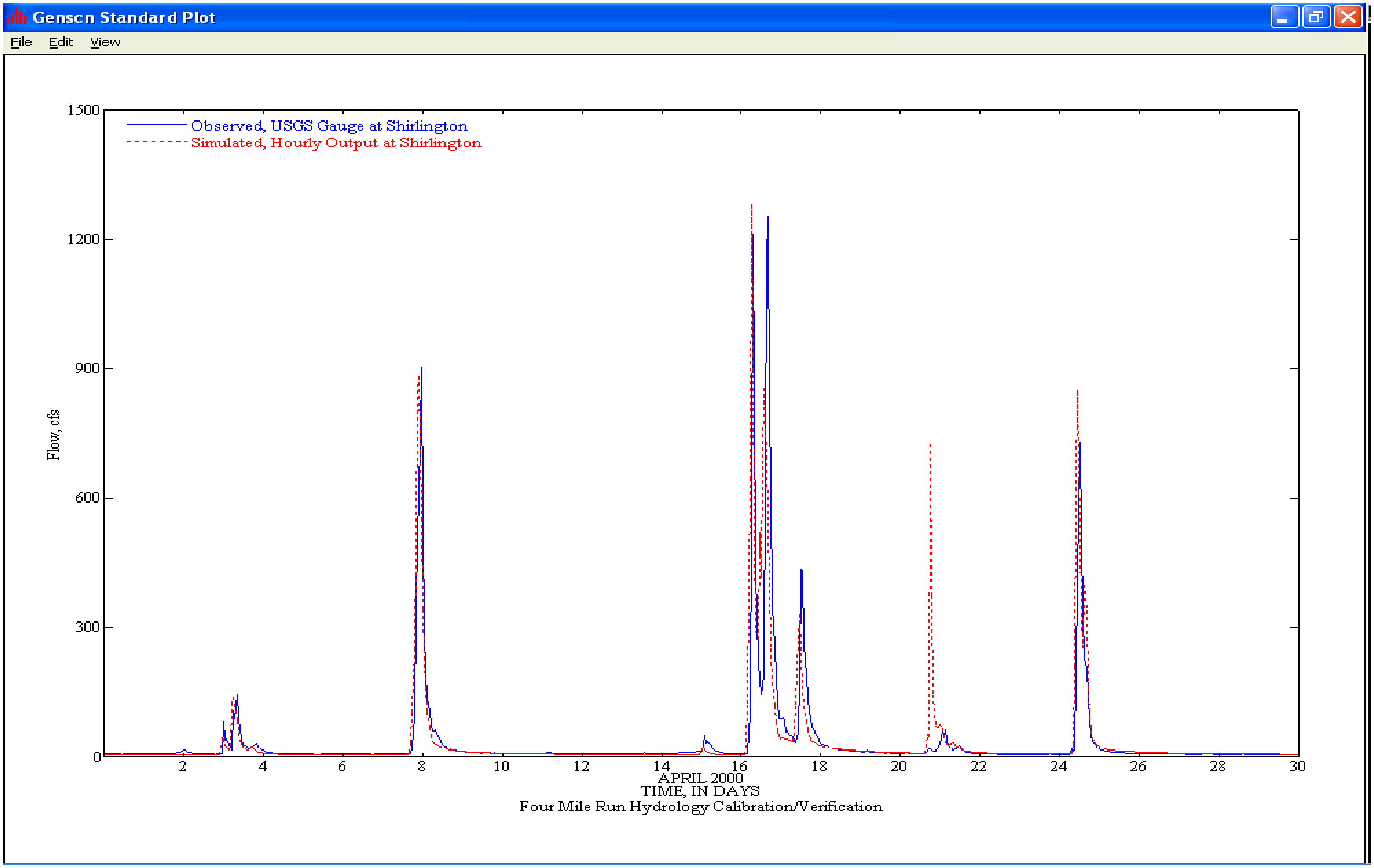


Figure 4-7. Sample Detail of Simulated and Observed Hourly Flow for April 2000

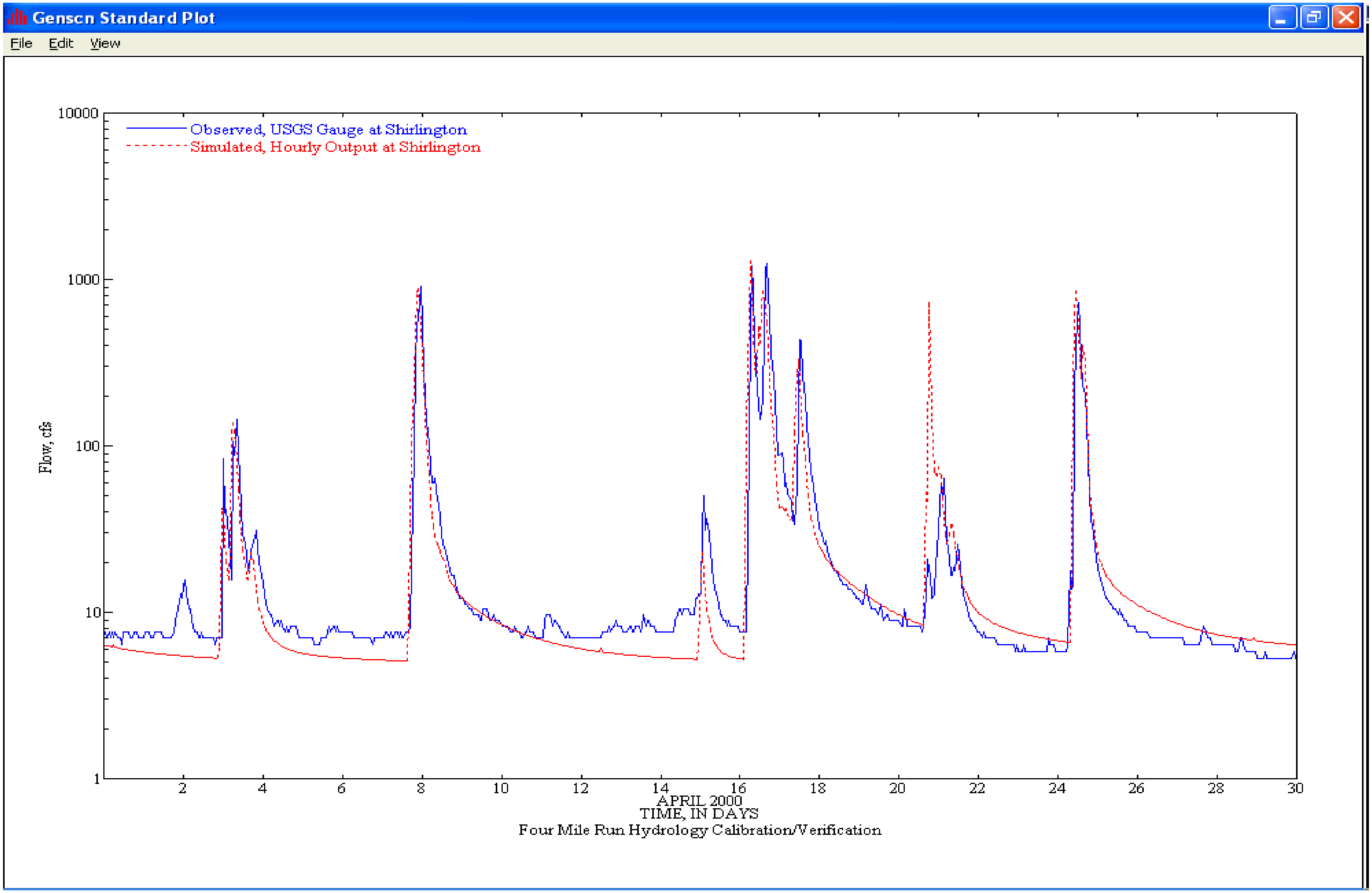


Figure 4-8. Sample Detail of Simulated and Observed Hourly Flow, Log Scale

4.6 Summary of Key Hydrology Model Parameters Adjusted in Calibration

The primary parameters adjusted during the calibration were the infiltration capacity (INFLT), the recession rate for groundwater (AGWRC) the recession rate for interflow (IRC), the amount of evapotranspiration from the root zone (LZTEP), the amount of interception storage (CEPSC), and the amount of soil moisture storage in the upper zone (UZSN) and the lower zone (LZSN). The final calibration values of all hydrology parameters are provided in Table 4-2.

4.7 Water Quality Modeling Approach - Source Representation

This section describes the approach taken for modeling the fate and transport of fecal coliform in Four Mile Run. The water quality portion of the model involved a linked two-step simulation process. First, the model simulated the fecal coliform concentration associated with the runoff (PQAL module of the PERLND section). Then, this load was transported in the different reaches using the GQAL module of the RCHRES section.

The PQAL module of HSPF was used to simulate the fecal coliform wash-off from the different land uses. The QUALOF option of PQAL was used to simulate the accumulation and removal of fecal coliform from the land by overland flow.

Next, the total fecal coliform loads for each source animal type were distributed over each of the land use categories that it occupies. Each animal type was evenly distributed over each of the land use categories that it occupies and the total fecal coliform loads for each animal type are spread evenly over the land use on a per acre basis. Table 4-3 shows the fecal coliform bacteria loading rate assumptions used for each species modeled and provides references for each assumption used.

Table 4-2. Input Parameters used in HSPF Simulation for Four Mile Run

PARAMETER	DEFINITION	UNITS	RANGE OF VALUES				FINAL CALIB.	FUNCTION OF…
			TYPICAL		POSSIBLE			
PERLND Parameters			MIN	MAX	MIN	MAX		
PWAT-PARM2								
FOREST	Fraction forest cover	none	0.00	0.5	0	0.95	0.1	Forest cover
LZSN	Lower zone nominal soil moisture storage	inches	3	8	2	15	5	Soil properties
INFILT	Index to infiltration capacity	in/hr	0.01	0.25	0.001	0.5	0.042	Soil and cover conditions
LSUR	Length of overland flow	feet	200	500	100	700	300	Topography
SLSUR	Slope of plane of overland flow	none	0.01	0.15	0.001	0.3	0.027-0.037[1]	Topography
KVARY	Groundwater recession variable	1/in	0	3	0	5	0	Calibrate
AGWRC	Base groundwater recession	none	0.92	0.99	0.85	0.999	0.988	Calibrate
PWAT-PARM3								
PETMAX	Temp below which ET is reduced	deg. F	35	45	32	48	40	Climate, vegetation
PETMIN	Temp below which ET is set to zero	deg. F	30	35	30	40	35	Climate, vegetation
INFEXP	Exponent in infiltration equation	none	2	2	1	3	2	Soil properties
INFILD	Ratio of max/mean infiltration capacities	none	2	2	1	3	2	Soil properties
DEEPFR	Fraction of GW inflow to deep recharge	none	0	0.2	0	0.5	0	Geology
BASETP	Fraction of remaining ET from baseflow	none	0	0.05	0	0.2	0	Riparian vegetation
AGWETP	Fraction of remaining ET from active GW	none	0	0.05	0	0.2	0	Marsh/wetlands ET
PWAT-PARM4								
CEPSC	Interception storage capacity	inches	0.03	0.2	0.01	0.4	0.1	Vegetation
UZSN	Upper zone nominal soil moisture storage	inches	0.10	1	0.05	2	0.1	Soil properties
NSUR	Mannings' n (roughness)	none	0.15	0.35	0.1	0.5	0.2	Land use, surface condition
INTFW	Interflow/surface runoff partition parameter	none	1	3	1	10	0.7[2]	Soils, topography, land use
IRC	Interflow recession parameter	none	0.5	0.7	0.3	0.85	0.5	Soils, topography, land use
LZETP	Lower zone ET parameter	none	0.2	0.7	0.1	0.9	0.4	Vegetation
QUAL-INPUT								
ACQOP	Rate of accumulation of constituent	#/day					8.15E9 – 1.44E10[1]	Land use
SQOLIM	Maximum accumulation of constituent	#					6.5 - 9 x ACQOP[1,4]	Land use
WSQOP	Wash-off rate	in/hr					2.0	Land use
IOQC	Constituent conc. in interflow	$\#/ft^3$					141,584	Calibrate
AOQC	Constituent conc. in active groundwater	$\#/ft^3$					4248	Land use

[1] Varies by individual PERLND model segments
[2] Value is outside suggested range for most HSPF applications, but acceptable for this urban application
[3] Varies with land use and PERLND model segments
[4] Varies monthly

Table 4-2 (Cont). Input Parameters used in HSPF Simulation for Four Mile Run

PARAMETER	DEFINITION	UNITS	RANGE OF VALUES TYPICAL MIN	TYPICAL MAX	POSSIBLE MIN	POSSIBLE MAX	FINAL CALIB.	FUNCTION OF…
IMPLND Parameters								
IWAT-PARM2								
LSUR	Length of overland flow	feet	200	500	100	700	468-2538[1,2]	Topography
SLSUR	Slope of plane of overland flow	none	0.01	0.15	0.001	0.3	0.027-0037[1]	Topography
NSUR	Mannings n (roughness)	none	0.15	0.35	0.1	0.5	0.1	Land use, surface condition
RETSC	Retention/interception storage capacity	inches	0.03	0.2	0.01	0.4	0.065	Land use, surface condition
IWAT-PARM3								
PETMAX	Temp below which ET is reduced	deg. F	35	45	32	48	40	Climate, vegetation
PETMIN	Temp below which ET is set to zero	deg. F	30	35	30	40	35	Climate, vegetation
IQUAL								
ACQOP	Rate of accumulation of constituent	#/day					ACQOP for PERLND/33	Land use
SQOLIM	Maximum accumulation of constituent	#					4 x ACQOP	Land use
WSQOP	Wash-off rate	in/hr					0.2	Land use
RCHRES Parameters								
HYDR-PARM2								
KS	Weighting factor for hydraulic routing						0.5	
FSTDEC	First order decay rate of the constituent	1/day					1	
THFST	Temperature correction coeff. for FSTDEC						2	

[1] Varies by individual IMPLND

[2] Value is outside suggested range for most HSPF applications, but acceptable for this urban application (combines overland flow + storm drainage for typical flow path)

Table 4-3. Modeled Fecal Coliform Bacteria Loading Rates by Host Species

Host Species	Fecal Coliform Production (count/animal/day)	Reference:
Waterfowl	7.99E+08	Canada Goose values from Accotink Creek TMDL, North River TMDL
Raccoon	4.09E+09	Best professional judgment
Human	1.88E+11	Mara & Oragui, 1981 (septic system equivalent)
Dog	4.09E+09	Long Island Regional Planning Board, 1978
Deer	5.00E+08	Interpolated from Metcalf & Eddy, 1991
Other Wildlife	1.88E+08	Average of four literature values for chicken

In the case of raccoon, literature values varied over an order of magnitude, with the majority of estimates given as greater than domesticated dog. Since estimates for dogs are known with more precision, and since adult raccoons typically have the body mass and food consumption of small adult dogs, the value for raccoon was set as being equivalent to that of dog.

Only one literature value was found for deer, which was used in several TMDL studies in Virginia, and it was not measured directly. The value for deer is nearly an order of magnitude below that for dog and raccoon. This is counterintuitive given that the typical adult body mass of deer is greater than that of dog and raccoon. For this reason, estimated deer densities provided in Table 4-4 are greater than suspected by naturalists most familiar with the watershed to generate the in-stream loadings suggested by the DNA study provided in Appendix A.

Table 4-4 shows the animal population densities by land use that were used for pervious segments (PERLNDs) in the TMDL model. These land use-specific population densities were arrived at with the aid of a spreadsheet through an iterative process to mimic daily bacteria loadings in proportion to the DNA evidence discussed in Chapter 3, as refined by interviews from the five naturalists. That is, while bacteria production rates for each animal were held constant using the values presented in Table 4-3, population densities for each animal were varied by land use in order to produce bacteria loads in proportion to the DNA evidence.

For pervious areas, daily bacteria loading rates for each animal source by land use were obtained by multiplying the animal densities presented in Table 4-4 by the daily fecal coliform bacteria production rates presented in Table 4-3. This information is presented in Table 4-5. The actual daily bacteria loading rates for each PERLND used in the model were obtained by summing the loading rates for each animal source, and is presented in Table 4-6.

The DNA sampling was not sufficient to note seasonal differences in animal sources, and there is no evidence to suggest that human and pet populations vary year-round in the Four Mile Run watershed. Additionally, while some waterfowl species are seasonally abundant, local naturalists note that resident waterfowl populations in urbanized regions are becoming increasingly important. These naturalists also note that no significant hibernation occurs among wintertime wildlife in the Four Mile Run watershed, although certain species slow their metabolism to conserve energy during the coldest months. As a simplifying modeling assumption, daily bacteria accumulation values (ACCUM) were held constant year-round in the model.

However, as presented in Section 2.3.1, there is a weak seasonal trend to bacteria values found in Four Mile Run. Since the primary bacteria sources have nearly constant year-round populations, the seasonal difference is presumed to be primarily attributable to differences in die-off kinetics. NVRC's current research on bacteria die-off in storm drains shows evidence that suggests greater bacteria die-off in open channels during colder months, even as the storm drains tend to generate higher bacteria densities year-round (NVRC, 2002, unpublished data). As of this writing, the fieldwork and data collection for this storm drain research are nearly complete, and the analysis and report are expected to be completed by June 30, 2002. This evidence, along with the information presented in Section 2.3.1, suggests that die-off rates for bacteria should be adjusted seasonally. However, the adjustment applied to this TMDL model is much less than an order of magnitude. Model representation of bacteria die-off is primarily controlled by SQOLIM, which is explained in Section 4.8.2. Trial-and-error was used to determine the seasonal adjustment needed to provide the best approximation of observed bacteria values across the seasons during the simulated calibration and verification period. SQOLIM is varied in the model by providing 12 monthly values. The values are applicable for the first day of each month, and a linear interpolation is used to compute values for the rest of the year. A monthly SQOLIM table is presented for PERLNDs in Table 4-7.

For impervious segments (IMPLNDs) in the model, daily bacteria loads were obtained simply by taking each PERLND daily loading rate and dividing by a factor of 33. This factor is identical to that used in the Accotink Creek TMDL model (USGS, 2002, unpublished data). Unfortunately, this is an area for which very little research is available to guide the TMDL modeler. Although it seems intuitive that bacteria loading rates should be lower on impervious surfaces than pervious surfaces, there are no literature values to guide the selection of an impervious bacteria loading rate for different animals. This is because most studies have focused on impacts from livestock where impervious surfaces are not an issue. Bannerman (1993) and MS4 data from Arlington County (2001) have shown, however, that whatever the loading rates, fecal coliform bacteria counts from impervious surfaces are often in the tens of thousands colony-forming units (cfu) per 100 mL of water from stormwater runoff.

Table 4-4. Modeled Animal Densities by Land Use

Land Use	Density/acre[1]					
	Waterfowl	**Raccoon**	**Human[2]**	**Dog[3]**	**Deer**	**Other[4] Wildlife**
Open Space/Parks	6.0	0.45	0.0007	0.12	3.0	8.0
Highway	0.5	1.0	0.0008	0.3	0	5.0
Medium to High Density Mixed Use	3.0	1.0	0.03	0.4	0	3.5
Medium to High Density Industrial	2.2	0.9	0.03	0.27	0.2	10.0
Public/Conservation/Golf	6.0	0.45	0.0007	0.12	3.0	8.0
High Density Residential	4.1	0.5	0.019	0.25	0.2	3.0
Medium Density Residential	4.0	0.48	0.0095	0.32	1.2	7.0
Medium to High Density Residential	3.0	0.45	0.021	0.2	0.2	2.0
Medium to High Density Commercial	3.0	0.45	0.024	0.12	0	2.6
Low to Medium Density Residential	3.3	0.48	0.0028	0.62	1.2	8.4
Low Density Commercial	4.5	0.65	0.016	0.13	0.4	8.0
Low Density Industrial	4.5	0.52	0.016	0.22	0.6	8.0
Low Density Mixed Use	4.0	0.48	0.01	0.32	1.2	7.0
Federal	4.5	0.65	0.016	0.13	0.4	8.0

[1] Density values reflect the best professional judgment from a combination of factors, including in-stream DNA matches, long-term field observations, and adjustments to account for differing bacteria die-off rates among host species.

[2] Human population density reflects contributions from only sanitary sewer cross-connections and homeless assuming a per-capita septic system equivalent load.

[3] Dog densities reflect "non-picked-up" population only

[4] Other wildlife densities as estimated in equivalent chickens

Table 4-5. Modeled Animal Loadings on Pervious Lands by Land Use

Land Use	PERLNDs[1]	Waterfowl		Raccoon		Human		Canine		Deer		Other Wildlife	
		#/ac.	#/ac./day	#/ac.	#/ac./day	#/ac.	#/ac./day	#/ac.	#/ac./day	#/ac.	#/ac./day	#/ac.	#/ac./day
Open Space/Parks	101, 201, 301	6.0	4.79E+09	0.45	1.84E+09	0.0007	1.31E+08	0.12	4.9E+08	3	1.5E+09	8	1.5E+09
Highway	102, 202, 302	0.5	4E+08	1	4.09E+09	0.008	1.5E+09	0.3	1.23E+09	0	0	5	9.38E+08
Med-Hi Dens Mixed	103, 203, 303	3.0	2.4E+09	1	4.09E+09	0.03	5.63E+09	0.4	1.63E+09	0	0	3.5	6.57E+08
Med-Hi Dens Industry	104, 204, 304	2.2	1.76E+09	0.9	3.68E+09	0.03	5.63E+09	0.27	1.1E+09	0.2	1E+08	10	1.88E+09
Public/Conserv/Golf	105, 205, 305	6.0	4.79E+09	0.45	1.84E+09	0.0007	1.31E+08	0.12	4.9E+08	3	1.5E+09	8	1.5E+09
Hi Dens Residential	106, 206, 306	4.1	3.28E+09	0.5	2.04E+09	0.019	3.56E+09	0.25	1.02E+09	0.2	1E+08	3	5.63E+08
Med Dens Residential	107, 207, 307	4.0	3.2E+09	0.48	1.96E+09	0.0095	1.78E+09	0.32	1.31E+09	1.2	6E+08	7	1.31E+09
Med-Hi Dens Resid	108, 208, 308	3.0	2.4E+09	0.45	1.84E+09	0.021	3.94E+09	0.2	8.17E+08	0.2	1E+08	2	3.75E+08
Med-Hi Dens Commerc	109, 209, 309	3.0	2.4E+09	0.45	1.84E+09	0.024	4.5E+09	0.12	4.9E+08	0	0	2.6	4.88E+08
Low-Med Dens Resid	110, 210, 310	3.3	2.64E+09	0.48	1.96E+09	0.0028	5.25E+08	0.62	2.53E+09	1.2	6E+08	8.4	1.58E+09
Low Dens Commercial	111, 211, 311	4.5	3.6E+09	0.65	2.66E+09	0.016	3E+09	0.13	5.31E+08	0.4	2E+08	8	1.5E+09
Low Dens Industrial	112, 212, 312	4.5	3.6E+09	0.52	2.12E+09	0.016	3E+09	0.22	8.99E+08	0.6	3E+08	8	1.5E+09
Low Dens Mixed Use	113, 213	4.0	3.2E+09	0.48	1.96E+09	0.01	1.88E+09	0.32	1.31E+09	1.2	6E+08	7	1.31E+09
Federal	214, 314	4.5	3.6E+09	0.65	2.66E+09	0.016	3E+09	0.13	5.31E+08	0.4	2E+08	8	1.5E+09

[1] Not all land uses are present in each model segment

Land Use	PERLNDs and IMPLNDs	ACQOP (Build-up) #/acre/day	
		PERLND	IMPLND
Open Space/Parks	101, 201, 301	1.03E+10	3.11E+08
Highway	102, 202, 302	8.15E+09	2.47E+08
Med-Hi Dens Mixed	103, 203, 303	1.44E+10	4.36E+08
Med-Hi Dens Industry	104, 204, 304	1.41E+10	4.28E+08
Public/Conserv/Golf	105, 205, 305	1.03E+10	3.11E+08
Hi Dens Residential	106, 206, 306	1.06E+10	3.20E+08
Med Dens Residential	107, 207, 307	1.02E+10	3.08E+08
Med-Hi Dens Resid	108, 208, 308	9.47E+09	2.87E+08
Med-Hi Dens Commerc	109, 209, 309	9.71E+09	2.94E+08
Low-Med Dens Resid	110, 210, 310	9.83E+09	2.98E+08
Low Dens Commercial	111, 211, 311	1.15E+10	3.48E+08
Low Dens Industrial	112, 212, 312	1.14E+10	3.46E+08
Low Dens Mixed Use	113, 213	1.03E+10	3.11E+08
Federal	214, 314	1.15E+10	3.48E+08

Table 4-6. Total Modeled Fecal Coliform Loadings by Land Use

Table 4-7. Maximum Limits of Fecal Coliform Accumulation (SQOLIM, #/ac.) for Seasonally Adjusted Die-off

PERLNDs*	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
101, 201, 301	6.67E+10	6.67E+10	7.18E+10	7.69E+10	8.20E+10	8.72E+10	9.23E+10	9.23E+10	8.72E+10	8.20E+10	7.69E+10	7.18E+10
102, 202, 302	5.30E+10	5.30E+10	5.70E+10	6.11E+10	6.52E+10	6.93E+10	7.33E+10	7.33E+10	6.93E+10	6.52E+10	6.11E+10	5.70E+10
103, 203, 303	9.36E+10	9.36E+10	1.01E+11	1.08E+11	1.15E+11	1.22E+11	1.30E+11	1.30E+11	1.22E+11	1.15E+11	1.08E+11	1.01E+11
104, 204, 304	9.19E+10	9.19E+10	9.90E+10	1.06E+11	1.13E+11	1.20E+11	1.27E+11	1.27E+11	1.20E+11	1.13E+11	1.06E+11	9.90E+10
105, 205, 305	6.67E+10	6.67E+10	7.18E+10	7.69E+10	8.20E+10	8.72E+10	9.23E+10	9.23E+10	8.72E+10	8.20E+10	7.69E+10	7.18E+10
106, 206, 306	6.87E+10	6.87E+10	7.40E+10	7.92E+10	8.45E+10	8.98E+10	9.51E+10	9.51E+10	8.98E+10	8.45E+10	7.92E+10	7.40E+10
107, 207, 307	6.60E+10	6.60E+10	7.11E+10	7.62E+10	8.13E+10	8.64E+10	9.14E+10	9.14E+10	8.64E+10	8.13E+10	7.62E+10	7.11E+10
108, 208, 308	6.15E+10	6.15E+10	6.63E+10	7.10E+10	7.57E+10	8.05E+10	8.52E+10	8.52E+10	8.05E+10	7.57E+10	7.10E+10	6.63E+10
109, 209, 309	6.31E+10	6.31E+10	6.80E+10	7.29E+10	7.77E+10	8.26E+10	8.74E+10	8.74E+10	8.26E+10	7.77E+10	7.29E+10	6.80E+10
110, 210, 310	6.39E+10	6.39E+10	6.88E+10	7.37E+10	7.87E+10	8.36E+10	8.85E+10	8.85E+10	8.36E+10	7.87E+10	7.37E+10	6.88E+10
111, 211, 311	7.46E+10	7.46E+10	8.04E+10	8.61E+10	9.19E+10	9.76E+10	1.03E+11	1.03E+11	9.76E+10	9.19E+10	8.61E+10	8.04E+10
112, 212, 312	7.42E+10	7.42E+10	7.99E+10	8.57E+10	9.14E+10	9.71E+10	1.03E+11	1.03E+11	9.71E+10	9.14E+10	8.57E+10	7.99E+10
113, 213	6.66E+10	6.66E+10	7.18E+10	7.69E+10	8.20E+10	8.72E+10	9.23E+10	9.23E+10	8.72E+10	8.20E+10	7.69E+10	7.18E+10
214, 314	7.46E+10	7.46E+10	8.04E+10	8.61E+10	9.19E+10	9.76E+10	1.03E+11	1.03E+11	9.76E+10	9.19E+10	8.61E+10	8.04E+10

* Not all land uses are present in each model segment

4.8 Existing Scenario Conditions

The water quality calibration runs were performed using the existing condition scenario. The intent of this scenario is to reproduce the long-term average fecal coliform fate and transport in the watershed. The simulation period selected for the calibration is from January 1, 1999 to May 31, 2001, which is the same as the hydrology calibration period. Bacteria calibration by matching simulated output to observed values is constrained by the following:

- The model generates a daily mean value, but observed data are from instantaneous grab samples. Bacteria data is notoriously variable, and often fluctuates by an order of magnitude over the course of a day, even during seemingly static baseflow conditions (Gregory, 2001).
- Observed data is often constrained by upper and lower detection limits. For example, of the 11 observed fecal coliform values collected by VADEQ in the model's calibration dataset, three are at a lower detection limit of 100, one is at a lower detection limit of 25, and one is at an upper detection limit of 8,000.
- Nearly all of the bacteria data were collected during baseflow periods. Only one storm was chased for collection of fecal coliform data, and this was for NVRC's BST study, which used 1,600 cfu/100mL as its upper detection limit. All the samples collected during this storm (from July 14, 2000) were at this upper detection limit.

4.8.1 Water Quality Parameters

Several variables in the water quality model affect the simulation of the amount of fecal coliform washed off the land and transported through the Four Mile Run sub-watersheds. Table 4-2 summarizes the final water quality calibration parameters for the Four Mile Run watershed. The most important variables are discussed below.

Rate of Surface Runoff That Removes 90 Percent of Stored Fecal Coliform Per Hour

One of the key parameters in the PQAL section that drives the amount of fecal coliform washed off the land is the rate of surface runoff that will remove 90 percent of stored fecal coliform per hour (WSQOP). WSQOP measures the susceptibility of the fecal coliform to wash off and adjusting it will change the fecal coliform peak concentrations during storm events. The final value used for the calibration is 2.0 inches per hour for pervious areas and 0.2 inches per hour for impervious areas, reflecting the reality that runoff from impervious surfaces occurs much more readily than runoff from pervious surfaces.

First Order Decay Rates of Fecal Coliform

Die-off from the pervious portions of the watershed was modeled with HSPF's first-order decay function. For all general quality constituents, the REMQOP factor is approximately equal to the first order decay coefficient, k. Thelin and Gifford (J. Environ. Qual. 12(1): 57-63) empirically determined this coefficient to be 0.11. Since REMQOP = ACQOP/SQOLIM, SQOLIM can be expressed as a multiple of ACQOP. Thus, the multiplication factor (MF) is the inverse of k=0.11, or 9, which was the peak summertime value used in the Four Mile Run model for each PERLND. This MF was varied monthly to account for observed seasonal differences in die-off noted in Section 2.3.1. The MF ranged from a low of 6.5 in January and February to a high of 9.0 in July and August, and is controlled by the monthly inputs for SQOLIM presented in Table 4-7.

Impervious portions of the watershed also used the first order decay function. In research conducted by Olivieri et al, 1977, bacteria concentrations in urban streams was independent of the days since the last rainfall event, indicating either a very rapid buildup or an accumulation limit (maximum loading) not much greater than daily loading. Thus, a lower multiplication factor is expected for IMPLNDs than for PERLNDs, and an MF of 4 was arrived at through calibration.

In-stream die-off was also included in the model for which FSTDEC was set equal to 1.0. The transport of fecal coliform in model reaches uses the GQAL section of the RCHRES module. The key input parameter for the GQAL section is first order in-stream decay of fecal coliform. The value used in the calibration is at the low end of the published range of one to five and one half/day (Thomann, 1987) to reflect the limited in-stream bacteria die-off when compared with more pristine streams. However, this variable was not sensitive to the final simulated fecal coliform concentrations in the stream.

4.8.2 Results of the Water Quality Calibration

This section presents the analysis of the calibration results and discusses the main fecal coliform component loads in Four Mile Run. The calibrated model runs identify the major sources and their potential impact on the development of allocation scenarios. The model was run for the period from January 1999 to May 2001. Figures 4-9 and 4-10 show the results of the final water quality calibration run. These figures indicate reasonably good agreement between observed and simulated values.

The main objective of the calibration runs was to get the best fit possible between simulated fecal coliform values and the range of observed and simulated fecal coliform data. However, when calibrating integrated watershed models such as HSPF, the objective is not to match exactly each simulated and observed observation, but to make sure that the long term simulated water quality response captures the range of observed values which better describes and reproduces the response in the watershed.

As mentioned at the beginning of Section 4.8, one of the main reasons for wide discrepancies between simulated and observed bacteria values is that field measurements of bacteria are nearly always instantaneous grab samples, which can be highly variable across the course of each day, whereas simulated values are computed as daily averages. This is shown in Figures 4-9 and 4-10 where some of the observed-instantaneous fecal coliform values differ from their corresponding simulated values. Also, it is likely that had the observed data that was constrained by the upper and lower detection limits been allowed to reflect accurate readings, a somewhat better fit would have been demonstrated. Overall, however, the model used for this TMDL captures the range of observed values sufficiently well.

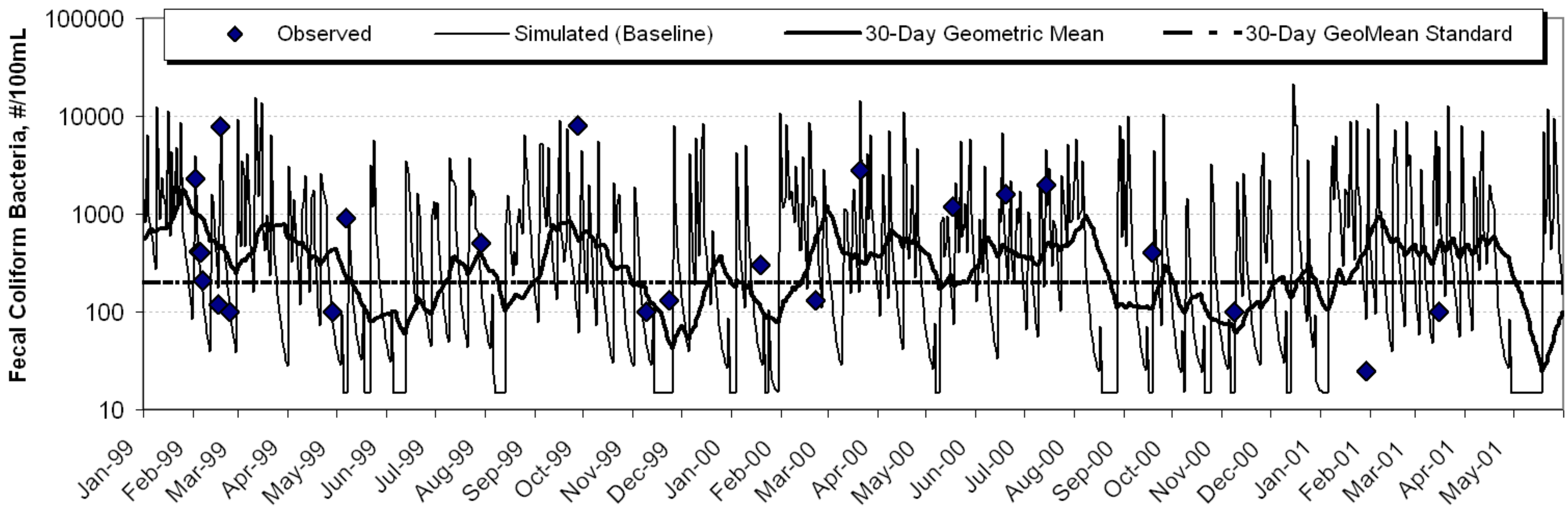


Figure 4-9. Simulated and Observed Daily Fecal Coliform, Log Scale

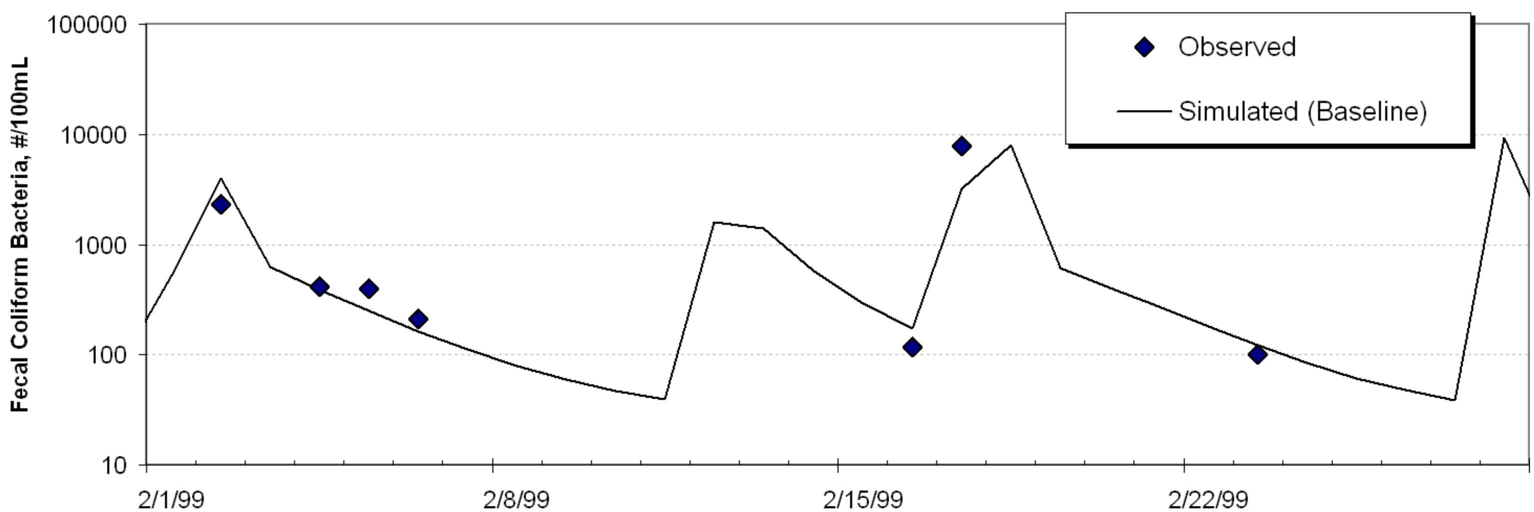


Figure 4-10. Sample Detail of Simulated and Observed Daily Fecal Coliform, Log Scale

5. Load Allocations

5.1 Background

The objective of a TMDL plan is to allocate allowable loads among the various pollutant sources so that the appropriate control actions can be taken to achieve water quality standards. The specific objective of the TMDL plan in Four Mile Run is to determine the required reductions in fecal coliform loadings from various non-point sources in order to meet state water quality standards. The state water quality standard for fecal coliform used in the TMDL development is the 30-day geometric mean of 200 counts/100 mL. The incorporation of the different sources into the TMDL is defined in the following equation (USEPA, 1999):

$$TMDL = WLA + LA + MOS$$

Where:

WLA	=	waste load allocation (point sources)
LA	=	load allocation (non-point sources)
MOS	=	margin of safety

The margin of safety (MOS) is included in the TMDL development process to account for any uncertainty on loadings and the fate of fecal coliforms in Four Mile Run. There are two basic approaches for incorporating the MOS (USEPA, 1999):

- The MOS is implicitly incorporated using conservative model assumptions to develop allocations or
- The MOS is explicitly specified as a portion of the total TMDL and the remainder is used for the allocations.

The allocation scenario for Four Mile Run was designed to meet the water quality standard of a geometric mean of 200 counts/100 mL. An MOS of 5 percent was incorporated explicitly in the TMDL equation by reducing the target fecal coliform concentration from 200 counts/100 mL to 190 counts/100 mL. In other words, the simulated concentrations were compared to a target of a geometric mean (of 30 data points) of 190 counts/100 mL. The time period selected for the load allocation covers the same period used in the water quality calibration (January 1999 to May 2001) and it includes both high and low flow conditions. The results of the simulation for the existing conditions are presented in Section 5.5.3.

5.2 Allocations Scenarios

The TMDL development requires that the level of reduction from each pollutant in a watershed be determined in order to meet the applicable water quality standard. The TMDL comprises the sum of individual waste load allocations (WLAs) for point sources and load allocations (LAS) for non-point sources. However, as explained in the following section, there are no WLAs for fecal coliform bacteria in the nontidal portion of the Four Mile Run watershed.

5.2.1 Wasteload Allocations

There are no VPDES permits that allow discharge of fecal coliform from point sources to the nontidal portion of Four Mile Run. Arlington County's 30 million gallon/day sewage treatment plant discharges downstream of the tidal/non-tidal boundary of this TMDL and easily complies with its 200 counts/100 mL limits specified in its VPDES permit. However, because the counties of Arlington and Fairfax have existing municipal separate storm sewer (MS4) permits, and because Alexandria and Falls Church are expected to receive MS4 permits in the near future, wasteload allocations (WLAs) for this TMDL were developed based on contributions from impervious surfaces in the study area. The basis for these impervious contributions is explained in Section 4.7.

5.2.2 Load Allocations

Four load allocation scenarios were evaluated to meet the TMDL goal of a 30-day geometric mean of 190 counts/100 mL. These scenarios are summarized in Table 5-1, and the modeling results for each scenario are shown in Figure 5-1.

Scenario 1 assesses the fecal coliform contribution of wildlife to Four Mile Run, with a 95% reduction in loadings from humans and dogs. The objective of this initial scenario is to assess the possibility of developing a TMDL allocation plan that meets state water quality standards only by reducing sources of fecal coliform caused by human activities, including management of pet waste. Scenario 1 indicates that the fecal coliform due to wildlife causes concentrations in the stream to violate the 30-day geometric mean 54% of the time. This scenario indicates that eliminating load allocations of fecal coliform caused by human activities (including controlling 95% of the pet waste) will not provide a TMDL that meets the Virginia water quality standards.

Table 5-1. Existing Conditions and TMDL Allocation Scenarios for Four Mile Run

	Reduction in Loadings from Existing Conditions (%)					% days Geometric Mean > than 190 MPN/100mL
	Waterfowl	Raccoon	Human	Dog	Other Wildlife	
Existing Conditions	0	0	0	0	0	65
Scenario 1	0	0	95	95	0	54
Scenario 2	50	50	95	95	0	41
Scenario 3	80	80	98	98	80	8
Scenario 4	95	95	98	98	95	0

Scenario 2 assesses the impact of reducing by 95% the direct sources from human activities (including pet waste) and a 50% reduction in anthropogenic wildlife (resident urban waterfowl and raccoons). Under this scenario the 30-day geometric mean, with the margin of safety, is exceeded 41 percent of the time, which indicates that further load reductions are needed.

Scenario 3 examines the benefits of reducing fecal coliform bacteria from all wildlife sources by 80% and from humans and dogs by 98%. Under this scenario, bacteria counts are expected to exceed the 190 TMDL limit eight percent of the time.

Scenario 4 is the only modeled scenario that is demonstrated to achieve the goals of the TMDL. It considers the case of controlling 98% of the fecal coliform bacteria from humans and dogs, as well as 95% of the bacteria from all wildlife. Loadings from this scenario for each land use are presented in Table 5-2, and serve as the basis for the numbers in the final TMDL shown in Table 5-3.

5.3 Future Growth

Although the Four Mile Run watershed is virtually built out in terms of existing land use reflecting current land use plans, the potential exists for small additions of infill development and population expansion. Census data shows that despite being nearly built out, population has increased steadily over the past several decades. For instance, NVRC's analysis of new census data shows an increase of nearly 11 percent from a population of 165,000 in 1990 to 183,000 in 2000. The pet population has almost certainly increased as well, although probably by less than

11 percent, as the majority of newer residents live in multi-family dwellings where pet ownership is restricted and many are recent immigrants that come from cultures with less of a tradition of owning pets. Further, some anthropogenic wildlife species, like resident geese and raccoons, have increased their numbers in the face of urbanization (Hadidian, 1997 and 1991). As a result of the intense development pressures in this watershed, driven largely by infill opportunities, there is reason to suspect that urban wildlife populations may have approached their carrying capacity locally.

Table 5-2. Loadings by Land Use for TMDL Allocation (Scenario 4)

Land Use	Average Annual Loadings for TMDL Scenario (#/year)	
	Pervious Lands	Impervious Lands
Open Space/Parks	1.08E+14	7.11E+10
Highway	5.59E+12	1.52E+12
Med-Hi Dens Mixed	2.68E+13	1.51E+12
Med-Hi Dens Industry	5.72E+12	6.88E+11
Public/Conserv/Golf	9.28E+13	2.46E+11
Hi Dens Residential	1.07E+13	9.73E+11
Med Dens Residential	3.87E+14	7.82E+12
Med-Hi Dens Resid	1.05E+14	3.18E+12
Med-Hi Dens Commerc	9.45E+12	6.62E+11
Low-Med Dens Resid	1.07E+14	1.39E+12
Low Dens Commercial	5.54E+13	1.12E+12
Low Dens Industrial	3.48E+12	1.96E+11
Low Dens Mixed Use	2.13E+13	2.82E+11
Federal	2.38E+13	7.20E+11
Total	***9.61E+14***	***2.04E+13***

The assumptions used in the model to develop estimates of fecal coliform loads are conservative and provide for a reasonable assurance that the estimated loads account for changes in the land use and populations in the Four Mile Run watershed.

5.4 Summary of TMDL Allocation Scenarios in Four Mile Run

A TMDL for fecal coliform has been developed for Four Mile Run and addresses the following issues.

- The TMDL meets the water quality standard based on the 30-day geometric mean, which explicitly incorporates a margin of safety of 5 percent. After the plan is fully implemented, the 30-day geometric mean will not exceed 190 counts/100 mL.
- The TMDL accounts for all fecal coliform sources (human, pets, and wildlife).
- Seasonal variations were explicitly included in the modeling approach for this TMDL. The use of a continuous simulation model explicitly incorporates the seasonal variations of rainfall pattern, simulated runoff, and fecal coliform washoff from the land surfaces.
- The TMDL allocation plan that met the 30-day geometric mean water quality target of 190 counts/100 mL requires a 98% reduction of fecal coliform from human sources, a 98% reduction of fecal coliform from dogs, and a 95% reduction of fecal coliform from all wildlife. This allocation plan is shown as Scenario 4 in Table 5-1, and its land use loadings are presented in Table 5-2.

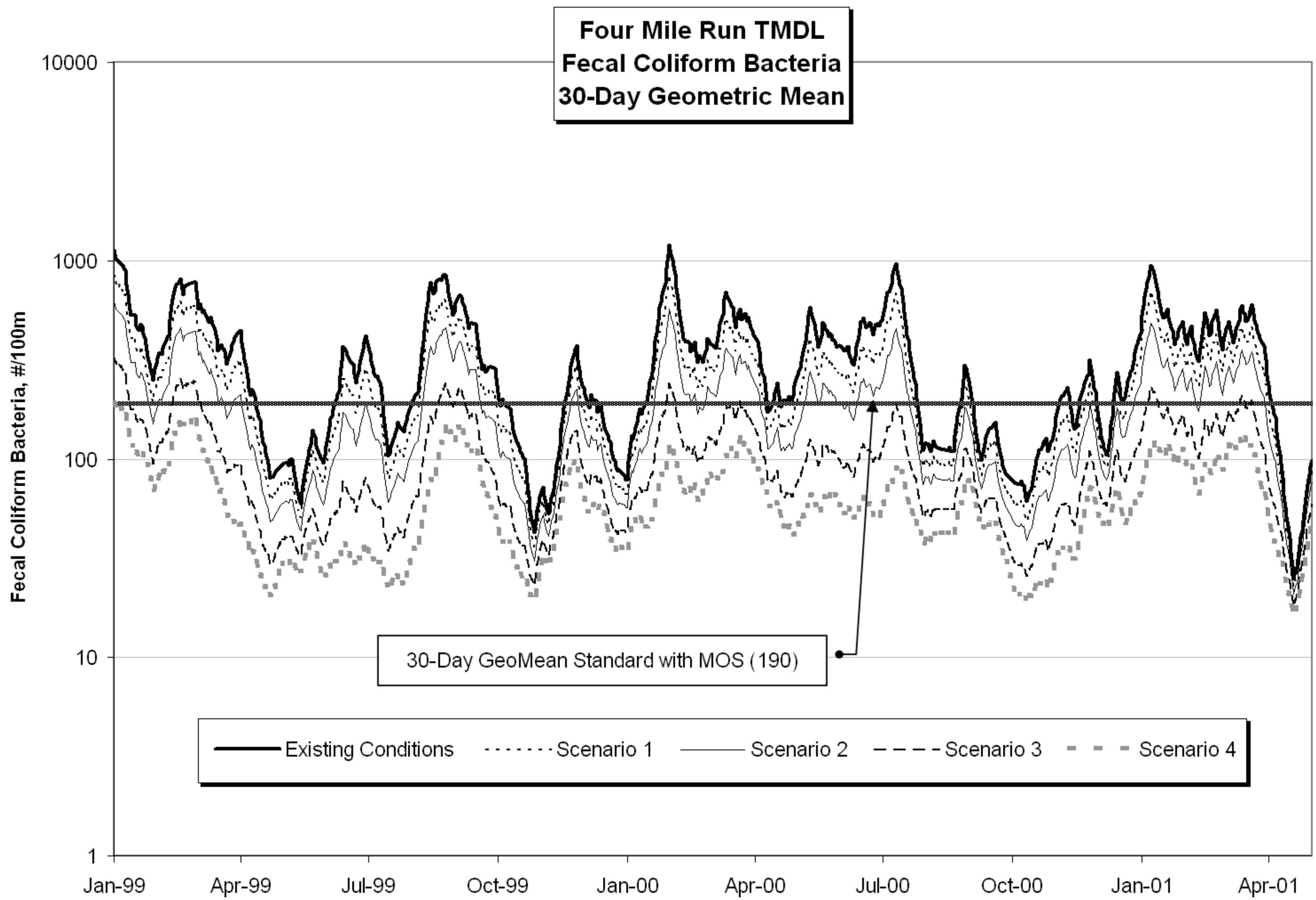


Figure 5-1. 30-Day Geometric Means for Existing Conditions and Four Scenarios

5.4.1 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 Four Mile 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 Four Mile Run were a mixture of dry and wet weather driven sources. TMDL development utilized a continuous simulation model that applies to both high and low flow conditions. Consequently, the critical conditions for Four Mile Run were addressed during TMDL development.

Table 5-3. Annual Fecal Coliform Loadings (counts/year) Used for Developing the Fecal Coliform TMDL for Four Mile Run

Parameter	WLA	LA	MOS*	TMDL
Fecal coliform	2.04E+13	9.61E+14	4.91E+13	1.03E+15

* Five percent of the TMDL

5.5 TMDL Implementation

DEQ intends for this TMDL to be implemented through best management practices (BMPs) in the watershed. Implementation will occur in stages. The benefits of staged implementation are:

1. as stream monitoring continues to occur, it allows for water quality improvements to be recorded as they are being achieved;
2. it provides a measure of quality control, given the uncertainties which exist in any model;
3. it provides a mechanism for developing public support;
4. it helps to ensure the most cost effective practices are implemented initially; and
5. it allows for the evaluation of the adequacy of the TMDL in achieving the water quality standard.

If a staged approach to implementation were followed, a useful interim reduction goal would be to achieve an instantaneous standards violation rate of 10% or less, because under the current monitoring frequency, this would allow Four Mile Run to be removed from the 303d impaired waters list. The scenarios shown in Tables 5-3 and 5-4 offer one approach to staging bacteria reductions. Table 5-4 shows the percent of days that the TMDL model predicts will violate the instantaneous standard for fecal coliform of 1000 MPN/100 mL. This table shows that the instantaneous standard will be met 90% of the time with a scenario that is intermediate of Scenarios 2 and 3, thus achieving this interim reduction goal.

Watershed stakeholders will have opportunity to participate in the development of the TMDL implementation plan. While specific goals for BMP implementation will be established as part of the implementation plan development process, some general guidelines and suggestions are offered below.

Table 5-4. Existing Conditions and TMDL Allocation Scenarios for Staged Implementation

	Reduction in Loadings from Existing Conditions (%)					% days > than 1000 MPN/100mL
	Waterfowl	Raccoon	Human	Dog	Other Wildlife	
Existing Conditions	0	0	0	0	0	24
Scenario 1	0	0	95	95	0	17
Scenario 2	50	50	95	95	0	13
Scenario 3	80	80	98	98	80	4
Scenario 4	95	95	98	98	95	0.1

In general, the Commonwealth intends for the required reductions to be implemented in an iterative process that first addresses those factors with the largest impact on water quality. For example in urban area like the Four Mile Run watershed, reducing the human bacteria loading from damaged or cross-connected sanitary sewer lines could be a focus during the first stage because of its health implications. This component could be implemented through stepped-up sanitary sewer inspections and sewer rehabilitation programs. Other management practices that might be appropriate for controlling urban wash-off from parking lots and roads and that could be readily implemented may include high efficiency street sweeping, improved garbage collection and control, and increasing the number of dog parks and improving their siting and management. Many of these practices have already been initiated and are being implemented in some of the local jurisdictions that share the watershed.

Adding and retrofitting regional ponds, such as those suggested in a report on the feasibility of regional ponds in the Four Mile Run watershed (Northern Virginia Planning District Commission, 1993), has the potential to improve water quality on multiple fronts. It is worth exploring the idea that fecal coliform levels downstream of such facilities may be partially mitigated by designing the pond outlet to release from an optimized depth less affected by bacteria on the water surface or in the sediments. Other possibilities include:

- Reducing bacteria from animal sources through approved, humane control of so-called "nuisance wildlife" like resident urban Canada Geese. A group founded in Northern Virginia—GeesePeace—has taken a lead in this arena. More information on the techniques advocated by this group is available at <www.geesepeace.org>.
- Increasing the opportunities for UV light exposure, which is highly effective at killing fecal coliform bacteria.
- Continuing to track down illicit sewer connections through the use of OBM and other tools.
- Improving enforcement of pooper scooper laws.
- Systematically cleaning out storm drain inlets and catchbasins in the watershed, as Arlington has begun in 2002.
- Increasing public education to improve watershed stewardship, as all four watershed localities have begun to do in earnest.
- Dissuading raccoons from using storm drains for nesting and as toilets by removing ledges and through other humane means. Consider using oral contraceptives for raccoons (bait additives are being developed to fight spread of rabies).
- Restoring stream conditions by exploring opportunities for bio-restoration and storm drain daylighting to encourage bacteria predation from other microbes like paramecium and rotifers.

6. Reasonable Assurance for Implementation

6.1 Follow-Up Monitoring

The Department of Environmental Quality will continue to monitor Four Mile Run in accordance with its ambient monitoring program. VADEQ and VADCR will continue to use data from these monitoring stations to evaluate reductions in fecal bacteria counts and the effectiveness of the TMDL in attaining and maintaining water quality standards.

6.2 Regulatory Framework

This TMDL is the first step toward the expeditious attainment of water quality standards. The second step will be to develop a TMDL implementation plan, and the final step is to implement the TMDL until water quality standards are attained.

Section 303(d) of the Clean Water Act (CWA) and current EPA regulations do not require the development of implementation strategies. However, including implementation plans as a TMDL requirement has been discussed for future federal regulations. Additionally, Virginia's 1997 Water Quality Monitoring, Information and Restoration Act (WQ MIRA) directs VADEQ in Section 62.1-44.19.7 to "develop and implement a plan to achieve fully supporting status for impaired waters". 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 cost, benefits and environmental impact 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, time line, legal or regulatory controls, time required to attain water quality standards, monitoring plan 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 VADEQ, VADCR, and other cooperating agencies.

Much of the Four Mile Run watershed is covered by existing VPDES permits for municipal separate storm sewer system (MS4). These permits are reviewed and re-issued at regular intervals. Recent MS4 permits have included language that recognizes that "it is the intention of the Commonwealth that the TMDL will be implemented using existing regulations and programs, and utilizing 40 CFR §122.44(k) which states that NPDES permit conditions may consist of "Best management practices to control or abate the discharge of pollutants when:…(2) Numeric effluent limitations are infeasible…".

For MS4/VPDES permits, VADEQ expects future permit revisions to require the implementation of BMPs to specifically address the TMDL pollutants of concern. VADEQ anticipates that BMP effectiveness would be determined through routine in-stream monitoring. If future monitoring indicates no improvement in stream water quality, the permit would require the MS4 to expand or better tailor its BMPs to achieve the TMDL reductions. However, only failing to implement the required BMPs would be considered a violation of the permit. DEQ acknowledges that it may not be possible to meet the existing water quality standard because of the wildlife issue associated with certain bacteria TMDLs (see Section 7.4 below). At some future time, it may therefore become necessary to investigate the stream's use designation and adjust the water quality criteria through a Use Attainability Analysis. Any changes to the TMDL resulting from a change in water quality standards for Four Mile Run would be reflected in new or revised MS4/VPDES permits.

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

6.3 Implementation Funding Sources

One potential source of funding for TMDL implementation is Section 319 of the Clean Water Act. In response to the federal Clean Water Action Plan, Virginia developed a Unified Watershed Assessment that identifies watershed priorities. Watershed restoration activities, such as TMDL implementation, within these priority watersheds are eligible for Section 319 funding. Increases in Section 319 funding in future years will be targeted towards TMDL implementation and watershed restoration. Other funding sources for implementation include the USDA's CREP program, the state revolving loan program, and the VA Water Quality Improvement Fund.

6.4 Addressing Wildlife Contributions

In some streams for which TMDLs have been developed, water quality modeling indicate that even after removal of all non-wildlife sources of fecal coliform the streams will not attain standards. Examples include TMDLs for Mountain Run (Yagow, 2001) and Holmans Creek (SAIC, 2001). As is the case for Four Mile Run, TMDL allocation reductions of this magnitude are not realistic and do not meet EPA's guidance for reasonable assurance. Based on the water quality modeling, many of these streams will not be able to attain standards without some reduction in wildlife. **Virginia and EPA are not proposing the elimination of wildlife to allow for the attainment of water quality standards.** This is obviously an impractical action. While managing over-populations 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. In such a case, after demonstrating that the source of fecal contamination is natural and uncontrollable by effluent limitations and BMPs, the state may decide to re-designate the stream's use for secondary contact recreation or to adopt site specific criteria based on natural background levels of fecal coliforms. The state must demonstrate that the source of fecal contamination is natural and uncontrollable by effluent limitations and BMPs through a so-called Use Attainability Analysis (UAA) as described at the end of Section 1.3.3. 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.

Based on the above, EPA and Virginia have developed a TMDL strategy to address the wildlife issue. The first step in this strategy is to develop an interim reduction goal such as the one presented in Section 5.5. The pollutant reductions for the interim goal are applied only to controllable, anthropogenic sources (narrowly defined as humans and pets) identified in the TMDL, setting aside any control strategies for wildlife. During the first implementation phase, all controllable sources would be reduced to the maximum extent practicable using a staged approach. Following completion of the first phase, VADEQ would re-assess water quality in the stream to determine if the water quality standard is attained. This effort will also evaluate if modeling assumptions used in the development of the TMDL were correct. If water quality standards are not being met, a UAA may be initiated to reflect the presence of naturally high bacteria levels attributable to uncontrollable sources. In some cases, the effort may never have to go to the second phase because the water quality standard exceedances that can be ascribed to wildlife in the model are relatively small and infrequent and may fall within the margin of error.

The second phase of the TMDL will result in the attainment of water quality standards. This phase involves a number of components outlined below:

- As described in Section 1.3 of this report, at EPA's recommendation, Virginia (along with other states) is scheduled to adopt a new standard for bacteria later this year. The new standard, based on the more specific E. coli and enterococcus tests, is considered by EPA to be a better indicator of human health risk than the more general fecal coliform standard. VADEQ began collecting E. coli and enterococcus data along Four Mile Run in 2001, and it is possible that the stream will fare better in terms of meeting its designated use under this new standard.
- As described in Section 1.3 of this report, Virginia is considering re-assigning the designated uses of certain streams from primary recreational contact to secondary contact. This would allow a different, more easily attainable, standard to be applied for affected streams. The process of re-designating a stream's use is highly regulated by the State and EPA.
- Another option that EPA allows for the states is to adopt site-specific criteria based on natural background levels of fecal coliforms. The State must demonstrate that the source of fecal contamination is natural and uncontrollable by effluent limitations and BMPs.

6.5 Local Water Quality Programs

In recent years, the four local governments that share the watershed have been actively managing nonpoint source pollution in the Four Mile Run watershed. Unfortunately, most of the current water quality problems are the result of a watershed that was essentially built-out decades prior to the present era of water quality protection. The activities currently being undertaken by all four watershed localities are far-reaching, and a partial list is included in Appendix E.

7. Public Participation

The development of the Four Mile Run TMDL would not have been possible without public participation. The first public meeting was held in Arlington on June 14, 2001 to discuss the water quality data and development of the TMDL. About 25 people attended. Copies of the presentation materials and diagrams outlining the development of the TMDL were available for public distribution. A public notice was placed in the *Virginia Register* about this meeting and a 30 day-public comment period. Four written public comments were received. A second public notice was published in the *Virginia Register* on March 11, 2002 to advertise a second public meeting in Alexandria on March 25, 2002 and a 30 day-public comment period ended on April 9.

Two themes emerged from the first round of comments. One was a desire to increase baseflow to the stream as a means for diluting bacteria levels and to begin to restore more natural background levels of bacteria. There was a desire to see micro-drainage, infiltration BMPs implemented in the watershed in a significant way. A prime example of this class of non-structural BMP is the rain garden, first developed in Prince Georges County, Maryland in the mid-1990s. Although rain gardens are becoming more popular, they are dependent on the availability of well-draining soils or extensive soil conditioning. Overall, the opportunity for wide-scale implementation of micro-drainage solutions in the Four Mile Run watershed is believed to be limited by relatively poorly draining soils and the dominance of small, built-out privately owned lots. Nevertheless, these opportunities, and many more, will be explored in the upcoming implementation phase of the TMDL process.

With regard to this comment, Dr. George Simmons (2001) notes that restoring natural stream functionalities is likely to bring the microbial community back into balance by encouraging greater natural predation by larger microbes like paramecium and rotifers that he believes are more abundant in more pristine streams. For this reason, a sensitivity analysis examined the impact of reducing imperviousness (and increasing baseflow) to determine the model's response to simulated fecal coliform bacteria levels. The results of this analysis showed that if overall imperviousness in the watershed were reduced by ten percent, the percent of days the geometric mean is over the 190 count threshold for baseline conditions drops from 65 to 60. When this ten percent reduction in impervious surfaces is integrated with Scenario 3 (80%

reduction in all wildlife contributions + 98% reduction in contributions from humans and dogs), the percent of days over the 190 count threshold is reduced from 8.2 to 7.7. It should be noted, however, that the exact response to such changes is not known in any way that could be predicted with confidence by any model.

The second theme mentioned in the four written public comments was a strong caution against attempting to change the current designated use of Four Mile Run as a stream used for primary contact recreation. While four voices from within a watershed population of 183,000 is not a consensus, and may not be consistent with the desires of some local government staff, the point was made that Four Mile Run is regularly used for contact recreation primarily because of its sheer proximity to a large urban population and its excellent public access through its greenway park system and popular streamside trails.

Many valuable inputs were received during the second round of comments, and a number have been addressed in the changes made between the draft and final TMDL report. These comments helped make a stronger, more useful TMDL document all-around.

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Appendix A

Estimating Nonpoint Fecal Coliform Sources in Northern Virginia's Four Mile Run Watershed

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ABSTRACT

Pulsed Field Gel Electrophoresis (PFGE) was conducted on *E. coli* DNA from seasonally-varied stream and sediment samples in the ultra-urban Four Mile Run watershed in Northern Virginia. This study found:

1) nonhuman species are the dominant sources of *E. coli* to Four Mile Run and its tributaries; 2) waterfowl contribute over one-third (37%) of those isolates that could be identified; 3) the presence of human *E. coli* is localized; 4) the predominant nonhuman sources are wildlife species that have intimate association with the waterways; 5) the major nonhuman mammal contributors are raccoon, dog, deer, and Norway rat; and, 6) the combined human and canine contribution is approximately 25% of those isolates that could be identified. Finally, circumstantial evidence suggests that without regard to specific host animals, *E. coli* bacteria seem to regrow, through cloning, within the storm drains and stream sediments, which in turn perpetuate elevated fecal coliform levels within the connected surface waters of Four Mile Run.

The continued high levels of *E. coli* suggest an ecosystem out of balance irrespective of the source. It is neither desirable nor practical to eliminate wildlife animal species in the watershed. Rather, it is suggested that, wherever possible, nutrient loadings be controlled to restore a more balanced microbial community to the stream network.

Keywords: urban streams, bacteria, E. coli, Pulsed Field Gel Electrophoresis (PFGE), DNA, storm drains, regrowth, nonpoint source pollution

INTRODUCTION

Since 1990, at least five separate organizations have cumulatively collected over 500 fecal coliform samples from the Four Mile Run watershed. Approximately 50% of these were found to have a Most Probable Number (MPN) greater than 1,000, which exceeds the state's water quality standard of fecal coliform density for the watershed (SWCB, 1997). Four Mile Run is listed as one of the streams on Virginia's 303(d) list of impaired stream segments because of the elevated levels of fecal coliform bacteria (Virginia DEQ, 1998). In addition to violating the fecal coliform standard, the Four Mile Run watershed is given a "high priority" ranking for potential nonpoint source pollution by the Virginia Department of Conservation and Recreation (Virginia DEQ and DCR, 1998), and is designated as a nutrient-enriched waterway by the State Water Control Board (1997).

In the 1992 re-authorization of the federal Clean Water Act, considerable emphasis was placed on developing watershed-based strategies that have potential to reduce nonpoint source pollution in impaired streams. The Northern Virginia Planning District Commission has initiated a phased approach for meeting the mandates of the Clean Water Act for Four Mile Run through a 604(b) Water Quality Grant to

Virginia DEQ (NVPDC, 1998). This research serves as a starting point toward achieving this goal. The purpose of this research project was to determine potential animal sources for fecal coliform contamination of Four Mile Run and its tributaries in Northern Virginia.

<u>Watershed Characteristics</u>

The Four Mile Run watershed (12,600 acres, 19.7 square miles) is a densely populated urban watershed where the dominant land use is medium to high density residential housing. Approximately 165,000 people live in the watershed, resulting in a population density of 13 people per acre (over 8,000 people per square mile) (NVPDC, 1996a). There are two NPDES-permitted point source discharges in the watershed; a concrete batch plant near Shirlington and the Arlington Waste Water Treatment Plant (WWTP) near Route 1. The Arlington WWTP discharges into the tidal portion of Four Mile Run near its confluence with the Potomac River. There are no combined storm/sanitary sewer lines by design, and testing by NVPDC and Arlington County to determine the extent of cross-connections between the sanitary sewer system and the storm sewer system confirms the overall integrity of these separate sewer systems, with only minor problems occasionally discovered.

A very large pet population accompanies a very dense human population in the watershed. An NVPDC analysis from 1994 estimated the canine density of the watershed to be approximately one dog for every 10 people, resulting in a density of 1.3 dogs/acre (over 800 per square mile). The analysis further estimated that more than 2,400 kg (over 5,000 pounds) of fecal waste is deposited in the watershed on a daily basis, which is conservatively based on 150 g of solid waste per dog (one-third of a pound) [1.3 dogs/acre * 12,600 acres]. It was not assumed that all canine waste would make its way into the stream, but that the potential exists for some of this waste to serve as a source of fecal coliforms. Besides humans and dogs, the watershed contains a variety of mammals and waterfowl that have adapted to an urbanized landscape.

METHODS

Details of the sampling protocol and procedures related to Quality Assurance and Quality Control (QA/QC) are contained in a separate QA/QC Plan. Pulsed Field Gel Electrophoresis (PFGE) is a widely used technique to resolve microbial strain recognition in clinical and natural environments (Goering, 1993; Maslow, et al., 1993; Edberg, et al., 1994; Buchrieser, et al., 1995; Tynkkynen, et al., 1999). Details of isolate selection for DNA analyses using the *Not*I restriction enzyme are summarized in the QA/QC document.

<u>Sample Collection, Locations and Times</u>

A total of 55 samples were collected in this study. Fecal coliform density was measured by the Fecal Coliform Direct Test using A-1 medium and the five tube, three dilution technique (Amer. Publ. Health Assoc., *et al*., 1992). Samples were taken from the water column, water-sediment slurries, and sediment cores. The locations for the samples used in this study are presented in Figure 1. Station location and their respective identification numbers are presented in Table 1.

Four seasonally varied sampling periods were used to characterize potential nonpoint fecal coliform sources to the Four Mile Run watershed. These were: August 1998 (summer period); May 1999 (spring period); November 1999 (fall period); and February 2000 (winter period). In addition, fecal coliform density samples were taken in June 2000, but DNA results from this sampling period are not included in this study.

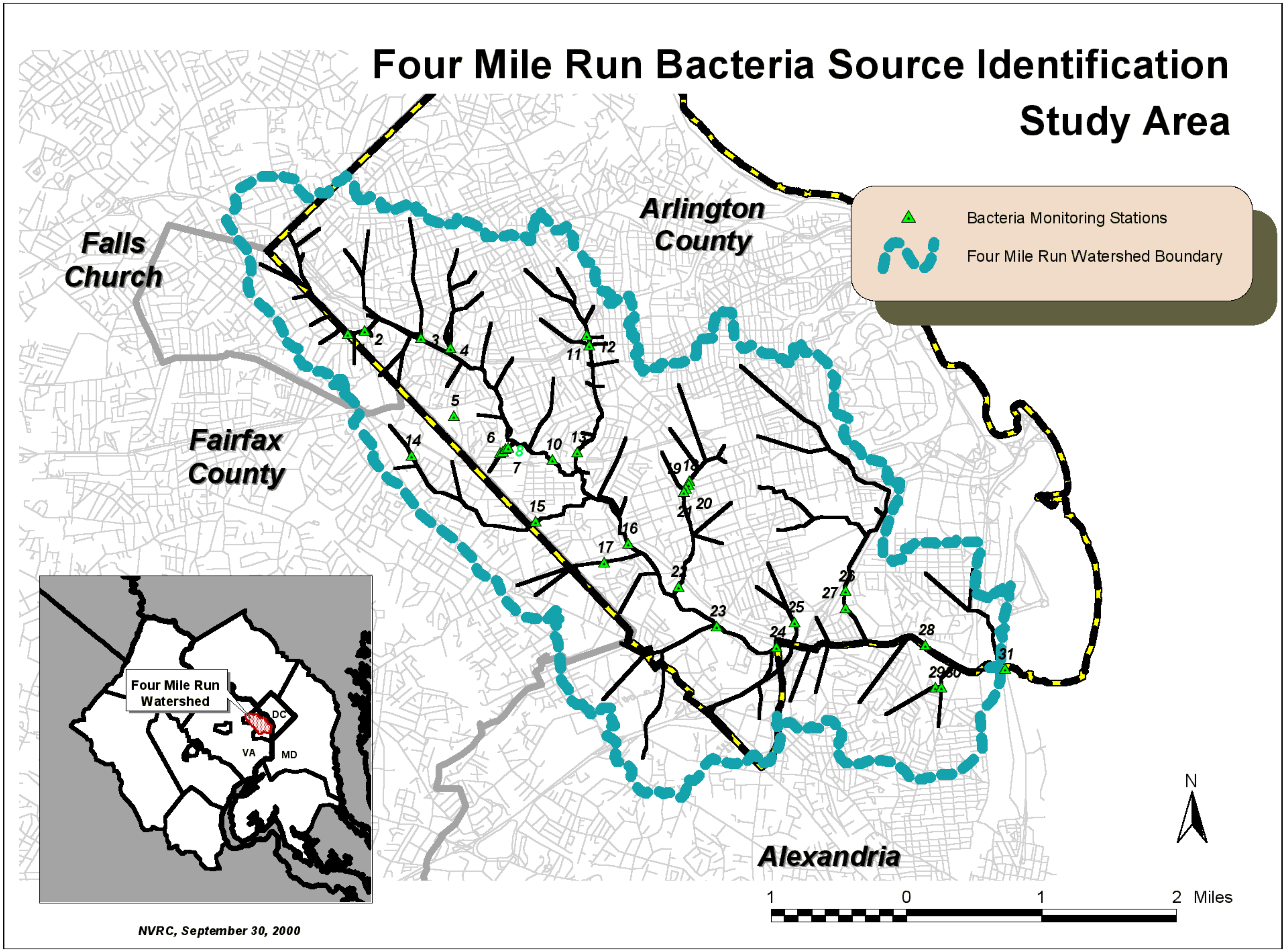

Figure 1. Map of Four Mile Run Watershed with Sample Locations

Table 1. Sample Locations and Identification Numbers

I.D.	Location	Alternate I.D.
1	Upper Four Mile Run at Falls Church line (Van Buren Street)	NVPDC#7
2	Upper Four Mile Run at Sycamore Street	
3	Ohio Street Branch at I-66 outfall	FM200 or FM210, Arlington
4	Westover Branch at I-66, outfall (twin box culvert to right of 2 m [78 in] circ.)	FM230, Arlington
5	Powhatan Run at N. Livingston Road, pristine site	u/s of FM300, Arlington
6	Manchester Street 1.1 m (42 in) outfall (Glencarlyn Branch)	FM 330, Arlington
7	46 m (150 ft) downstream (d/s) of Manchester Street outfall	d/s of FM 330, Arlington
8	91 m (300 ft) d/s of Manchester Street outfall	d/s of FM 330, Arlington
9	137 m (450 ft) d/s of Manchester Street outfall	d/s of FM 330, Arlington
10	Middle Four Mile Run, bike trail crossing just u/s of Rt. 50	NVPDC#6
11	Ballston Beaver Pond, along open channel	Near LR112, Arlington
12	Box culvert under Ballston just d/s of Beaver Pond	
13	Lubber Run at Route 50	NVPDC#5
14	Upper Long Branch d/s of Patrick Henry Drive	
15	Upper Long Branch at Carlin Springs Road	NVPDC#4
16	Four Mile Run at Columbia Pike	1AFOU004.22, Va. DEQ
17	Baileys Branch at S. Frederick Street	FM350, Arlington
18	Doctors Run at S. 6th Street & S. Quincy Street, biggest outfall	DB100, Arlington
19	Doctors Run 61 m (200 ft) d/s of S. 6th Street & S. Quincy Street	d/s of DB100, Arlington
20	Doctors Run 122 m (400 ft) d/s of S. 6th Street & S. Quincy Street	d/s of DB100, Arlington
21	Doctors Run 183 m (600 ft) d/s of S. 6th Street & S. Quincy Street	d/s of DB100, Arlington
22	Doctors Run at Barcroft Park Footbridge	NVPDC#8
23	Lucky Run outfall at Four Mile Run	NVPDC#3
24	Four Mile Run at Shirlington Road	NVPDC#2
25	Nauck Branch	FM450, Arlington
26	Lower Long Branch at I-395 near 28th Street S., outfall—quad box culvert	274 m (900 ft) d/s of LL180, Arlington
27	Lower Long Branch in Arna Valley, 26th Street S.	NVPDC#1
28	Arlington Sewage Treatment Plant outfall	
29	Alexandria trib behind Cora Kelly Community Center, u/s of outfall	
30	Alexandria trib behind Cora Kelly Community Center, corrugated metal pipe outfall	
31	Four Mile Run at George Washington Parkway	1AFOU000.19, Va. DEQ

Statistical Comparison of Populations:

The χ^2 Goodness-of-fit analysis for populations was used to test statistical differences between the *E. coli* clonal populations from the different animal groups based on their PFGE patterns. For these analyses, the entire banding profile (from 780-20 kilobase pairs) was divided into six equal units and the frequency of bands within each unit was used for comparative purposes at $\alpha = 0.10$. The percent of bands within each unit was also presented as a histogram in a separate document to visually display differences in banding patterns between *E. coli* populations of the different animal groups.

Computer-based Search of DNA Library:

The calculated numerical value of each band (molecular size as kb) was loaded into flat files (plain text, ASCII files) with respect to each animal group. All animal groups were then combined to create a single library. A TCL computer program (Tool Command Language©, an embeddable scripting language, release 8.0p2; copyright by the Regents of the University of California, Sun Microsystems, Inc., and other parties) was used to compare *E. coli* strains from field samples with *E. coli* strains from known sources in our library. A band-to-band comparison was made and expressed as a percent similarity. The program allows the investigator to adjust the lower limit of percent comparison (i.e., 75%, 78%, 80%, etc.) between known and unknown strains, and the range of kilobase pairs used for each two bands being compared (i.e. ± 5 kilobase pairs, ± 10 kilobase pairs, etc).

Libraries Used in This Study:

Several DNA libraries were used in this study. The libraries, their respective animal species, and number of PFGE patterns per species are listed in Table 2. The total number of strains used to determine potential animal sources was 843. All *E. coli* strains came from individual animals. Specifically, in the case of humans, the strains came from individuals and not from septic tanks.

Assigning Potential Sources Based on DNA Profile Analysis:

In trying to assign a "best fit," the first factor considered was similarity as measured by the degree of correlation between the strain from an unknown source and a strain from a known animal in the Virginia Tech DNA library. For example, if the DNA bands from a strain of an unknown source matched 90% of the DNA bands with an *E. coli* strain from Canada Goose, and only 82% with a strain from a canine source, it would be concluded that the unknown strain was more likely to come from a Canada Goose because there was a higher correlation with the Canada Goose strain.

However, there were instances where a strain from an unknown source correlated with a human strain and a canine strain at the same similarity (88% for example). In this case, the library provided a match but it was not be possible to differentiate between canine and human. If, however, the unknown strain matched with several human strains and only one canine strain from the library, it was considered to be more likely to come from a human source based on the number of matches. Furthermore, there are fewer human strains in the Virginia Tech DNA library than canine, and if matches were random, then a greater number of canine matches would be expected. However, because *E. coli* from dogs and humans cannot be statistically separated by this methodology used in this study, it is not possible to conclude that the unknown strain is not from a canine source.

If an unknown strain was approximately equally similar to more than one animal group and the number of matches were also approximately equal among animal groups, a visual band-to-band comparison would be made to determine which animal group might be the more likely candidate. The presence or absence of matches in the heavier segments of DNA often provided clues as to the degree of greater similarity because there are many fewer bands in the 750-500 kilobase pair range than below this range.

Geography also played a role given that *E. coli* from known sources from several geographic areas were combined for this study, and given that there is very little known about geographic variability in *E. coli* PFGE patterns from the same animal species. Therefore, if the pattern from an unknown source matched an *E. coli* pattern from a goose in the Cornell library from the Long Island Sound area at 88%, but matched a raccoon strain from the Northern Virginia/Four Mile Run library at 84%, assignment to raccoon would probably be made, assuming a spurious correlation with the goose, and a more likely correlation with the raccoon.

Source ecology also played a factor in assigning most likely sources. In a situation where the strain from an unknown source matched approximately equally with a horse isolate collected from scat in the Rappahannock basin, a raccoon from Northern Virginia, and a pelican from the Chesapeake Bay, it would be concluded that the unknown strain was most likely from the raccoon simply because horses and pelicans are far less common in the study watershed. Another example of the way ecology was considered is a situation of similar correlation with strains from a canine source in the Cornell library and a Norway rat from the Northern Virginia/Four Mile Run library. There are very few Norway rat samples in the Virginia Tech DNA library and the fact that the unknown strain of *E. coli* matched a Norway rat strain was a compelling reason to assign a likely match. That is, all else being equal, the researchers selected matches with those animals in the watershed from which scat had been collected, especially where the researchers believed the species to be underrepresented in the DNA libraries.

However, in some cases source assignments were unclear regardless of consideration of the factors described above. For example, if a strain from an unknown source matched with an *E. coli* strain from bovine (Dr. Eugene Yagow’s library from Virginia’s Rappahannock basin), and that was the only match, then that animal was assigned as the possible source. In this particular case, there are several possible theories that can explain such a match. First, the match of the unknown strain to a bovine source could be false because there are no known bovines living in the Four Mile Run watershed. A second theory is that the match could be misleading because the unknown strain could be a crossover strain of *E. coli* common to multiple animal groups, perhaps picked up by birds feeding on insect larvae in bovine dung, passed through the bird’s digestive tract, and deposited in the watershed by the birds while in transit. A third possibility is that the match might be correct and the data could suggest that *E. coli* from bovine are somehow making their way into the watershed through a presently unknown transport mechanism (such as leachate from restaurant dumpsters). A fourth explanation is that because the *E. coli* populations of bovine and deer are not statistically different from each other (possibly due to the complex ruminant digestive system that each animal groups possesses) the bovine signatures may be serving as surrogates for deer *E. coli*.

RESULTS

Fecal Coliform Densities

Sample locations and results of fecal coliform densities are presented in Table 3. Stormwater outfalls, fine sediments, and samples of microbial films from sediment/water mixture samples tended to have the higher densities. Most Probable Number (MPN) values of ≥1600 were scored as numerical values of 1700 for purposes of calculation.

TABLE 2. Numbers of Isolates from the Different Libraries Used in the Analysis of Potential Fecal Coliform Sources From Study Area Locations

(All library samples maintained by Virginia Tech, *n = 843*)

Eastern Shore/Chesapeake Bay Library (collected 1994 – 1997):

Muskrat	34
Raccoon	71
Deer	39
Beaver	20
Otter	22
Human	67
Canine	42
Laughing Gull	29
Herring Gull	33
Pelican	7
Tern	16
Canada Goose	45
Wood Duck	3
Merganser	5
Porcine	15
Total	*448*

Cornell Long Island Sound Library (collected 1994 – 1997):

Human	7
Raccoon	54
Deer	25
Canine	21
Horse	25
Herring Gull	24
Black Back Gull	16
Canada Goose	14
Black Duck	5
Mallard Duck	9
Mute Swan	14
Mallard Duck	11
Teal	5
Black Duck	26
Total	*256*

Four Mile Run (Northern Va) Library* (collected 1999 – 2000):

Red Fox	5
Raccoon	16
Flying Squirrel	3
Gray Squirrel	5
Opossum	7
Canine	27
Norway Rat:	6
Feline	5
Human	8
Seagull	4
Canada Goose	8
Total	*94*

Yagow (Rappahannock basin) Library (collected 1998 – 1999):

Muskrat	1
Raccoon	1
Deer	3
Beaver	1
Canine	8
Horse	8
Bovine	22
Canada Goose	1
Total	*45*

***** Number of isolates does not correspond with the number of scat samples collected for this study because some samples contained multiple strains of *E. coli* and other samples lacked viable *E. coli*.

DNA Profiles (PFGE Patterns) From Four Mile Run and Its Tributaries

A total of 539 bacterial isolates were removed from 55 samples of either water, a water/sediment mix, or sediment from Four Mile Run and its tributaries during this study period. Of the 539 isolates that were removed for DNA profile analysis, 100 of these could not be analyzed for reasons of taxonomic or restriction failure. The remaining 439 isolates were keyed to *Escherichia coli* (*E. coli*) using the Analytical Profile Index (API 20E) for the Enterobacteriaceae and other gram negative bacteria. These isolates provided the basis for resolving potential animal sources that could contribute to the nonpoint fecal coliform problem in Four Mile Run and its tributaries. Of the 439 isolates, 133 showed no match at 80% similarity ± 10 kilobase pairs (kbp) with any of the 843 strains of *E. coli* from known sources in the Virginia Tech DNA library (Table 2). Twenty-eight (28) isolates from the study matched at equal similarity with multiple strains in the Virginia Tech DNA library, but were inconclusive with regard to a specific species. However, within this group of 28 isolates, all suggested a nonhuman source, and nearly all suggested a nonhuman mammal source. The remaining 278 isolates did show a match at 80% similarity ± 10 kbp with a particular animal species in the library. Data in Figure 3 and Table 3 summarize these matches. Some isolates experienced taxonomic and restriction failure and others were inconclusive with regard to potential animal source. Table 4 summarizes these results.

DISCUSSION

<u>Is the major source of nonpoint fecal coliform contamination human or non-human in origin?</u>

The data suggested, that on the basis of the 278 isolates which did show one or more matches with strains of *E. coli* from known sources, potential contribution from human sources was moderate. Forty-six (46) isolates (17%) were considered to be of human origin, whereas 232 isolates (83%) were considered to be of nonhuman origin. The potential contribution from human sources ranged between 13-21% for all four seasonal sampling periods.

<u>Is the human source localized?</u>

The data suggested that possible contributions from human sources were localized. In particular, stations associated with Doctors Run (Feb '00, 13 isolates), Four Mile Run at Columbia Pike (Nov '99, 6 isolates), Donaldson Run at Military Road (Aug '98, 9 isolates), and Lucky Run (May '99, 11 isolates) suggested potential inputs of *E. coli* from human sources. Human signatures were not suggested at any of the other collecting sites.

<u>Is the nonhuman source mammal or avian in origin?</u>

As stated above, 232 isolates were identified as being of nonhuman origin. Of this pool (232 isolates), the data suggested that 127 isolates (55%) were from a mammalian source and 105 isolates (45%) were from one or more species of waterfowl (geese, gulls, and ducks).

<u>Is the major mammal contribution from domestic or wild animal species?</u>

Several animals stand out in the mammal group. Of the 127 isolates attributed to nonhuman mammal sources, raccoon were the most dominant representative of the group with 42 isolates (33%) being represented; deer were second with a total of 42 isolates (33%) (assuming that the bovine isolates served as surrogates for deer; canine isolates were third (24 isolates - 19%); and the Norway rat was fourth with 11 isolates (9%). Feline (3 isolates -2 %); opossum (3 isolates - 2%); beaver (1 isolate -1 %); and, muskrat (1 isolate -1 %) comprised the remaining matches. The dominance of raccoon in an urban watershed is consistent with findings by Hadidian, et al. (1991, 1997). These data suggested that wild

Table 3. Fecal Coliform Densities at Study Area Locations

	I.D.	Alternate Station I.D.	Fecal Coliform, MPN Water	Water/ Sed.	Sedi-ment	Decimal Latitude	Decimal Longitude
28-Aug-98							
Note: Drought conditions							
1) Lower Long Branch in Arna Valley, 26th Street S.	27	NVPDC#1	2			38.8484	-77.0748
2) Four Mile Run at Shirlington Road	24	NVPDC#2	900			38.8431	-77.0861
3) Lucky Run outfall at Four Mile Run	23	NVPDC#3	500			38.8456	-77.0962
4) Upper Long Branch at Carlin Springs Road	15	NVPDC#4	≥1600			38.8587	-77.1268
5) Lubber Run at Route 50	13	NVPDC#5	500			38.8678	-77.1201
6) Middle Four Mile Run, bike trail crossing just u/s of Rt. 50	10	NVPDC#6	1600			38.8668	-77.1242
7) Upper Four Mile Run at Falls Church line (Van Buren Street)	1	NVPDC#7	900			38.8825	-77.1589
8) Doctors Run at Barcroft Park footbridge	22	NVPDC#8	900			38.8507	-77.1028
9) Donaldson Run at Military Road (outside of study area)	*n/a*		*500*			*38.9111*	*-77.1134*
10) Gulf Branch at Military Road (outside of study area)	*n/a*		*1600*			*38.9193*	*-77.1199*
06-May-99							
Note: Drought conditions							
1) Ballston Beaver Pond, along open channel (Lubber Run)	11	Near LR112, Arlington	900			38.8831	-77.1190
2) Powhatan Run at N. Livingston Road, pristine site	5	u/s of FM300, Arlington	50			38.8722	-77.1408
3) Manchester Street 1.1 m (42") outfall (Glencarlyn Branch)	6	FM 330, Arlington	≥1600			38.8675	-77.1330
4) Four Mile Run at Shirlington Road	24	NVPDC#2	1600			38.8431	-77.0861
5) Lucky Run outfall at Four Mile Run	23	NVPDC#3	500			38.8456	-77.0962
6) Four Mile Run at Columbia Pike	16	1AFOU004.22, Va. DEQ	900			38.8561	-77.1112

Table 3. *(continued)*			Fecal Coliform, MPN				
	I.D.	Alternate Station I.D.	Water	Water/ Sed.	Sedi- ment	Decimal Latitude	Decimal Longitude
23-Nov-99							
1) Upper Long Branch downstream of Patrick Henry Drive	14		80	170	80	38.8669	-77.1478
2) Upper Four Mile Run at Sycamore Street	2		30	300	30	38.8830	-77.1561
3) Box culvert under Ballston just downstream of Beaver Pond	12		900	500		38.8818	-77.1185
4) Lubber Run at Route 50	13	NVPDC#5	50	220	30	38.8678	-77.1201
5) Four Mile Run at Columbia Pike	16	1AFOU004.22, Va. DEQ	240		30	38.8561	-77.1112
6) Doctors Run at Barcroft Park footbridge	22	NVPDC#8	80		30	38.8507	-77.1028
7) Lucky Run outfall at Four Mile Run	23	NVPDC#3	900			38.8456	-77.0962
8) Four Mile Run at Shirlington Road	24	NVPDC#2	300		22	38.8431	-77.0861
9) Lower Long Branch in Arna Valley, 26th Street S.	27	NVPDC#1	≥1600		33	38.8484	-77.0748
10) Four Mile Run at George Washington Parkway	31	1AFOU000.19, Va. DEQ	130			38.8409	-77.0478
22-Feb-00							
1) Ohio Street Branch at I-66, outfall	3	FM200 or FM210, Arlington	50	900		38.8822	-77.1467
2) Westover Branch at I-66, outfall (twin box culvert to right of 2 m [78"] circular pipe)	4	FM230, Arlington	≥1600	≥1600	≥1600	38.8810	-77.1417
3) Powhatan Run at N. Livingston Road (pristine site)	5	u/s of FM300, Arlington	23	280		38.8722	-77.1408
4) Manchester Street 1.1 m (42") outfall (Glencarlyn Branch)	6	FM 330, Arlington	900	≥1600		38.8675	-77.1330
5) Baileys Branch at S. Frederick Street	17	FM350, Arlington	80	300		38.8536	-77.1152
6) Four Mile Run at Columbia Pike	16	1AFOU004.22, Va. DEQ	130	500	80	38.8561	-77.1112
7) Doctors Run at S. 6th Street & S. Quincy Street, biggest outfall	18	DB100, Arlington	1600	≥1600		38.8645	-77.1014
8) Lucky Run outfall at Four Mile Run	23	NVPDC#3	500	≥1600		38.8456	-77.0962
9) Nauck Branch	25	FM450, Arlington	500	1600	1600	38.8464	-77.0832
10) Lower Long Branch at I-395 near 28th Street S., outfall--quad box culvert	26	274 m (900') d/s of LL180, Arlington	2	21	500	38.8506	-77.0748
11) Arlington Sewage Treatment Plant outfall	28	FM545?, Arlington	0			38.8438	-77.0613
12) Four Mile Run at George Washington Parkway	31	1AFOU000.19, Va. DEQ	14	300		38.8409	-77.0478

Table 3. *(continued)*			Fecal Coliform, MPN				
	I.D.	**Alternate Station I.D.**	**Water**	**Water/ Sed.**	**Sedi-ment**	**Decimal Latitude**	**Decimal Longitude**
19-Jun-00							
Note: Samples from June 19, 2000 at Stations 5 - 12 were taken at 5 minute intervals at all four stations approximately simultaneously (in late morning). DNA results for June 19 not available for this study.							
1) Alexandria trib behind Cora Kelly Community Center, CMP outfall	**30**		900			38.8383	-77.0584
2) Alexandria trib behind Cora Kelly Community Center, upstream of outfall	**29**		≥1600			38.8383	-77.0594
3) Arlington Sewage Treatment Plant outfall	**28**	FM545?, Arlington	0			38.8438	-77.0613
4) Four Mile Run at Columbia Pike	**16**	1AFOU004.22, Va. DEQ	1600			38.8561	-77.1112
5) Doctors Run at S. 6th Street & S. Quincy Street, biggest outfall	**18**	DB100, Arlington	≥1600, ≥1600, ≥1600			38.8645	-77.1014
6) Doctors Run 61 m (200 ft) downstream of S. 6th Street & S. Quincy Street	**19**	d/s of DB100, Arlington	900, ≥1600, 900			38.8640	-77.1015
7) Doctors Run 122 m (400 ft) d/s of S. 6th Street & S. Quincy Street	**20**	d/s of DB100, Arlington	500, 900, 500			38.8635	-77.1019
8) Doctors Run 183 m (600 ft) d/s of S. 6th Street & S. Quincy Street	**21**	d/s of DB100, Arlington	900, 300, 900			38.8630	-77.1022
9) Manchester Street, 1.1 m (42 in) outfall	**6**	FM 330, Arlington	900, 500, ≥1600			38.8675	-77.1330
10) 46 m (150 ft) d/s of Manchester Street outfall	**7**	d/s of FM 330, Arlington	≥1600, 1600, ≥1600			38.8677	-77.1325
11) 91 m (300 ft) d/s of Manchester Street outfall	**8**	d/s of FM 330, Arlington	1600, 1600, ≥1600			38.8680	-77.1321
12) 137 m (450 ft) d/s of Manchester Street outfall	**9**	d/s of FM 330, Arlington	1600, 900, ≥1600			38.8682	-77.1317

TABLE 4. Number of Isolates by DNA Match with Best Species

Animal Species	FIELD DATES 28Aug98	6May99	23Nov99	22Feb00	TOTALS
Non-*E. coli* fecal coliforms[1]	0	37	4	11	52
No API Code	3	1	31	2	37
No Restriction	3	3	3	2	11
No Matches	18	9	67	39	133
Human	9	11	11	15	46
Raccoon	4	5	22	11	42
Canine	1	0	10	13	24
Deer	10	0	1	18	29
Bovine	0	0	3	10	13
Norway Rat	10	0	0	1	11
Feline	0	0	3	0	3
Opossum	0	0	0	3	3
Beaver	0	0	1	0	1
Muskrat	0	0	1	0	1
Herring Gull	6	18	1	0	25
Mallard Duck	0	18	13	1	32
Black Duck	0	0	6	2	8
Laughing Gull	8	0	1	0	9
Canada Goose	8	0	8	3	19
Black Back Gull	5	0	1	0	6
Tern	0	0	3	3	6
Undetermined	4	8	8	8	28
TOTALS	***89***	***110***	***198***	***142***	***539***

[1] Non-*E. coli* fecal coliforms = NECFC

Isolates Analyzed:

133 No Matching Records
52 NECFC
37 No API Code
11 Failed Restriction
28 Inconclusive Identification
278 Acceptable Matches
539 Total Number of Isolates Considered

Acceptable Matches:

46	Human
42	Raccoon
29	Deer
24	Canine
13	Bovine
11	Norway Rat
8	Other Mammals
105	Waterfowl
278	***Total***

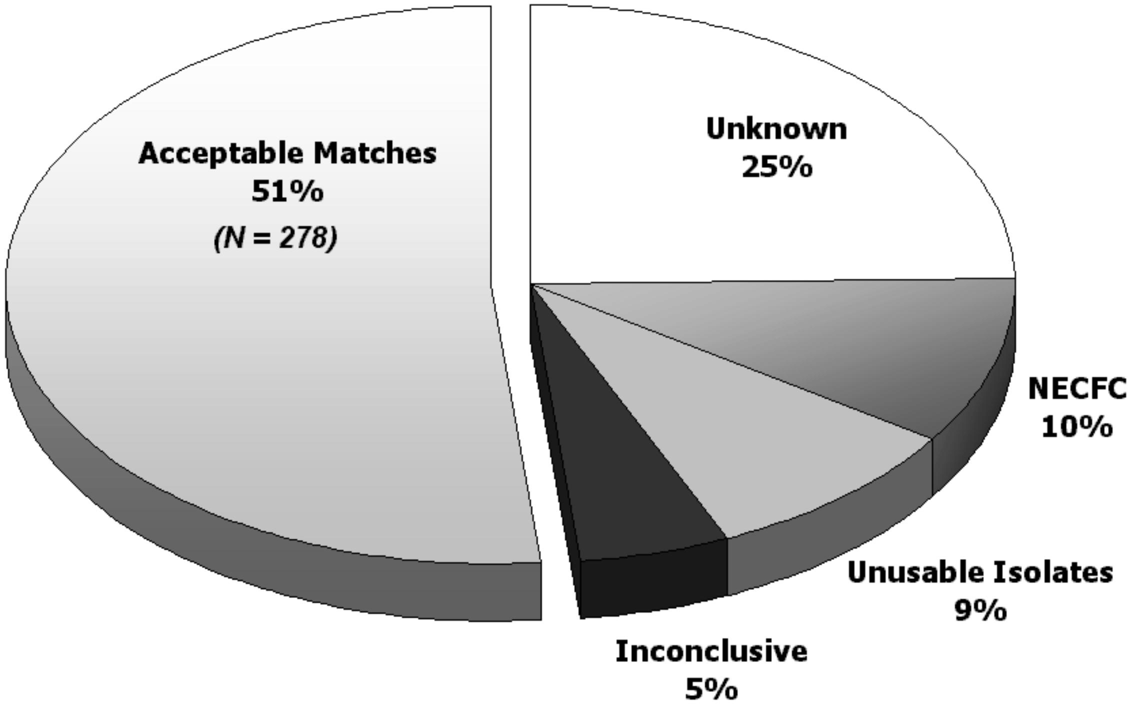

Figure 2. Success of Isolate Matching, N = 539

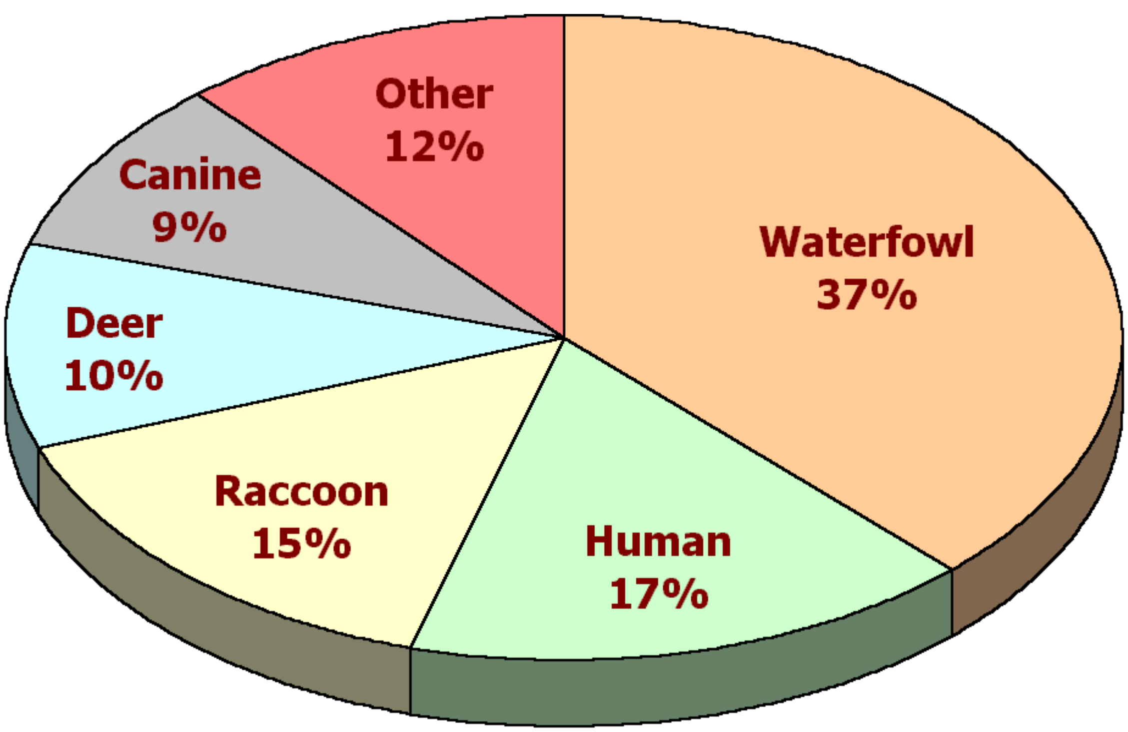

Figure 3. Distribution of Acceptable Matches by Animal Group, N = 278

animal species, rather than domestic animal species, contributed the greater percentage of fecal coliform isolates to Four Mile Run and its tributaries.

The fact that deer signatures were much more frequent than would have been suspected can be explained in several ways. One explanation has to do with frequency of occurrence of isolates, and the other explanation deals with assignment to a particular source. In the August 1998 samples, all ten isolates at Station 7 had the same profile. Assignment was made to "deer" as a result of band-to-band comparisons, but herring gull was a strong second choice. In the Feb '00 samples, all 10 isolates from Station 4 showed the same identical profile and, again, band-to-band comparisons suggested a "deer" signature, but Black Back Gull, raccoon, and canine were also possible choices. Stations 8 and 10 each had one isolate that suggested "deer," but muskrat and Canada goose were also reasonable choices. At Station 2, however, five isolates all had the same pattern, and "deer" was the only match suggested. Even if the other possible choices are considered, except in one case, the alternate choice is a wild animal source.

At the present time, the most limiting aspect of this research effort, aside from the modest size of the library, is the fact that canine and human *E. coli* populations cannot be separated statistically, despite this study's efforts to expand the source library for these two species. Caugant (1981) demonstrated that certain strains of bacteria can move freely between humans and canines that share the same living space. However, of the total pool of identifiable isolates, only 70 isolates (25%) could be assigned to human or canine and 208 (75%) isolates were assigned to wild animal sources.

The subject of urban wildlife ecology is still in its infancy and much still remains to be understood about the relationship of certain wildlife species to expanding urban environments (Murphy 1988).

The data **<u>do not suggest</u>** that there were more wildlife individuals in the watershed than canine or human individuals. The data **<u>do suggest</u>** that certain wildlife species have a greater, disproportionate, representation and effect on fecal coliform density in the watershed because of their direct contact and intimate association with the waterways. Furthermore, the frequency of occurrence of a wild animal species is not necessarily occur in direct relationship to the frequency of occurrence of their fecal coliform signature. Survival and regrowth of specific strains from a given animal also have to be considered as well as the specific time of collection.

The conclusion, suggested from the data in this study, that wildlife animal sources were a major contributor to the fecal coliform problem, has also been corroborated by fecal coliform studies in tidal creeks and estuaries in the southern Chesapeake Bay (Simmons, 1994; Simmons and Herbein, 1995; Simmons, et al, 1995; Herbein et al, 1996).

<u>What is the role of sediments?</u>

Two sampling periods (November 1999, and February 2000) focused on the contribution of water/sediment slurries and sediments to the fecal coliform problem. The MPN geometric mean for all sites in November for the fecal coliform densities in water was 149.3; for water/sediment slurries 239.7; and, for sediments 32.6. Estimates of sediment MPN density for this period consisted of adding 1 gm of sediment in 99 mls of buffered water, and the sediments consisted of very coarse sand and/or gravel. Some of the water/sediment slurries came from inside stormwater pipes and contained little/no sediment. While these data suggest that the greatest number of fecal coliforms existed in the water column and as a microbial film attached to substrate, additional research using sonication is recommended to confirm this.

This exercise was repeated in February 2000. At this time, the composition of the sediments and amounts added to buffered water was different than in the November exercise. In February, two samples of very fine sediments were collected at each stormwater outfall and 1.0 gm was added to 100 ml of buffered water. In two other samples, 6.0 and 15.0 gms of sediment were added to the buffered water because the sediments were so coarse that it was not possible to weigh out 1.0 gram exclusive of residual water in the syringe. The MPN geometric mean in February for the fecal coliform densities in water was 132.3; for water/sediment slurries 592.9; and for sediments 574.3.

The role of sediments as potential reservoirs has been documented by other researchers (Van Donsel and Geldreich, 1971; Gerba and McLoed, 1976; Hood and Ness, 1982; Stephenson and Rychert, 1982; Sherer, et al., 1992; Davies, et al., 1995; and, Reay, 2000). The February data showed that microbial films and sediments can serve as reservoirs and potentially contribute to the nonpoint fecal coliform problem in Four Mile Run. This contribution could be through the addition of cells to the water column from regrowth of either microbial films or from the sediments. Contributions through regrowth and subsequent sampling of clonal populations from the water column could explain the low strain diversity found by this investigation in many of the samples collected from stormwater outfalls.

<u>What is the role of non-*E. coli* fecal coliforms (NECFC)?</u>

Non-*E. coli* fecal coliforms (NECFC) are those bacteria that also are characterized as part of the Enterobacteriaceae along with *E. coli*. NECFC species not only inhabit the intestinal tract of animals along with *E. coli*, but also they may occur as free-living organisms in aquatic systems as well. In routine examination of freshwaters using gas formation as a method of identification, these other Enterobacteriaceae species may give a false reading. Therefore, in trying to determine nonpoint *E. coli* sources, detailed identification of isolates must be made to rule out the presence of non-*E. coli* fecal coliform species.

The role of NECFC was not as significant in the final analysis of sources as originally believed, and the data suggested that NECFC contributed only in a minor way to the overall nonpoint fecal coliform source question. However, in some cases and based on the number of isolates analyzed at random, the data suggested that NECFC could be significant in isolated or localized situations. For example, at Station 3 in the May 6, 1999 sampling period, the 20 isolates removed for restriction analysis were all *Citrobacter freundii*. Likewise, on the same date at Station 6, 16 of the 20 isolates removed were *Enterobacter cloacae*. At Station 6 for the February 22, 2000 sampling, five of the 10 isolates removed were *C. freundii*. Even though the data suggested that NECFC occurred at a low density level, they did contribute to the overall fecal coliform density.

Of the 539 isolates removed from samples for restriction analysis, 89 isolates (17%) fell into the category of “NECFC" or “unidentified API profile.” Of these 89 isolates, 55 isolates were identified with the API profile system to be *C. freundii*, *E. cloacae*, *Kluyvera*, spp, *Klebsiella pneumoniae*, or *K. ozaenae*. Of these taxonomic groups, *C. freundii* and *E. cloacae* comprised the greatest number of isolates (29 and 18, respectively) that were encountered in the NECFC group.

Is there any seasonal variation?

No discernable pattern of seasonal variation among acceptable human or non-human matches was evident in this study. Furthermore, even the density of fecal coliforms was just as elevated during the winter sampling period as during the warmer months. This may point to a storm drain effect, as these drains have been previously documented to moderate baseflow temperatures within Four Mile Run (NVRC, 1996b).

What is the effect of baseflow drainage through storm drains?

Two-thirds of the watershed's original stream network has been converted to underground drainage, primarily in its headwaters. The data collected from storm drains suggested that drainage from these conduits during baseflow periods contributed significantly to the fecal coliform problem in Four Mile Run and its tributaries. For example, the MPN geometric mean of fecal coliform densities in open stretches of Four Mile Run and its tributaries was 231.1 (N=23); whereas, the MPN geometric mean of fecal coliform densities from stormwater outfalls during the same period was 400.2 (N=11). In addition to temperature moderation, storm drains also prevent die-off by shielding the bacteria from the sun's ultraviolet radiation. However, as with most *E coli* studies, these counts were highly variable and more data are needed to confirm a statistically valid correlation.

In June 2000 a study was conducted at two stormwater outfalls (Doctors Run and Manchester Street) to determine the degree to which fecal coliform density from the outfalls diminished with distance downstream. The distance downstream from each outfall was approximately 100 meters. The fecal coliform density at the Doctors Run outfall was $\geq$ 1600 and had decreased to a geometric mean of 624.0 at the downstream sampling point. At the Manchester Street outfall, the geometric mean of the fecal coliform density at the outfall was 914.5 but the density increased to a geometric mean of 1347.7 at the downstream sampling point. In the latter case, given the range of density associated with MPN values, the data demonstrate that there was little/no removal of fecal coliform density within the 100 meter stretch and that the open water portion of the stream was influenced by the discharge from the stormwater line. In the former case (Doctors Run), the data suggest that, while the stream had some filtration capacity to reduce fecal coliform densities, the density in the stream was also influenced by the stormwater discharge.

The influence of storm drains on the fecal coliform problem can be explained in two possible ways. First, the density of animal scat in the storm drains may provide a constant source of fecal coliforms as the water passes over the scat deposits. Second, and a more likely explanation, is that scat material is deposited in the storm drains, fecal coliforms are transported from the scat, become deposited in the storm drains, re-grow, and contribute to the microbial film found in the storm drains. Clonal populations lift-off, or are scoured by the moving water, and provide a continuous source, or inoculation, of fecal coliforms to the discharging water.

The importance of regrowth has been investigated by Simmons and his students (Carey and Simmons, 1995) in relation to discharge from a poultry processing plant on Virginia's Eastern Shore. Sediments are also important reservoirs for fecal coliform introduction to surface waters as noted by other investigators (cited above). Additional water chemistry data from Four Mile run and its tributaries (Northern Virginia Planning District Commission, 1996b) indicate that sufficient quantities of nutrients and carbon are available to support regrowth in the storm drains.

Additional research on urban portions of Northern Virginia (Harms and Southerland (1975); Randall, et al. (1978); and, Environmental Systems Analysis, Inc (1999)) corroborates a dominant deleterious influence of storm drains on water quality. Detrimental urban runoff contributions of nutrients, sediment, and other pollutants are well documented in the nonpoint source literature. Environmental Systems

Analysis, Inc. (1999) completed a baseline macroinvertebrate assessment of Four Mile Run and found that the substrate at most sampling sites showed dominance of a few pollution-tolerant macroinvertebrates, and stations characterized by high levels of algal growth (evidence of nutrient loading), sedimentation, and erosive flows from high storm drain discharges during wet weather.

SUMMARY

Based on the interpretation of DNA profile analyses of pulsed field gel electrophoresis patterns for those *E. coli* isolates from Four Mile Run and its tributaries that could be matched with *E. coli* strains from known sources in the Virginia Tech library; and, from fecal coliform densities of water, water/sediment slurries, and sediment, the data suggested the following:

1. nonhuman species are the dominant sources of *E. coli* to Four Mile Run and its tributaries;
2. waterfowl contribute over one-third (37%) of those isolates that could be identified;
3. the presence of human *E. coli* is localized;
4. the nonhuman sources are wildlife species that have intimate association with the waterways;
5. the predominant nonhuman mammal contributors are raccoon, dog, deer, and Norway rat;
6. the combined human and canine contribution is approximately 25% of those isolates that could be identified;
7. the organisms contributing to the presence of *E. coli* are those animals which would normally be expected in an urban watershed;
8. discharge from storm drains during baseflow seems to play a significant role in the fecal coliform problem;
9. without regard to specific host animals, *E. coli* bacteria seem to regrow, through cloning, within the storm drains and stream sediments, which in turn perpetuate elevated bacteria levels within the connected surface waters of Four Mile Run.

The data **do not suggest** there were more wildlife individuals in the watershed than canine or humans, but the data **do suggest** that certain wildlife species may have a greater, disproportionate, representation in the DNA profile analysis because of their direct contact and intimate association with the waterways. The DNA profile analysis is not a tool for estimating population density of any given animal species, but it may be an excellent method to identify those animals that have an impact on water quality.

It is neither desirable nor practical to eliminate wildlife animal species in the watershed. Ecologically speaking, the microbial community, including *E. coli*, is doing what heterotrophic microorganisms do – absorb nutrients and decompose organic compounds. The continued high levels of *E. coli* suggest an ecosystem out of balance irrespective of the source.

While the citizens of Four Mile Run and those governmental agencies whose job it is to oversee and improve water quality in Four Mile Run deserve considerable credit for improving water quality in Four Mile Run and its tributaries, much remains to be done to reduce nutrient loading which may contribute to the regrowth of those *E. coli* which make their way into the waterways.

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Appendix B

Documentation of Weather Data
Collected for Four Mile Run Bacteria TMDL
("4mr.wdm" File for Use by HSPF Model)

This appendix lists the weather data files and pertinent notes about the preparation of the data. The figure at the end of this appendix is a computer screenshot of the header information of every climatic timeseries dataset in the file "4mr.wdm" which was available for use by the water quality model used to develop the Four Mile Run bacteria TMDL. Although many timeseries datasets were collected and stored in this cabinet file, only a few were used in the final model runs. These are listed below.

```
DSN 117 ATMP, observed hourly air temperature at Seven Corners, minor gaps filled
DSN 122 PREC, observed hourly precipitation at Seven Corners, minor gaps filled
DSN 202 WIND, observed hourly wind speed at Reagan National Airport
DSN 204 WIND, observed hourly wind speed at Seven Corners, minor gaps filled
DSN 309 DPTP, observed hourly dewpoint at Reagan National Airport (DCA)
DSN 412 PEVT, disaggregated daily-to-hourly potential evapotranspiration at DCA
DSN 500 PREC, observed hourly precipitation at DCA
```

Climatic Data

The closest meteorological station to the Four Mile Run watershed is Washington, DC Reagan National Airport. Observations have been kept continuously since November 1870. The official observations have been taken at Washington (Reagan) National Airport since June 1941 (http://www4.ncdc.noaa.gov/).

Rain gauges maintained by the Fairfax County Health Department and Arlington County Department of Public Works in and near the Four Mile Run watershed operated from the mid 1990s through the present and are operated intermittently. This includes data on Skyline, Sislers, and Seven Corners. Continuous stream temperature data at five-minute intervals during wet weather periods and hourly intervals for baseflow times have been collected at the USGS Four Mile Run stream gauge at Arlington since October 1999. Other data is obtained from the NOAA National Climatic Data Center web site <http://www.ncdc.noaa.gov>:

TD3280 Surface Airways Hourly and Solar Radiation
The variables from this dataset include:

```
ALC1:   Sky condition (cloud cover in tenths) – lowest layer
ALC2:   Sky condition (cloud cover in tenths) – second layer
ALC3:   Sky condition (cloud cover in tenths) – third layer
ALM1:   Sky condition (cloud cover in eighths) – lowest layer
ALM2:   Sky condition (cloud cover in eighths) – second layer
ALM3:   Sky condition (cloud cover in eighths) – third layer
ALTP:   Altimeter setting
CLHT:   Ceiling height
DPTC:   Dewpoint temperature, °C
DPTP:   Dewpoint temperature, °F
```

```
HZVS:   Prevailing horizontal visibility
PWTH:   Present of prevailing weather at time of observation
RHUM:   Relative humidity
SLVP:   Sea level pressure, millions & tenths
TMCD:   Dry bulb air temperature, °C & tenths
TMPD:   Dry bulb air temperature, °F
TMPW:   Wet bulb air temperature, °F & tenths
WND2:   Wind direction and speed
```

TD9956 Global Hourly Surface Observations
The variables from this dataset include:

```
APC3   : ATMOSPHERIC-PRESSURE-CHANGE THREE HOUR CHANGE QUANTITY
ATOLD  : AIR-TEMPERATURE-OBSERVATION-LEVEL DEWPOINT TEMPERATURE
WOSPD  : WIND-OBSERVATION SPEED RATE
WOLSPD : WIND-OBSERVATION-LEVEL SPEED RATE
WOLDIR : WIND-OBSERVATION-LEVEL DIRECTION ANGLE
WODIR  : WIND-OBSERVATION DIRECTION ANGLE
ATOLDS : AIR-TEMPERATURE-OBSERVATION-LEVEL DENSITY RATE
ATOLT  : AIR-TEMPERATURE-OBSERVATION-LEVEL AIR TEMPERATURE
ATOD   : AIR-TEMPERATURE-OBSERVATION DEW POINT TEMPERATURE
ATOT   : AIR-TEMPERATURE-OBSERVATION AIR TEMPERATURE
APOSP  : ATMOSPHERIC-PRESSURE-OBSERVATION STATION PRESSURE RATE
APOSLP : ATMOSPHERIC-PRESSURE-OBSERVATION SEA LEVEL PRESSURE
APOLP  : ATMOSPHERIC-PRESSURE-OBSERVATION-LEVEL PRESSURE RATE
APOLH  : ATMOSPHERIC-PRESSURE-OBSERVATION-LEVEL HEIGHT DIMENSION
APOA   : ATMOSPHERIC-PRESSURE-OBSERVATION ALTIMETER RATE
WGOSPD : WIND_GUST-OBSERVATION SPEED RATE
APCQ24 : ATMOSPHERIC-PRESSURE-CHANGE TWENTY FOUR HOUR QUANTITY
APCTEN : ATMOSPHERIC-PRESSURE-CHANGE TENDENCY CODE
PRSWOA : PRESENT-WEATHER-OBSERVATION AUTOMATED ATMOSPHERIC CONDITION CODE
PRSWM1 : PRESENT-WEATHER-OBSERVATION MANUAL    ATMOSPHERIC CONDITION CODE
PRSWM2 : PRESENT-WEATHER-OBSERVATION MANUAL    ATMOSPHERIC CONDITION CODE
PRSWM3 : PRESENT-WEATHER-OBSERVATION MANUAL    ATMOSPHERIC CONDITION CODE
PRSWM4 : PRESENT-WEATHER-OBSERVATION MANUAL    ATMOSPHERIC CONDITION CODE
PRSWM5 : PRESENT-WEATHER-OBSERVATION MANUAL    ATMOSPHERIC CONDITION CODE
PRSWM6 : PRESENT-WEATHER-OBSERVATION MANUAL    ATMOSPHERIC CONDITION CODE
PRSWM7 : PRESENT-WEATHER-OBSERVATION MANUAL    ATMOSPHERIC CONDITION CODE
PSTWA1 : PAST-WEATHER-OBSERVATION    AUTOMATED ATMOSPHERIC CONDITION CODE
PSTWA2 : PAST-WEATHER-OBSERVATION    AUTOMATED ATMOSPHERIC CONDITION CODE
PSTWM1 : PAST-WEATHER-OBSERVATION    MANUAL    ATMOSPHERIC CONDITION CODE
PSTWM2 : PAST-WEATHER-OBSERVATION    MANUAL    ATMOSPHERIC CONDITION CODE
PSTWOP : PAST-WEATHER-OBSERVATION PERIOD QUANTITY
SCOCIG : SKY-CONDITION-OBSERVATION CEILING HEIGHT DIMENSION
SCOHCG : SKY-CONDITION-OBSERVATION HIGH CLOUD GENUS CODE
SCOLCB : SKY-CONDITION-OBSERVATION LOWEST CLOUD BASE HEIGHT DIMENSION
SCOLCG : SKY-CONDITION-OBSERVATION LOW CLOUD GENUS CODE
SCOMCG : SKY-CONDITION-OBSERVATION MID CLOUD GENUS CODE
SCOTCV : SKY-CONDITION-OBSERVATION TOTAL COVERAGE CODE
SCOTLC : SKY-CONDITION-OBSERVATION TOTAL LOWEST CLOUD COVER CODE
VODIS  : VISIBILITY-OBSERVATION DISTANCE DIMENSION
VOVAR  : VISIBILITY-OBSRVATION VARIABILITY CODE
```

Rainfall data that covers periods of wet, dry, and normal annual rainfall are used to calibrate the hydrological model, calibrate water quality (fecal coliform) model, and perform modeling runs for TMDL allocation. The first two years of data are used to initialize the state variables, and are not used for the comparison of observed data or the assessment of the TMDL *(NVRC Proposal 3/9/2001).*

Daily Flow Data

Daily flow data is available from the USGS Four Mile Run stream gauge station at Shirlington. Continuous streamflow records at five-minute intervals during wet weather periods and hourly intervals for baseflow times have been collected at the USGS Four Mile Run stream gauge at Shirlington since October 1998 (prior to that, daily records exist for much of the 1970s and peak monthly discharges exist for most of the 1980s and 1990s) *(NVRC Proposal 3/9/2001)*.

Land Use

Land use data is used to evaluate various parameters in the model. NVRC has developed its own Northern Virginia regional land use theme with a multi-jurisdictional 15-key land use classification. NVRC also has complete standard GIS data CDs from Arlington County and Fairfax County. Other themes include population data by census tract for the 2000 census; rain gauge locations (point theme) with accompanying Thiessen polygon theme; regional street centerline theme; high-resolution digital orthophoto raster photographic images for USGS quarter-quadrangles for the watershed; high detail geologic unit theme for the entire watershed; high detail soils unit theme for Arlington only; septic system point-to-parcel theme for Arlington only; ten-foot USGS contours for entire watershed; ground surface elevation points for over 5,000 surveyed locations in Arlington County; five-foot contours for Arlington County based on 5,000 surveys points and other information; detailed storm drain and channel geometry; and detailed drainage junction point theme *(NVRC Proposal 3/9/2001)*.

Datafile Description

The original datafiles are:

usgs_gauge_4mr_no_header.txt FLOW
Flow data for Shirlington from 10/1/98 to 7/1/01

skyline_prec.txt PRECIPITATION
Precipitation data for Skyline and Sislers locations from 7/1/98 to 6/30/01

7corners_prec.txt RAIN
WIND DIRECTION
WIND SPEED
TEMP
Precipitation data (RAIN) for Seven Corners. File also includes WIND DIRECTION, WIND SPEED, and TEMP. Missing data values coded as "." Changed this MISVAL to –9.99 for this datafile.

The files in the 4mr.wdm file are:

DSN 121 7Corners data with gaps filled by DSN 102 Sislers data

7Corners PREC: DSN 121(1998/7/1 – 2001/6/30) and DSN 105(1998/7/1 - 2001/3/27)
Corrected value for 8/21/99 19:00 hours from PREC=60.0 to PREC=0.60
Columns were shifted in original dataset which caused this error.

DSN 105 and DSN 121 have missing values which were replaced by values from the SISLERS dataset (DSN 102):

Date	time	new value
1999/9/16	14:00	0.050
	15:00	0.00
	16:00	0.00
2000/9/26	13:00	0.00

Seven Corners Temperature data:

DSN 107 7Corners	ATMP	9 periods of missing data
DSN 117 7Corners	ATMP	Missing values replaced with National Airport data, using TMPD (DSN 317)

Seven Corners Wind data:

DSN 109 7Corners	WIND	19 periods of missing data
DSN 111 7Corners	WDIR	20 periods of missing data

The missing data for the Wind speed and direction were filled with Reagan National Airport data, using WND2, wind direction and speed from the TD3280 Surface Airways Hourly and Solar Radiation data file. The variable WND2 is a composite variable of wind speed and direction, in the format XXYYY, where XX is the direction in ten's of degrees and YYY is the speed I knots. A value for WND2 of 28014 means the direction is 280º and the speed is 14 knots. WND2 was split into two separate variables, WDIR, wind direction, and WIND, wind speed. These two datasets were used to fill in the gaps of missing data for the Seven Corners files.

DSN 202 DCA	WDIR	Hourly Wind Direction at DCA Reagan National Airport
DSN 203 DCA	WIND	Hourly Windspeed at DCA Reagan National Airport

DSN 110 7Corners	WIND	Hourly Windspeed at 7Corners – gaps filled with DCA
DSN 112 7Corners	WDIR	Hourly Wind Direction at 7Corners - gaps filled with DCA

Fecal coliform data:

Two separate files were created for the fecal coliform measurements at the two VA-DEQ stations: Four Mile Run at Columbia Pike (1AFOU004.22, Va. DEQ) and Four Mile Run at George Washington Parkway (1AFOU000.19, Va. DEQ). The instantaneous grab sample FC measurements which were taken 4 to 6 times per year by DEQ were incorporated into a daily format required by the modeling program.

DSN 219 GW	FCOLI	DEQ Fecal coliform data
DSN 222 Col_Pike	FCOLI	DEQ Fecal coliform data

The NVRC fecal coliform data was collected at the Columbia Pike Station. Arlington County Parks collected fecal coliform data at site 3, which was fairly close to the DEQ Columbia Pike station. These data were combined into one file along with the DEQ data.

DSN 225 Col_Pike FCOLI Columbia Pike, DEQ+NVRC+Arl.Parks F.C. Data

Potential Evapotranspiration

The daily Potential Evapotranspiration (PET) was computed using the Hamon method, which requires the latitude, and the minimum and maximum daily air temperature. The daily PET was disaggregated into hourly data. The latitude used was 38º52'N for Reagan National Airport.

DSN 405 00013743(DCA)	TMAX	TMPD-Maximum Daily Temperature
DSN 407 00013743(DCA)	TMIN	TMPD-Minimum Daily Temperature
DSN 410 00013743(DCA)	DEVT	Computed daily PET (in)
DSN 412 00013743(DCA)	PEVT	Disaggregated PET (daily to hourly)

National Climatic Data Center (NCDC)
http://www.ncdc.noaa.gov

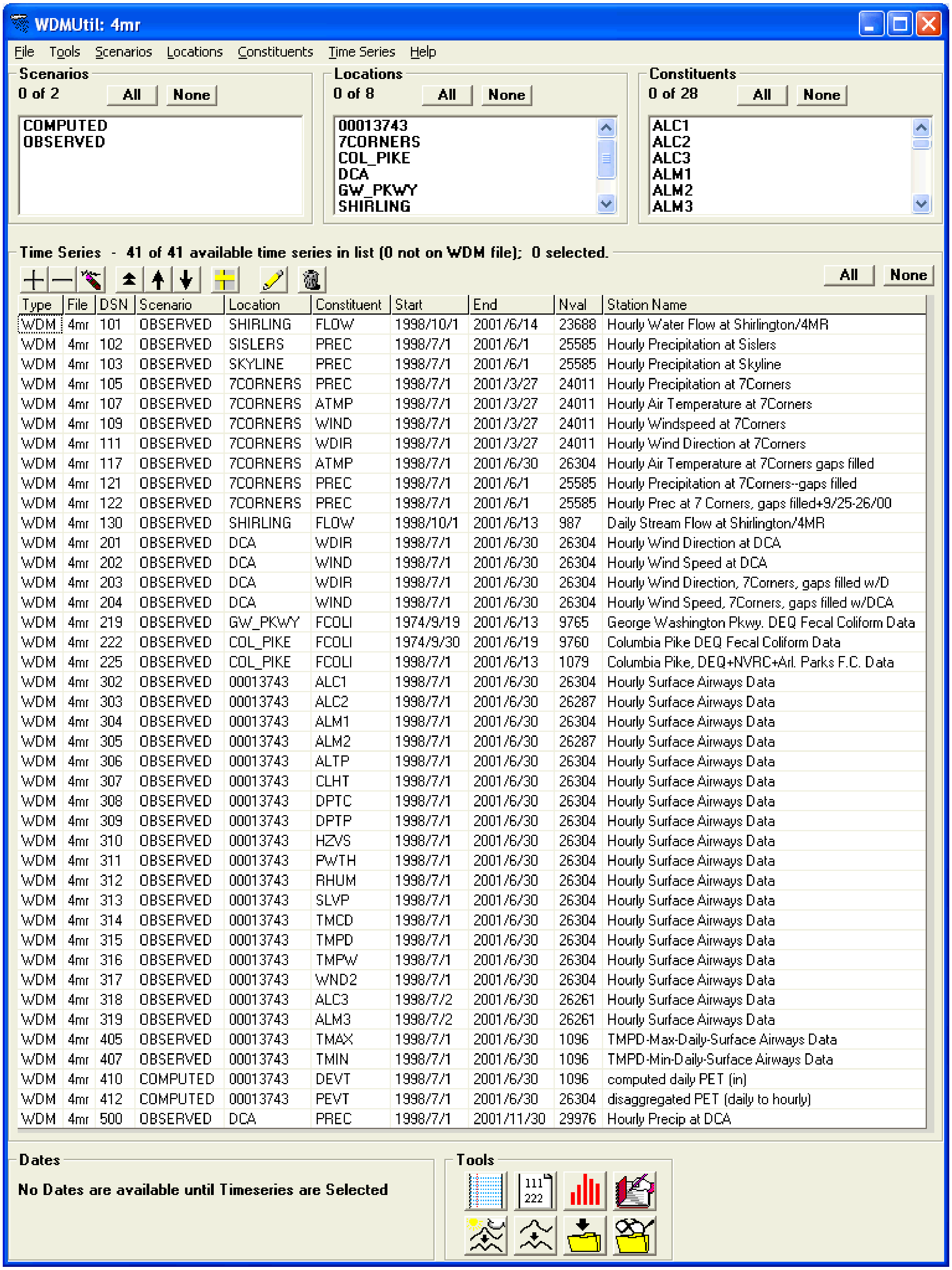
Data is from TD3280. See documentation in file TD3280.doc for detailed definitions of variables. The TD3280 file is entitled Surface Airways Hourly and Airways Solar Radiation.

Data is imported from file TD3280_7-1-1998—6-30-2001.txt

Files imported are:

> ALC1, ALC2, ALC3, ALM1, ALM2, ALM3, ALTB, CLHT, DPTC, DPTP, HZVS, PWTH, RHUM, SLVP, TMCD, TMPD, TMPW, WND2

Dates are 1998/7/1 – 2001/6/30 and the data are hourly.



Type	File	DSN	Scenario	Location	Constituent	Start	End	Nval	Station Name
WDM	4mr	101	OBSERVED	SHIRLING	FLOW	1998/10/1	2001/6/14	23688	Hourly Water Flow at Shirlington/4MR
WDM	4mr	102	OBSERVED	SISLERS	PREC	1998/7/1	2001/6/1	25585	Hourly Precipitation at Sislers
WDM	4mr	103	OBSERVED	SKYLINE	PREC	1998/7/1	2001/6/1	25585	Hourly Precipitation at Skyline
WDM	4mr	105	OBSERVED	7CORNERS	PREC	1998/7/1	2001/3/27	24011	Hourly Precipitation at 7Corners
WDM	4mr	107	OBSERVED	7CORNERS	ATMP	1998/7/1	2001/3/27	24011	Hourly Air Temperature at 7Corners
WDM	4mr	109	OBSERVED	7CORNERS	WIND	1998/7/1	2001/3/27	24011	Hourly Windspeed at 7Corners
WDM	4mr	111	OBSERVED	7CORNERS	WDIR	1998/7/1	2001/3/27	24011	Hourly Wind Direction at 7Corners
WDM	4mr	117	OBSERVED	7CORNERS	ATMP	1998/7/1	2001/6/30	26304	Hourly Air Temperature at 7Corners gaps filled
WDM	4mr	121	OBSERVED	7CORNERS	PREC	1998/7/1	2001/6/1	25585	Hourly Precipitation at 7Corners--gaps filled
WDM	4mr	122	OBSERVED	7CORNERS	PREC	1998/7/1	2001/6/1	25585	Hourly Prec at 7 Corners, gaps filled+9/25-26/00
WDM	4mr	130	OBSERVED	SHIRLING	FLOW	1998/10/1	2001/6/13	987	Daily Stream Flow at Shirlington/4MR
WDM	4mr	201	OBSERVED	DCA	WDIR	1998/7/1	2001/6/30	26304	Hourly Wind Direction at DCA
WDM	4mr	202	OBSERVED	DCA	WIND	1998/7/1	2001/6/30	26304	Hourly Wind Speed at DCA
WDM	4mr	203	OBSERVED	DCA	WDIR	1998/7/1	2001/6/30	26304	Hourly Wind Direction, 7Corners, gaps filled w/D
WDM	4mr	204	OBSERVED	DCA	WIND	1998/7/1	2001/6/30	26304	Hourly Wind Speed, 7Corners, gaps filled w/DCA
WDM	4mr	219	OBSERVED	GW_PKWY	FCOLI	1974/9/19	2001/6/13	9765	George Washington Pkwy. DEQ Fecal Coliform Data
WDM	4mr	222	OBSERVED	COL_PIKE	FCOLI	1974/9/30	2001/6/19	9760	Columbia Pike DEQ Fecal Coliform Data
WDM	4mr	225	OBSERVED	COL_PIKE	FCOLI	1998/7/1	2001/6/13	1079	Columbia Pike, DEQ+NVRC+Arl. Parks F.C. Data
WDM	4mr	302	OBSERVED	00013743	ALC1	1998/7/1	2001/6/30	26304	Hourly Surface Airways Data
WDM	4mr	303	OBSERVED	00013743	ALC2	1998/7/1	2001/6/30	26287	Hourly Surface Airways Data
WDM	4mr	304	OBSERVED	00013743	ALM1	1998/7/1	2001/6/30	26304	Hourly Surface Airways Data
WDM	4mr	305	OBSERVED	00013743	ALM2	1998/7/1	2001/6/30	26287	Hourly Surface Airways Data
WDM	4mr	306	OBSERVED	00013743	ALTP	1998/7/1	2001/6/30	26304	Hourly Surface Airways Data
WDM	4mr	307	OBSERVED	00013743	CLHT	1998/7/1	2001/6/30	26304	Hourly Surface Airways Data
WDM	4mr	308	OBSERVED	00013743	DPTC	1998/7/1	2001/6/30	26304	Hourly Surface Airways Data
WDM	4mr	309	OBSERVED	00013743	DPTP	1998/7/1	2001/6/30	26304	Hourly Surface Airways Data
WDM	4mr	310	OBSERVED	00013743	HZVS	1998/7/1	2001/6/30	26304	Hourly Surface Airways Data
WDM	4mr	311	OBSERVED	00013743	PWTH	1998/7/1	2001/6/30	26304	Hourly Surface Airways Data
WDM	4mr	312	OBSERVED	00013743	RHUM	1998/7/1	2001/6/30	26304	Hourly Surface Airways Data
WDM	4mr	313	OBSERVED	00013743	SLVP	1998/7/1	2001/6/30	26304	Hourly Surface Airways Data
WDM	4mr	314	OBSERVED	00013743	TMCD	1998/7/1	2001/6/30	26304	Hourly Surface Airways Data
WDM	4mr	315	OBSERVED	00013743	TMPD	1998/7/1	2001/6/30	26304	Hourly Surface Airways Data
WDM	4mr	316	OBSERVED	00013743	TMPW	1998/7/1	2001/6/30	26304	Hourly Surface Airways Data
WDM	4mr	317	OBSERVED	00013743	WND2	1998/7/1	2001/6/30	26304	Hourly Surface Airways Data
WDM	4mr	318	OBSERVED	00013743	ALC3	1998/7/2	2001/6/30	26261	Hourly Surface Airways Data
WDM	4mr	319	OBSERVED	00013743	ALM3	1998/7/2	2001/6/30	26261	Hourly Surface Airways Data
WDM	4mr	405	OBSERVED	00013743	TMAX	1998/7/1	2001/6/30	1096	TMPD-Max-Daily-Surface Airways Data
WDM	4mr	407	OBSERVED	00013743	TMIN	1998/7/1	2001/6/30	1096	TMPD-Min-Daily-Surface Airways Data
WDM	4mr	410	COMPUTED	00013743	DEVT	1998/7/1	2001/6/30	1096	computed daily PET (in)
WDM	4mr	412	COMPUTED	00013743	PEVT	1998/7/1	2001/6/30	26304	disaggregated PET (daily to hourly)
WDM	4mr	500	OBSERVED	DCA	PREC	1998/7/1	2001/11/30	29976	Hourly Precip at DCA

Appendix C

List of Acronyms

BMP	best management practice
BST	bacteria source tracking
CBD	central business district
cfs	cubic feet per second (for measuring stream flow)
cfu	colony-forming units (when determining bacteria counts)
CWA	Clean Water Act
DNA	deoxyribonucleic acid
DPRCR	Parks, Recreation and Community Resources (an Arlington County department)
GIS	geographic information systems
HSPF	Hydrological Simulation Program - Fortran
LA	load allocation (for nonpoint sources in TMDLs)
mL	milliliters
MOS	margin of safety
MPN	most probable number
MS4	municipal separate storm sewer system
NPDES	National Pollution Discharge Elimination System
NVRC	Northern Virginia Regional Commission
NWS	National Weather Service
OBM	optical brightener monitoring
RNA	ribonucleic acid
STP	Sewage Treatment Plant
SWMM	Storm Water Management Model (an EPA-supported modeling system)
TMDL	Total Maximum Daily Load
VADCR	Virginia Department of Conservation and Recreation
VADEQ	Virginia Department of Environmental Quality
VPDES	Virginia Pollution Discharge Elimination System
USEPA	United States Environmental Protection Agency
WinHSPF	Windows (interface for the) Hydrological Simulation Program – Fortran
WLA	wasteload allocation (for point sources and MS4 discharges in TMDLs)
WQ MIRA	Water Quality Monitoring, Information and Restoration Act

Appendix D

Observed Fecal Coliform Bacteria Data at Columbia Pike during Simulated TMDL Model Period

Date	Time	Source	MPN	Remarks
February 2, 1999	830	DPRCR	2300	collected near end of rain
February 4, 1999	830	DPRCR	410	
February 5, 1999	830	DPRCR	400	
February 9, 1999	830	DPRCR	209	
February 16, 1999	830	DPRCR	118	
February 17, 1999	1240	VADEQ	7800	collected 1 hour after 0.11” rain
February 23, 1999	830	DPRCR	100	
March 3, 1999	830	DPRCR	140	
March 16, 1999	830	DPRCR	136	
April 28, 1999	1402	VADEQ	≤100	at lower detection limit
May 6, 1999	1130	NVRC	900	drought conditions
July 29, 1999	935	VADEQ	500	
September 27, 1999	1300	VADEQ	≥8000	at upper detection limit
November 9, 1999	1215	VADEQ	≤100	at lower detection limit
November 23, 1999	1045	NVRC	240	
January 19, 2000	1045	VADEQ	300	
February 22, 2000	1100	NVRC	130	
March 21, 2000	1050	VADEQ	2800	collected during rain
May 17, 2000	1210	VADEQ	1200	
June 19, 2000	1230	NVRC	1600	light rain the night before
July 14, 2000	1900	NVRC	≥1600	at upper detection limit, storm
September 18, 2000	1130	VADEQ	400	
November 8, 2000	1115	VADEQ	≤100	at lower detection limit, drought
January 29, 2001	1200	VADEQ	≤25	at lower detection limit
March 15, 2001	830	DPRCR	≤200	at lower detection limit

Appendix E

Water Quality Initiatives in Four Mile Run
By Local Governments

Arlington County
City of Alexandria
Fairfax County
City of Falls Church

Arlington County

Watershed Management in Arlington County

About 70% of the Four Mile Run watershed is located within Arlington County. Because of the importance of its watersheds to its citizens and its urban ecology, Arlington County is committed to reducing nonpoint source pollution and improving water quality and riparian and aquatic habitat. Arlington County's **Watershed Management Plan**, adopted by the County Board in April 2001, recommends a number of programs to help protect and restore local streams as well as downstream water quality in the Potomac River and the Chesapeake Bay. This plan is downloadable from the web at:
www.co.arlington.va.us/des/epo/watershed_intro.htm

The County Board approved funding for the FY 2002 budget to begin implementing several of these recommended programs, including:

- biological stream monitoring,
- expanded street sweeping,
- more frequent site inspections,
- new catch basin cleaning,
- new storm sewer inspection program,
- enhanced public outreach and education, and
- a stormwater utility feasibility study.

The Watershed Management Plan also recommends that the County begin a long-term program to restore and maintain the County's natural stream "infrastructure" to improve stream ecology and enhance recreation and open space.

These programs cannot quickly and easily undo the effects of more than 80 years of development on County streams. The existing built-out nature of Arlington County further increases the magnitude of this challenge because there is little space for regional BMPs to attenuate and treat stormwater runoff. Overall, Arlington County's approach to watershed management is to implement as many 'best practices' to reduce stormwater pollution as fiscally and physically possible for a densely developed urban area, consistent with the 'maximum extent practicable' requirements of the County's Municipal Separate Storm Sewer System (MS4) permit.

Arlington County currently implements a systematic TV inspection program for its sanitary sewer network. Together with the dry weather inspections conducted under the County's MS4 permit and NVRC's optical brightener monitoring program, this program is part of a comprehensive effort to identify sanitary sewer cross connections—the major, controllable potential source of human bacteria.

Other initiatives include:

- Recently strengthened its Chesapeake Bay Preservation Ordinance to protect headwater streams and increase funding of source control/pollution prevention initiatives.
- Developed environmentally sensitive dog park policy and established a system of well-managed dog exercise areas (DEA) that encourage responsible dog ownership. For example, trash cans and free pooper scooper bags are available at each DEA.
- Will share with Alexandria a million dollar EPA grant for planning improvements to Four Mile Run.
- Watershed outreach activities, including storm drain markers customized for Four Mile Run (see graphic below) and high-impact posters in MetroRail stations designed to increase awareness of nonpoint source pollution and foster behavioral change.
- Closely cooperates with Arlingtonians for a Clean Environment, which initiates many stream clean-ups and watershed and nonpoint source management outreach activities.

City of Alexandria

- The City has recently approved a new Water Quality Master Plan and Chesapeake Bay planning documents.
- Alexandria is a Gold Award winner in Virginia's Chesapeake Bay Community Partner program.
- The City is home of award-winning, nationally renowned "Targets of Opportunities" BMP program. Alexandria has fostered many innovative ultra-urban BMPs (a coin termed by Alexandria's City Engineer in 1991), some of which serve the Four Mile Run watershed.
- Alexandria's Parks Commissioner, Judy Noritake, worked with Congressman Moran to secure one million dollars from EPA to investigate how to make the Four Mile Run flood control channel more environmentally friendly and aesthetically inviting.

Alexandria has begun a multi-year watershed awareness/education campaign that includes roadway signage identifying streams by name and as Chesapeake Bay drainage, and replacing existing manhole covers with lids that include a "Don't Dump" message.

Fairfax County

Summary of Fairfax County Water Quality Programs Relevant to Four Mile Run

- **Wastewater Collection Line Maintenance and Inspection Program**
  Preventive Sewer Maintenance
  Rehabilitiation of Sanitary Sewers

- **Wildlife Management Programs**
  Deer Management
  Geese Management

- **Pet Waste Ordinance Program**

- **USGS Study to Identify Human Sources of Fecal Coliform in Accotink Creek**
  (lessons learned from this similar watershed may be applied to Four Mile Run)

- **Watershed Management**

- **Fairfax County Water Quality Monitoring Programs**
  Stream Water Quality Program
  Stream Protection Strategy Program
  NPDES Water Quality Monitoring Program

Overview of Current Fairfax County Water Quality Programs Relevant to Four Mile Run

Fairfax County has several ongoing programs and projects related to water quality and watershed management applicable to Four Mile Run. These programs are intended to address many water quality and quantity issues including the following:

- Fecal Coliform Bacteria TMDL
- Nutrients - Virginia Tributary Strategies
- Flooding
- Ecological Health
- Recreational Uses

The following sections summarize the current programs and projects being implemented by Fairfax County. Each section presents the overall Countywide efforts (where applicable) followed by a description of activities within Four Mile Run.

Fairfax County co-funding and support of a USGS study to identify human sources of fecal coliform in Accotink Creek (has relevance to Four Mile Run in terms of lessons learned)

The USGS in cooperation with the Virginia DCR, City of Fairfax, and Fairfax County has initiated and funded a study to identify the human sources of fecal coliform bacteria within the Accotink Creek watershed, which has a similar land use and age of development as found in the Four Mile Run watershed. This study will provide the information to develop an implementation plan that addresses the control of human bacteria pollution for the Accotink Creek TMDL. This study will attempt to identify where these sources originate and how they are distributed in the watershed.

The new study will include a comprehensive, multiple-tracer investigation of the stream, tributaries, and flowing storm drains with the intent of identifying the distribution and pinpointing the sources of the human fecal coliform inputs to Accotink Creek.

The study will be conducted over a three-year period starting in July 2001. A total of eight sampling campaigns are planned to ensure an accurate characterization of all the potential contributors. During each field campaign, approximately 115 samples will be collected along the main channel of Accotink Creek, tributaries and storm drains. A host of chemical and biological tracer techniques will be used to identify the sources of human wastewater.

The data collected in this study will be analyzed in several ways to develop a thorough understanding of the spatial distribution and transport mechanisms of the human wastewater signal in Accotink Creek. This study will support the implementation plan for a TMDL to address water quality impairments based on violations of the fecal coliform bacteria standard, and is expected to have significant implications for implementation strategies to reduce bacteria in Four Mile Run.

Wastewater Collection Line Maintenance and Inspection Program

Wastewater Collection Division (WCD), an agency of Fairfax County's Department of Public Works and Environmental Services, is responsible for the operation and maintenance of the County's sanitary sewer system. This is one of nation's largest wastewater collection systems and consists of over 3,100 miles of sewer lines, 61 pumping stations and 52 flow metering stations, among others. The WCD's mission is to collect about 100 million gallons of wastewater daily and convey it to five regional wastewater treatment plants.

Fairfax County's wastewater collection program is featured on the U. S. Environmental Protection Agencies (EPA) website (www.epa.gov/npdes/sso/virginia/). WCD is using a capacity, management, operation and maintenance (CMOM) approach based on the EPA-recommended model to abate sanitary sewer overflows (SSOs), extend the life of its sewer system assets, and improve customer satisfaction.

Countywide Sewer Maintenance Program:

In order to maintain the structural integrity of the collection system, WCD performs several key functions including, among others, preventive sewer maintenance and sanitary sewer rehabilitation.

Preventive Sewer Maintenance: This is one of the most important operations performed by the WCD and involves physical inspection of the entire system followed by rodding and flushing the lines blocked by tree root intrusion and heavy grease accumulation, two major causes for sanitary sewer backups into private homes and overflows into surface waters. As a direct result of this proactive approach, the number of sewer backups and overflows (SSOs) in the County's system is one of the lowest in the nation. In FY 2001, a total of 48 blockages occurred in the system that resulted in 23 SSOs and 25 backups. All sewer backups into private properties are reported to the County's Risk Management Division and all SSOs are reported within 24 hours to the Virginia DEQ and followed by a written report within five days.

Rehabilitation of Sanitary Sewers: Rehabilitation of aging and deteriorated sewer lines and manholes is an integral element of the WCD's operations. Over the past several years, WCD has taken a very proactive approach toward sewer system rehabilitation, especially in the old neighborhoods, by using various trenchless technologies that have no adverse impacts on citizens, environment and traffic. Over $6.0 million are spent annually on rehabilitation of the County's sanitary sewer infrastructure, which starts with measuring wastewater flows throughout the collection system to identify sewer lines with excessive stormwater infiltration, a sign of severely deteriorated infrastructure. This is followed by inspection of all sewer lines using remote-controlled closed circuit television (CCTV) cameras. Severely deteriorated sewer lines identified by the CCTV inspection are rehabilitated by using state-of-the-art trenchless technologies. In addition to prolonging the infrastructure life by several decades, this rehabilitation program significantly reduces stormwater infiltration and thus preserves the capacity of both the collection and treatment facilities. In FY 2001, over 24 miles of old sewers were rehabilitated using cured-in-place pipe lining process.

Stream Water Quality Program: The primary objective of the program is to monitor the water quality of streams in Fairfax County and provide trend data for finding potential sources of stream pollution. 85 sites county-wide are sampled twice a month for fecal coliforms. One of these sites is in the Four Mile Run watershed. Current and archived stream data is available at: www.fairfaxcounty.gov/service/hd/strannualrpt.htm.

Wildlife Management Programs

The Fairfax County Park Authority and the Division of Animal Control in cooperation with other County agencies operates programs related to wildlife management. These programs include:

Deer Management: The County has adopted an Integrated Deer Management Program to address problems associated with the overabundance of deer in areas of the County. Information is available at www.fairfaxcounty.gov/comm/deer/deermgt.htm.

Geese Management: Geese are a federally protected migratory bird species that are managed by state and federal agencies. The County participates in programs to control goose populations at several locations throughout the County. Training workshops sponsored by GeesePeace, a nonprofit organization whose goal is to build better communities through innovative and humane solutions to wildlife conflict, are offered at Wakefield Recreation Center. Trained GeesePeace volunteers will identify the location of geese nests and watch the nests for egg laying. Once eggs are laid, volunteers, working under a Federal permit, will addle the eggs to minimize the number of gosling births in the spring. The project uses a protocol created by the Humane Society of the United States. Addling takes place in April and May. Addling is effective in preventing an increase in the resident population, and over time normal mortality should lead to a reduction in the non-migratory population.

Beginning in the spring of 2000, GeesePeace coordinated a concentrated effort to target the top 20 potential sites for nesting in Fairfax County and provide training for nest watchers and professional egg addlers needed to carry out an effective program. Fairfax County provided GIS mapping documentation and analysis and necessary equipment to carry out the program.

GeesePeace partners and Park Authority staff addled over 1,200 eggs at sixty sites across the County, including over 650 eggs in Fairfax County parks. No adult geese were harmed and preliminary estimates show that up to 13,000 fewer Canada Geese will live in Fairfax County by 2008 as a result of this addling. More information is available at www.geesepeace.org.

Pet Waste Ordinance Program

Under County Code 41-2-5, pet owners are not allowed to have dogs run at large on public or private properties and owners must pick up waste deposited by their pets on the property of others. Dogs must be restrained by a dependable leash and controlled by a responsible person when off the property of the owner. The County "Pooper-Scooper" program requires that pet owners pick up waste from their pets into plastic bags and disposed of it appropriately. Property owners can report offenders to either the Fairfax County Health Department or the Department of Animal Control, which is responsible for administering the County's ordinance relating to control of pets and proper waste disposal by their owners. Violation of the animal regulations may result in a fine ranging up to $250.

Watershed Management

The Stormwater Planning Division of the Fairfax County Department of Public Works and Environmental Services (DPWES) initiated a watershed master planning program in July 2001. Watershed management plans will be developed for all 30 watersheds within Fairfax County over the next 5 to 7 years. The watershed plans will provide an assessment of management needs and will prioritize solutions within each watershed. The overall goal for the development of watershed management plans is to provide a consistent basis for the evaluation and implementation of solutions for protecting and restoring the receiving water systems and other natural resources of the County. Public participation will be the key to a successful program.

One of the primary objectives of the program is to develop "Friends of" groups for each watershed that will participate in establishing goals and implementing grassroots efforts to protect and restore their watershed.

The watershed management plan for Four Mile Run will address both water quality and quantity issues including the fecal coliform bacteria TMDL.

Water Quality Monitoring Programs

Stream Water Quality Program: The primary objective of the program is to monitor the water quality of streams in Fairfax County and provide trend data for finding potential sources of stream pollution. 85 sites across the County are sampled twice a month for fecal coliforms. One of these sites is located in the Four Mile Run watershed. Current and historic stream data is available at: www.fairfaxcounty.gov/service/hd/strannualrpt.htm.

Stream Protection Strategy Program: The Stream Protection Strategy (SPS) program was initiated in September 1997, when the Fairfax County Board of Supervisors requested that staff from the Department of Public Works and Environmental Services (DPWES) evaluate the need to implement a comprehensive assessment of County streams. The SPS program monitors the ecological health of County streams based on their biological, physical, and chemical conditions. A comprehensive baseline survey was initiated in 1998 that included monitoring 114 stream segments countywide. This baseline study established the first survey of fish and benthic macro-invertebrate (aquatic insects) communities in the County. The results of the SPS baseline study, published in January 2001, are being used as a tool to help identify and prioritize watershed for protection and restoration. Future plans for the SPS program include implementing a long-term monitoring program that will assess water quality trends and the effectiveness of management strategies. Information on the SPS program and the complete baseline report are available at www.fairfaxcounty.gov/gov/DPWES/environmental/SPS_Main.htm.

NPDES water quality monitoring program: Under the current VPDES/MS4 permit, the County may conduct dry-weather screening of several storm sewer outfalls for illicit discharges within the Four Mile Run watershed. The monitoring of outfalls also includes testing for fecal coliforms. The MS4 monitoring program is conducted on an annual basis countywide.

Activities Specific to Four Mile Run

- In February 2001, after a minor SSO occurred into the headwater reach of the Four Mile Run mainstem between the creek and Whitcomb Place, nearly 1000 feet of old sanitary sewer was rehabilitated using a cured-in-place pipe lining process. As a result of this incident, WCD has prioritized inspection of the sanitary sewer network serving homes along Westmoreland Road and the Brillyn Park neighborhood in upper Four Mile Run.

- In September 1999, Fairfax County quickly took action to correct an illicit connection from a hotel laundry room in the Seven Corners area that was discharging laundry waste directly to the Upper Long Branch tributary of Four Mile Run. The illicit connection was discovered by NVRC staff performing OBM across the Four Mile Run watershed.

City of Falls Church

A partial list of initiatives include:

- Recently completed city-wide water quality study that builds on a mid-1990s water quality planning study for Falls Church by Woodward-Clyde;
- Creation of an urban Forest greenways and buffer demonstration project in Four Mile Run/East Falls Church Park;
- Implementation of an effective Chesapeake Bay Preservation Ordinance.

Customized storm drain marker co-developed by staff from Arlington, Alexandria, Falls Church, and NVRC, and funded by NVRC's regional Four Mile Run Watershed Management Program. As of Earth Day, April 20, 2002, these markers are now being placed on storm drain inlets throughout the Four Mile Run watershed.