Stressor Analysis Report for the Benthic Macroinvertebrate Impairments in Holmes Run, Fairfax County, Virginia and Tripps Run, Fairfax County, Virginia, and the City of Falls Church, Virginia

Prepared for
Virginia Department of Environmental Quality

Prepared by
Interstate Commission on the Potomac River Basin

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Cover Photos

Left: Holmes Run, March 14, 2013. Right: Tripps Run, March 14, 2013. Photos by DEQ.

Disclaimer

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Acronyms

$CaCO_3$	Calcium Carbonate
CCU	Cumulative Criterion Unit
CEM	Channel Evolution Model
Cl	Chloride
CWA	Clean Water Act
DCIA	Directly Connected Impervious Area
DCR	Virginia Department of Conservation and Recreation
DEQ	Virginia Department of Environmental Quality
DO	Dissolved Oxygen
DPWES	Fairfax County Department of Public Works and Environmental Services
E. coli	*Escherichia coli*
EPA	U.S. Environmental Protection Agency
HBI	Hilsenhoff Biotic Index
IBI	Index of Biological Integrity
IC25	Inhibition Concentration for a 25% Effect
ICPRB	Interstate Commission on the Potomac River Basin
LOEC	Lowest-Observable-Effects-Concentration
LRBS	Log_{10} Relative Bed Stability Index
LWD	Large Woody Debris
MS4	Municipal Separate Storm Sewer System
NED	National Elevation Dataset
NH_4	Ammonia
NO_2	Nitrite
NO_3	Nitrate
NOEC	No-Observable-Effect-Concentration
PO_4	Orthophosphate
ProbMon	Probabilistic Monitoring
SC	Specific Conductance
SI	Stressor Identification Analysis
SPA	Stream Physical Assessment
SSURGO	Soil Survey Geographic
TDS	Total Dissolved Solids
TKN	Total Kjeldahl nitrogen
TMDL	Total Maximum Daily Load
TN	Total Nitrogen
TP	Total Phosphorus
TSS	Total Suspended Solids
USGS	United States Geological Survey
VDOT	Virginia Department of Transportation
VPDES	Virginia Pollutant Discharge Elimination System
VSCI	Virginia Stream Condition Index
VSMP	Virginia Stormwater Management Program
WET	Whole Effluent Toxicity

Units of Measurement

cfu	Colony-forming unit
kg/m^3	Kilogram per cubic meter
$kg\text{-}m/s^2$	Kilogram-meter per square second
m	Meter
m/s^2	Meters per square second
mg/l	Milligrams per liter
mi	Mile
NTU	Nephelometric turbidity unit
UG/L	Microgram per liter
µmho/cm	Micromho per centimeter

Executive Summary

Holmes Run and Tripps Run are located in the heavily urbanized sections of Northern Virginia in the suburbs of Washington, DC. **Figure ES-1** shows the location of the watersheds. Holmes Run is a tributary to Cameron Run, which drains 44 square miles of Northern Virginia before entering the Potomac River near the City of Alexandria. Tripps Run is a tributary to Holmes Run, which it joins at Lake Barcroft, a 135 acre impoundment which once served as a water supply reservoir for the City of Alexandria, but today is owned by the Lake Barcroft Association on behalf of the residents.

The Holmes Run and Tripps Run watersheds are among the oldest suburbanized areas in Northern Virginia. Both watersheds are almost completely built-out, except for parkland adjacent to the stream corridors. Much of this development took place in the 1950's and 1960's, before the advent of extensive storm water controls (Versar, 2007). Medium density residential land is the most extensive land use in both watersheds. Thirty percent of the Tripps Run watershed and 25% of the Holmes Run watershed are covered by impervious surfaces.

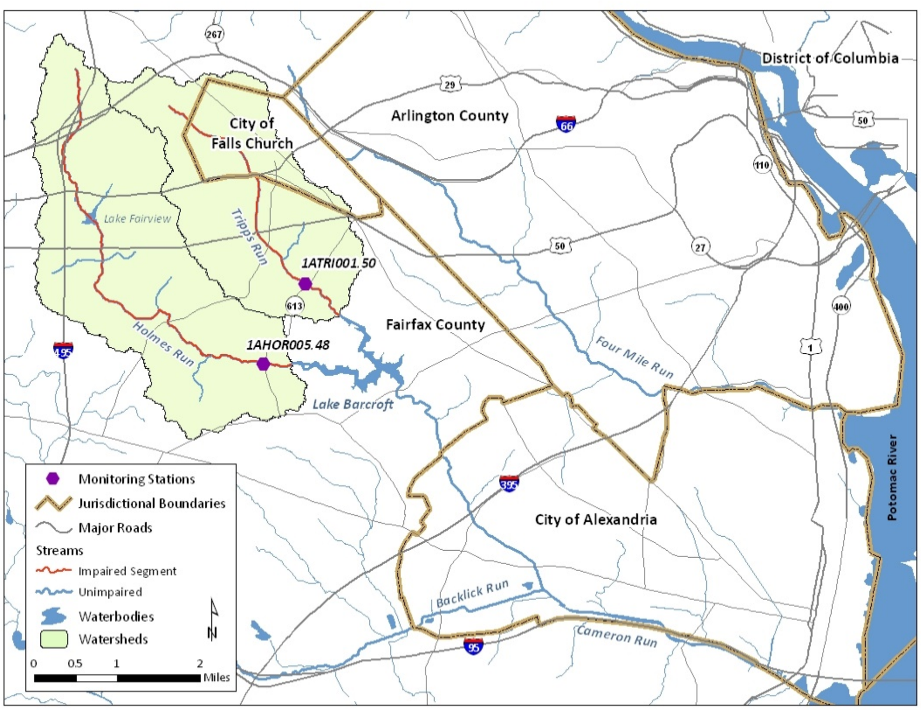

Figure ES-1: Location of the Impaired Segments of Holmes Run and Tripps Run

Both Holmes Run and Tripps Run suffer from what has been called "the urban stream syndrome," (Meyer et al., 2005; Walsh et al., 2005) which is characterized by the following symptoms:

- Flashier flows
- Elevated nutrient and/or contaminant concentrations
- Fewer smaller streams and lower stream density
- Altered channel morphology
- Reduction in biological diversity with increases in pollution-tolerant taxa

The Virginia Department of Environmental Quality (DEQ) uses biological monitoring of benthic macroinvertebrate communities to assess the ecological health of wadeable freshwater streams and to determine support for the aquatic life use. For non-coastal streams, assessment of the benthic macroinvertebrate community is based on the Virginia Stream Condition Index (VSCI), a multi-metric index of the biological integrity of the benthic community (Burton and Gerritsen, 2003). The VSCI is scored on a scale of 0 to 100, where 100 represents the best biological condition and 0 represents the worst. A score of 60 is the threshold for biological impairment. DEQ performed biological assessment seven times each at stations 1AHOR005.48 and 1ATRI001.88 on Holmes Run and Tripps Run, respectively, between 2004 and 2010. The station locations are shown on **Figure ES-1**.

All 14 biological assessments in Holmes Run and Tripps Run had VSCI scores below 60. Based on the results of benthic macroinvertebrate monitoring, DEQ has placed the sections of Holmes Run and Tripps Run on Virginia's List of Impaired Waters (Category 5 of the Integrated List) because they are not supporting their aquatic life use. **Table ES-1** summarizes the impairment listings for Holmes Run and Tripps Run. The stream segments were first listed in the 2004 for not supporting their aquatic life use. They have been listed as impaired in all subsequent Integrated Assessments (2006, 2008, 2010, and 2012). The impaired section of Holmes Run is 5.78 miles in length, and runs from the headwaters to the point at which Holmes Run enters Lake Barcroft. The watershed of the impaired section of Holmes Run lies entirely within Fairfax County. The impaired section of Tripps Run is 3.65 miles in length and stretches from the headwaters to the point at which Tripps Run enters Lake Barcroft. Its watershed includes portions of Fairfax County and of the City of Falls Church. **Figure ES-1** shows the location of the impaired stream segments.

Table ES-1: Holmes Run and Tripps Run Benthic Impairments				
Name	**ID**	**Description**	**Size**	**Initial Listing**
Holmes Run	VAN-A13R-03	Headwaters of Holmes Run to start of Lake Barcroft	5.78 mi	2004
Tripps Run	VAN-A13R-04	Headwaters of Tripps Run to start of Lake Barcroft	3.65 mi	2004

Biological monitoring in Holmes Run and Tripps Run has determined that these waterbodies are not supporting their aquatic life use, but biological monitoring does not determine the cause of the biological impairments in these waterbodies. Until the cause(s) of the biological impairments have been determined, it is not possible to take any action to address the impairment. A Stressor Identification Analysis (SI) needs to be performed to determine the stressor(s) to the biological community. The goal of this report is to determine the causes of biological impairment in Holmes Run and Tripps Run through SI. SI is an analysis of evidence provided by monitoring data and scientific literature which attempts to identify the most likely stressors of the biological community, i.e. the causes of the biological impairment.

The SI is based on information collected from (1) DEQ biological monitoring and concurrent habitat assessment; (2) water quality monitoring; (3) whole effluent toxicity (WET) tests; and (4) geomorphic assessments. DEQ has conducted four water quality monitoring studies in Holmes Run and Tripps Run:

1. Since 2004, ambient water quality monitoring has been performed at the Holmes Run and Tripps Run biological monitoring locations, 1AHOR005.48 and 1ATRI001.50, respectively. Twenty ambient samples have been collected at each station; 15 of the 20 samples at each station have been collected since 2010.
2. Continuous monitoring for temperature, DO, pH, salinity, and specific conductance was conducted in both Holmes Run and Tripps Run from 6/16/10 to 6/18/10 and again in Holmes Run from 8/17/11 to 8/31/11.
3. Samples targeting storm flows were collected in Holmes Run and Tripps Run at the biological monitoring station locations in February and March of 2012; four samples were collected at each station.

4. A special study was conducted at four locations on Tripps Run in April and May of 2012 to determine whether there was a geographically-specific source of high nitrate concentrations in Tripps Run.

Table ES-2 shows the number of observations available by constituent from water quality monitoring at 1AHOR005.48 and 1ATRI001.50.

Table ES-2: Number of Observations by Constituent from DEQ Water Quality Monitoring in Holmes Run and Tripps Run

Constituent	Holmes Run 1AHOR005.48	Tripps Run 1ATRI001.50
DO, pH, Temperature, Conductivity (Field)	24	26
Chloride	17	16
Total Dissolved Solids	17	17
Specific Conductivity	24	26
Nutrients	19	18
Metals: Cadmium, Chromium, Copper, Lead, Silver, Nickel, Zinc	6 Total 3 Dissolved	5 Total 2 Dissolved

WET testing was performed using samples collected from Holmes Run and Tripps Run on February 27, 2012. WET tests compare the response of test species to the water from sampled streams against the response from a control sample with no toxic substances present. In this case, the test species were water fleas (*Ceriodaphnia dubia*) and fathead minnows (*Pimephales promelas*).

In 2010 DEQ conducted a geomorphic assessment on Holmes Run and Tripps Run at stations 1AHOR005.48 and 1ATRI001.50, respectively. Measurements were made of the geometric mean substrate diameter, slope, percent of sands and fine particles, and the percent embeddedness (without fines or bedrock). The geomorphic assessment included the calculation of the Log_{10} Relative Bed Stability Index (LRBS), which measures the relative stability of the bed substrate in a stream and how it is altered by anthropogenic impacts. DEQ has adopted the interpretation that LRBS scores below -1.0 indicate that a stream is carrying excessive sediment, while scores above -0.5 have a normal sediment load (DEQ, 2012).

In addition to monitoring performed by DEQ, Fairfax County Department of Public Works and Environmental Services (DPWES) supports its own biological monitoring program which samples both fish and benthic macroinvertebrates. Sampling results are assessed according to fish and benthic indices of biological integrity (IBIs) developed by the DPWES. On behalf of DPWES, CH2MHill (2005) conducted a physical assessment of Fairfax County streams with four components: (1) a habitat assessment; (2) an infrastructure inventory; (3) a geomorphic assessment based on a channel evolution model (CEM); and (4) an overall stream characterization based on the other three components.

The SI for Holmes Run and Tripps Run examined twelve potential stressors to determine the strength of the evidence linking them to the biological impairments in these streams. Based on an evaluation of the monitoring data and the scientific literature, the potential stressors were divided into three categories:

1. **Non-Stressors**: Stressors with data indicating normal conditions, without water quality exceedances, or without any observable impacts usually associated with stressors.
2. **Possible Stressors**: Stressors with evidence indicating possible link to the biological impairment, but the evidence is inconclusive.
3. **Most Probable Stressors**: Stressor(s) with the most consistent evidence linking them to the biological impairment.

Three sets of numerical benchmarks were used to help evaluate potential stressors in the SI:

1. When Virginia's water quality standards contained in 9VAC25-260 et seq. (State Water Control Board, 2011) have numerical criteria for a constituent, those criteria were used in the SI. Constituents with explicit numerical criteria include temperature, pH, dissolved oxygen (DO), total chloride, ammonia, and most metals.
2. For nutrients and other constituents without numerical criteria, monitoring results were compared to the 90th percentile concentrations observed in the DEQ Probabilistic Monitoring (ProbMon) program dataset from 2001-2008 (Dail et al., 2006). Sample sites for the ProbMon program are chosen at random, so that the collection of sample sites constitutes a random sample of Virginia's streams.
3. The ProbMon program has also adopted thresholds identifying suboptimal conditions for six potential biological stressors that do not have water quality criteria: (1) total nitrogen (TN), (2) total phosphorus (TP), (3) total dissolved solids (TDS), (4) the cumulative impact of dissolved metals (using the Cumulative

Criterion Unit (CCU) Metals Index), (5) habitat degradation, and (6) sedimentation (using the LRBS).

Table ES-3: Categorization of Potential Stressors in Holmes Run and Tripps Run

Category	Stressor	
Non-Stressors	Temperature	pH
	Dissolved Oxygen	Toxics
	Metals	
Possible Stressors	Nutrients	Sediment
	Total Dissolved Solids	Specific Conductance
	Chloride	
Most Probable Stressors	Hydromodification	Poor Riparian Habitat

For temperature, dissolved oxygen, pH, and metals, the monitoring data showed no violations of Virginia's water quality standards protecting aquatic life. WET tests on water fleas and fathead minnows did not indicate that toxics were a stressor in either Holmes Run or Tripps Run.

While there is some evidence that nutrients or sediment may be biological stressors in Holmes Run or Tripps Run, the weight of evidence indicates that neither nutrients nor sediment are the most probable stressors. Although sedimentation and embeddedness habitat scores in both Holmes Run and Tripps Run have been frequently marginal, Holmes Run and Tripps Run have relatively stable stream beds, according to LRBS Index. In comparison with the 90th percentile of ProbMon data, nutrient concentrations in Holmes Run and Tripps Run are high, relative to other streams in Virginia, but these high concentrations may be the result, not the cause, of the impaired biological communities in these streams. Similarly, while chloride concentrations and concentrations of TDS and specific conductance, which are associated with chlorides, are high relative to other streams in Virginia, there are no violations of the chronic chloride criterion for support of aquatic life. Therefore, chlorides, TDS, and specific conductance were not identified as the most probable stressors.

The most probable stressors are hydromodification and poor riparian habitat. Hydromodification, including the straightening of the main channel, as well as the wholesale replacement of headwater and small-order streams by storm sewers, is the dominant stressor in both Holmes Run and Tripps Run. The loss of small-order streams leads to the disruption of the food web on the main channel. By removing the upstream source of colonists from the mainstem, the loss of small-order streams reduces the resilience of the mainstem biological community and its ability to respond to disturbances, such as the flow-related disturbances commonly associated with urbanized watersheds. The extent of poor condition of the riparian habitat in Holmes Run and Tripps Run has been documented in Fairfax County's physical assessment of their streams (CH2MHill, 2005). Poor riparian habitat contributes to a disruption of the food web by reducing the input of plant litter, the major source of energy to the aquatic community. Poor riparian habitat also reduces the input of large woody debris, a key component of habitat diversity in streams. Hydromodification and poor riparian habitat are jointly sufficient to account for the biological impairments in Holmes Run and Tripps Run, though some of the possible stressors discussed in the previous section—nutrients, sediment, and chloride—may also be making a contribution to the impairment of the benthic communities in these streams.

A public meeting was held on May 31, 2012 at the Woodrow Wilson Library in Falls Church, Virginia, to introduce this project to the public. No public comments were received during the public comment period following the meeting.

1 Introduction

The Clean Water Act (CWA) requires that all waters of the Unites States support swimming, sustain and protect aquatic life, and maintain other beneficial uses such as water supply or shellfish propagation and harvest. Virginia has adopted water quality standards to meet the goals of the CWA. These standards specify (1) designated uses for waterbodies, such as a primary contact recreation use, to support swimming, or an aquatic life use, to sustain and protect aquatic life, as well as (2) the water quality criteria necessary to support these uses. The CWA also requires states to assess their waters to determine if they are meeting water quality standards. Waterbodies not meeting standards, i.e. impaired waterbodies, are documented in a state's biannual Integrated Assessment on the state's Integrated List.

Holmes Run is a tributary to Cameron Run. The Cameron Run watershed drains 44 square miles of Northern Virginia before entering the Potomac River near the City of Alexandria. Tripps Run is a tributary to Holmes Run, joining at Lake Barcroft, an impoundment on Holmes Run. Based on benthic macroinvertebrate monitoring at stations 1AHOR005.48 and 1ATRI001.88 on Holmes Run and Tripps Run, respectively, the Virginia Department of Environmental Quality (DEQ) has placed the sections of both these streams above Lake Barcroft on Virginia's List of Impaired Waters (Category 5 of the Integrated List) because they are not supporting their aquatic life use. **Figure 1-1** shows the location of the monitoring stations and the impaired stream segments.

The goal of this report is to determine the causes of biological impairment in Holmes Run and Tripps Run through a Stressor Identification Analysis (SI). SI is an analysis of evidence provided by monitoring data and scientific literature which attempts to identify the most likely stressors of the biological community, i.e. the causes of the biological impairment.

The remainder of this introductory section discusses the regulatory background to listing Holmes Run and Tripps Run as biologically impaired and the regulatory implications of the SI. **Section 2** characterizes the Holmes Run and Tripps Run watersheds in greater detail. **Section 3** reviews existing monitoring data. **Section 4** presents the results of the SI. **Section 5** offers a brief summary of the conclusions and returns to the question of the regulatory implications of the SI.

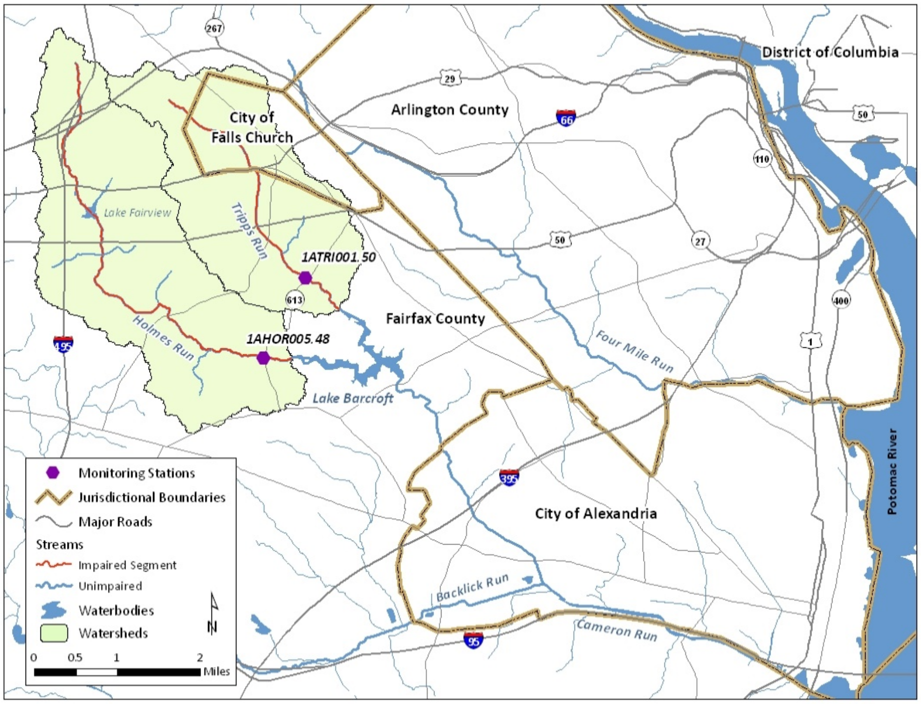

Figure 1-1: Location of the Impaired Segments of Holmes Run and Tripps Run

1.1 Applicable Water Quality Standards

Virginia's water quality standards consist of designated uses for a waterbody and water quality criteria necessary to support those designated uses. The standards applicable to the impairments in Holmes Run and Tripps Run are discussed below.

1.1.1 Designated Uses

Designated uses are statutory management objectives for a waterbody. CWA specifies that all waters must be "fishable and swimmable," that is, support their use for contact recreation and for sustaining a healthy aquatic community. According to Virginia Water Quality Standards (9 VAC 25-260-5):

"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)."

1.1.2 Water Quality Criteria

Water quality criteria can be numerical or narrative. The General Standard defined in Virginia Water Quality Standards (9 VAC 25-260-20) provides general, narrative criteria for the protection of designated uses from substances that may interfere with attainment of such uses. The General Standards states:

All state waters, including wetland, shall be free from substances attributable to sewage, industrial waste, or other waste in concentrations, amounts, or combinations which contravene established standards or interfere directly or indirectly with designated uses of such water or which are inimical or harmful to human, animal, plant, or aquatic life.

1.1.3 Virginia Stream Condition Index

DEQ uses biological monitoring of benthic macroinvertebrate communities to assess the ecological health of wadeable freshwater streams and to determine whether aquatic life use is supported. For non-coastal streams, assessment of the benthic macroinvertebrate community is based on the Virginia Stream Condition Index (VSCI). The VSCI is a multi-metric index of the biological integrity of the benthic community (Burton and Gerritsen, 2003). The benthic community at a monitoring location is measured against the benthic communities found in reference streams (streams with minimum anthropogenic impacts) using a suite of eight metrics. The VSCI combines these metrics into a single score. The VSCI and its component metrics are discussed in more detail in **Section 3.1**.

Potential VSCI scores range from 0 to 100, with higher scores indicating relatively better ecological health. DEQ has set a score of 60 as the threshold for impairment. Scores below 60 indicate an impaired biological community.

1.2 Impairment Listings

Table 1-1 summarizes the impairment listings for Holmes Run and Tripps Run. The stream segments were first listed in the 2004 for not supporting their aquatic life use. They have been listed as impaired in all subsequent Integrated Assessments (2006, 2008, 2010, and 2012). The impaired section of Holmes Run is 5.78 miles in length, and runs from the headwaters to the point at which Holmes Run enters Lake Barcroft. The watershed of the impaired section of Holmes Run lies entirely within Fairfax County. The impaired section of

Tripps Run is 3.65 miles in length and stretches from the headwaters to the point at which Tripps Run enters Lake Barcroft. Its watershed includes portions of Fairfax County and of the City of Falls Church.

The impairment listings were based on biological monitoring performed on Holmes Run and Tripps Run at stations 1AHOR005.48 and 1ATRI001.50, respectively. The monitoring stations are located just upstream of where the streams pass underneath of State Route 613, Sleepy Hollow Road. **Figure 1-2** shows the VSCI scores from the biological monitoring. **Table 1-2** summarizes the same information. All VSCI scores from sampling in Holmes Run and Tripps Run are below 60, the VSCI impairment threshold score.

Table 1-1: Holmes Run and Tripps Run Benthic Impairments

Name	ID	Description	Size	Initial Listing
Holmes Run	VAN-A13R-03	Headwaters of Holmes Run to start of Lake Barcroft	5.78 mi	2004
Tripps Run	VAN-A13R-04	Headwaters of Tripps Run to start of Lake Barcroft	3.65 mi.	2004

Table 1-2: Holmes Run and Tripps Run VSCI Scores

Sample Date	Holmes Run	Tripps Run
6/9/2004	30.7	34.8
11/29/2004	35.5	35.6
9/25/2007	39.7	23.7
4/7/2008	18.7	24.9
10/1/2008	40.2	44.7
4/15/2010	32.9	26.2
11/9/2010	37.1	21.6

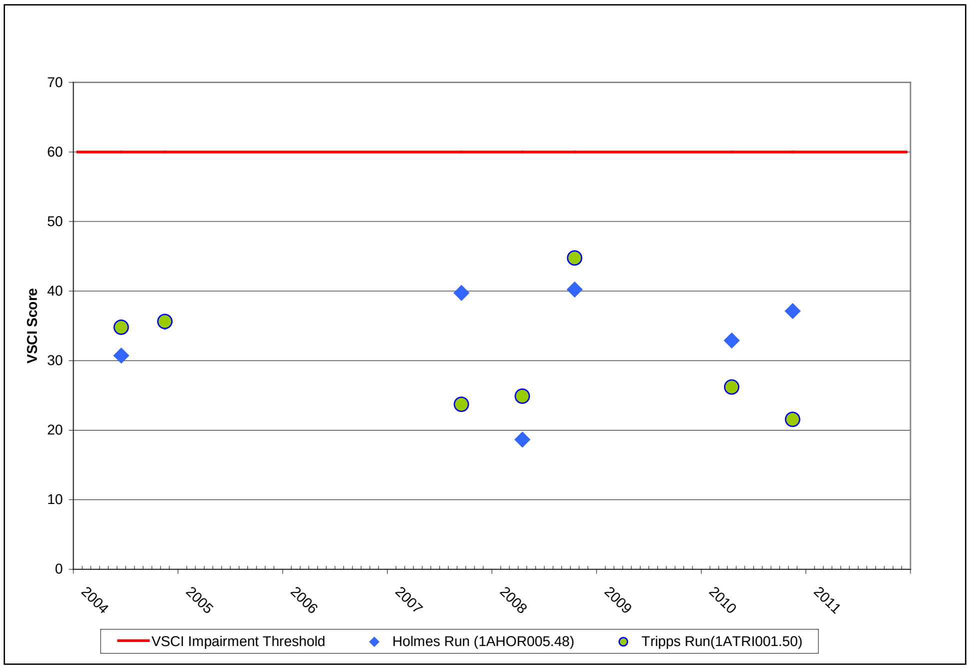

Figure 1-2: VSCI Scores for Holmes Run and Tripps Run

1.3 Goals of Stressor Identification Analysis

Section 303(d) of the CWA and the EPA's Water Quality Planning and Management Regulations (40 CFR part 130) generally require states to develop Total Maximum Daily Loads (TMDLs) for waterbodies that are exceeding water quality standards. TMDLs represent the total pollutant loading that a waterbody can receive without exceeding water quality standards. Impaired waterbodies requiring TMDLs are listed in Category 5 of the Integrated List. Currently, Holmes Run and Tripps Run are both listed in Category 5 on Virginia's Integrated List.

Biological monitoring in Holmes Run and Tripps Run has determined that these waterbodies are not supporting their aquatic life use, but the biological monitoring does not determine the cause of the biological impairments in these waterbodies. Until the cause(s) of the biological impairments have been determined, it is not possible to take any action to address the impairment. A Stressor Identification Analysis (SI) needs to be performed to determine the stressor(s) to the biological community. Once the stressor(s) have been identified, TMDLs can be developed for any pollutant identified as a stressor of the biological community.

Not all stressors are pollutants amenable to TMDL development. CWA distinguishes the general class of pollution, defined as " the man-made or man-induced alteration of physical, biological, chemical, and radiological integrity of water and other media (CWA, Section 502, General Definitions)," from pollutants, which are restricted to "[d]redged spoil, solid waste, incinerator residue, sewage, garbage, sewage sludge, munitions, chemical wastes, biological materials, radioactive materials, heat, wrecked or discarded equipment, rock, sand, cellar dust and industrial, municipal, and agricultural waste discharge into water (CWA, Section 502, General Definitions)." TMDLs can only be developed for pollutants. If a stressor is not a pollutant, U.S. Environmental Protection Agency (EPA) guidance (EPA, 2005) provides an alternative category in the Integrated List, 4C, for waterbodies impaired by natural causes or pollution.

The goal of SI, therefore, is to identify the stressors of the biological communities in Holmes Run and Tripps Run. If the stressors are pollutants, then TMDLs should be developed for those pollutants. If the stressors are due to natural causes, or if all stressors are pollution but not pollutants, then the impairment listings should be revised in the next Integrated Report.

2 Watershed Description

This section describes the Holmes Run and Tripps Run watersheds. Land use, population, soils, topography, and permitted facilities are discussed in the sections below.

2.1 Watershed Description and Identification

Holmes Run and Tripps Run are located in the heavily urbanized sections of Northern Virginia in the suburbs of Washington, DC. **Figure 2-1** shows the location of the watersheds. Tripps Run begins in Fairfax County inside the Capital Beltway (Interstate 495). It flows through the City of Falls Church before re-entering Fairfax County at Lee Highway (U. S. Route 29). Within Falls Church, the mainstem of Tripps Run is confined to either a culvert or a concrete-lined channel. It remains a concrete channel from where it re-enters Fairfax County until it crosses Annandale Road (Route 649). Tripps Run ends in Lake Barcroft, a 135 acre impoundment which was originally constructed in 1915 as a water supply reservoir for the City of Alexandria. Today, Lake Barcroft is owned by the Lake Barcroft Association on behalf of the residents and it is only used for recreation.

The headwaters of Holmes Run are located north of Route 66 outside the Capital Beltway (Route 495) in Tysons Corner, a major commercial area in Fairfax County. Holmes Run flows roughly parallel to the Capital Beltway before turning southeast and flowing into Lake Barcroft. There is a downstream section of Holmes Run, which flows from the Lake Barcroft dam to Backlick Run, however, the biological impairment addressed in the report includes only the upper portion of Holmes Run from its headwaters to Lake Barcroft. Hereafter references to Holmes Run or the Holmes Run watershed will refer only to the portion above Lake Barcroft. The benthic impairment in Tripps Run also runs from its headwaters to Lake Barcroft. The impaired sections are shown in **Figure 2-1**.

The Holmes Run and Tripps Run watersheds are among the oldest suburbanized areas in Northern Virginia. Both watersheds are almost completely built-out, except for parkland adjacent to the stream corridors. Much of this development took place in the 1950's and 1960's, before the advent of extensive storm water controls (Versar, 2007). Medium density residential land is the most extensive land use in both watersheds. According to the analysis described below in **Section 2.1.3**, 30% of the Tripps Run watershed and 25% of the Holmes Run watershed are covered by impervious surfaces.

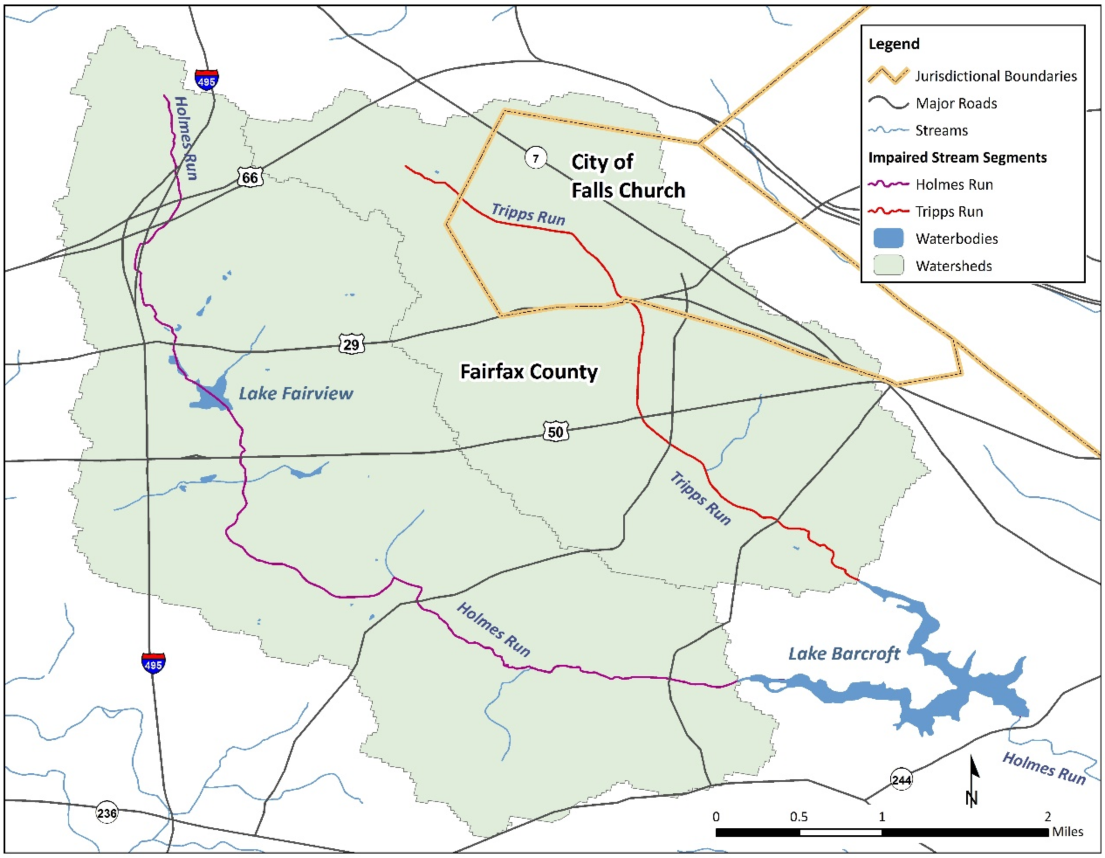

Figure 2-1: Location and Boundaries of the Holmes Run and Tripps Run Watersheds

2.1.1 Topography

A National Elevation Dataset (NED) was used to characterize the topography in the watershed (USGS, 1999). NED data obtained from the United States Geological Survey (USGS) show that elevation in the Holmes Run watershed ranges from approximately 207 to 491 feet above mean sea level, with an average elevation of 338 feet above mean sea level. The elevation in the Tripps Run watershed ranges from approximately 209 to 483 feet above mean sea level, with an average elevation of 327 feet.

2.1.2 Soils

The Holmes Run and Tripps Run watersheds soil characterization was based on data obtained from the Soil Survey Geographic (SSURGO) database (NRCS, 2012). According to SSURGO, there are 29 soil series located in the watersheds (**Table 2-1**).

Table 2-1: Soil Series within the Holmes Run and Tripps Run Watersheds

Soil Name	Holmes Run		Tripps Run	
	Acres	Percentage of Watershed	Acres	Percentage of Watershed
Barkers Crossroads loam	53	1.1%	2	0.1%
Barkers Crossroads-Nathalie complex	0	0.0%	17	0.5%
Codorus and Hatboro soils	237	5.0%	1	0.0%
Codorus silt loam	12	0.2%	0	0.0%
Danripple gravelly loam	18	0.4%	24	0.7%
Fairfax loam	70	1.5%	32	1.0%
Glenelg silt loam	473	9.9%	70	2.1%
Grist Mill-Gunston complex	98	2.1%	7	0.2%
Hatboro silt loam	4	0.1%	0	0.0%
Kingstowne sandy clay loam	12	0.2%	3	0.1%
Kingstowne-Danripple complex	98	2.1%	85	2.6%
Kingstowne-Sassafras complex	42	0.9%	6	0.2%
Kingstowne-Sassafras-Neabsco complex	0	0.0%	2	0.0%
Meadowville loam	66	1.4%	15	0.5%
Nathalie gravelly loam	6	0.1%	3	0.1%
Sassafras sandy loam	4	0.1%	0	0.0%
Sassafras-Marumsco complex	3	0.1%	0	0.0%
Sumerduck loam	98	2.1%	32	1.0%
Wheaton loam	56	1.2%	34	1.0%
Wheaton-Codorus complex	81	1.7%	88	2.7%
Wheaton-Fairfax complex	333	7.0%	218	6.6%
Wheaton-Glenelg complex	1,471	30.9%	1,533	46.6%
Wheaton-Meadowville complex	239	5.0%	222	6.7%
Wheaton-Sumerduck complex	139	2.9%	228	6.9%
Woodstown sandy loam	10	0.2%	3	0.1%
Urban land	642	13.5%	483	14.7%
Urban land-Barker Crossroads complex	116	2.4%	0	0.0%
Urban land-Kingstowne complex	93	1.9%	14	0.4%
Urban land-Wheaton complex	264	5.5%	172	5.2%
Water	24	0.5%	0	0.0%
Total	**4,760**	**100%**	**3,294**	**100%**

Note: Numbers may not add due to rounding.

The hydrologic soil group linked with each soil association is presented in **Table 2-2**. The hydrologic soil groups represent different levels of infiltration capacity of the soils.

Hydrologic soil group "A" designates soils that are well to excessively well drained, whereas hydrologic soil group "D" designates soils that are poorly drained. Consequently, more rainfall becomes part of the surface water runoff along poorly drained soils. Descriptions of the hydrologic soil groups are presented in **Table 2-3**. As **Table 2-2** shows, soils in both the Holmes Run and Tripps Run watersheds are predominately poorly drained soils of hydrologic group D, or have been disturbed by development.

Table 2-2: Soil Hydrologic Groups within Holmes Run and Tripps Run Watersheds

Hydrologic Group – Dominant Condition	Holmes Run		Tripps Run	
	Acres	Percentage of Watershed	Acres	Percentage of Watershed
B	621	13.1%	121	3.7%
C	374	7.8%	60	1.8%
D	2,627	55.2%	2,444	74.2%
Disturbed Urban Soils	1,114	23.4%	669	20.3%
Water	24	0.5%	0	0.0%
Total	**4,760**	**100.0%**	**3,294**	**100.0%**

Note: Numbers may not add due to rounding.

Table 2-3: Descriptions of Soil Hydrologic Groups

Soil Hydrologic Group	Description
A	High infiltration rates. Soils are deep, well-drained to excessively-drained sand and gravels.
B	Moderate infiltration rates. Deep and moderately deep, moderately well and well-drained soils with moderately coarse textures.
C	Moderate to slow infiltration rates. Soils with layers impeding downward movement of water or soils with moderately fine or fine textures.
D	Very slow infiltration rates. Soils are clayey, have a high water table, or shallow to impervious cover.

2.1.3 Land Use

The land use characterization for the Holmes Run and Tripps Run watersheds was based on zoning and land cover data provided by Fairfax County, VA (K. Bennett, DPWES. Personal communication, 2009) and the City of Falls Church, VA (S. Kahn, City of Falls Church. Personal communication, 2009).

The jurisdictions' own land use categories were converted to a common set of land use classifications according to **Table 2-4**. Six major land use categories were used: water, residential, industrial, commercial, transportation, and open space. These were subdivided into 12 minor categories shown in **Table 2-4**. **Table 2-5** describes these categories.

Figure 2-2 depicts the land use distribution in the two watersheds. **Table 2-6** shows the classification of land uses in the Holmes Run watershed. **Table 2-7** shows the classification of land uses in the Tripps Run watershed. Both watersheds are highly developed: developed land accounts for 86% of the Holmes Run watershed and 93% of the Tripps Run watershed. About half of the Holmes Run watershed and over 60% of the Tripps Run watershed is residential land. Transportation is the next largest category of land use in both watersheds, accounting for 20% of the Holmes Run watershed and 19% of the Tripps Run watershed. About 16% of the Holmes Run watershed and 11% of the Tripps Run watershed is commercial land. Industrial land occupies less than 1% of either watershed.

Table 2-4: Classification of Jurisdiction Land Use Categories

Zoning Codes		Source/Shapefile (Field)	
		Falls Church	Fairfax County
Land Use Category	Zoning Category	Zoning ZN_CODE	ca-base_year_ scenario_land_use_ (CLU_CODE)
Water	Water		OW
Open space	Open space		OS
	Vacant/underutilized		VUR
Residential	High-density	R-C, R-M, R-TH	HDR
	Medium-density	R-1B	MDR
	Low-density	R-1A	ESR, LDR
Commercial	Transitional/development	C-D, O-D, T-1, T-2	
	Commercial	B-1, B-2, B-3	
	High-intensity commercial		HIC
	Low-intensity commercial		LIC
Industrial	Industrial	M-1	IND
Transportation	Transportation/Utilities		TRA

Table 2-5: Zoning and Land Cover Categories within the Holmes Run and Tripps Run Watersheds		
Model Land Use	**Zoning Category**	**Description**
Open Space	Open Space	Public open spaces, parks, recreation zones, and golf courses are included in this category.
	Vacant/underutilized	In these parcels the existing land use is significantly less than zoned or planned, or the parcels are vacant.
Residential	Low density	This category includes estate residential areas, single family homes on 8,000 square foot or larger lots, and townhouse developments with nine or fewer units per acre.
	Medium density	Single and two family homes, townhouses, and medium density apartment dwellings are permitted in these neighborhoods.
	High density	These areas area zoned for high rise, high density multifamily structures and cluster residences.
Commercial	Mixed use	A mix of residential and commercial uses a permitted in these zones.
	Transitional/Development	This category includes transitional areas and coordinated development districts.
	Commercial	These are developed areas in which commercial uses predominate.
	High intensity commercial	These areas are zoned for High intensity commercial uses.
	Low intensity commercial	These areas are zoned for low intensity commercial uses.
Industrial	Industrial	These parcels are zoned for industrial uses.
Transportation	Transportation/Utilities	These areas include utilities and infrastructure (e.g. roads, railroads).

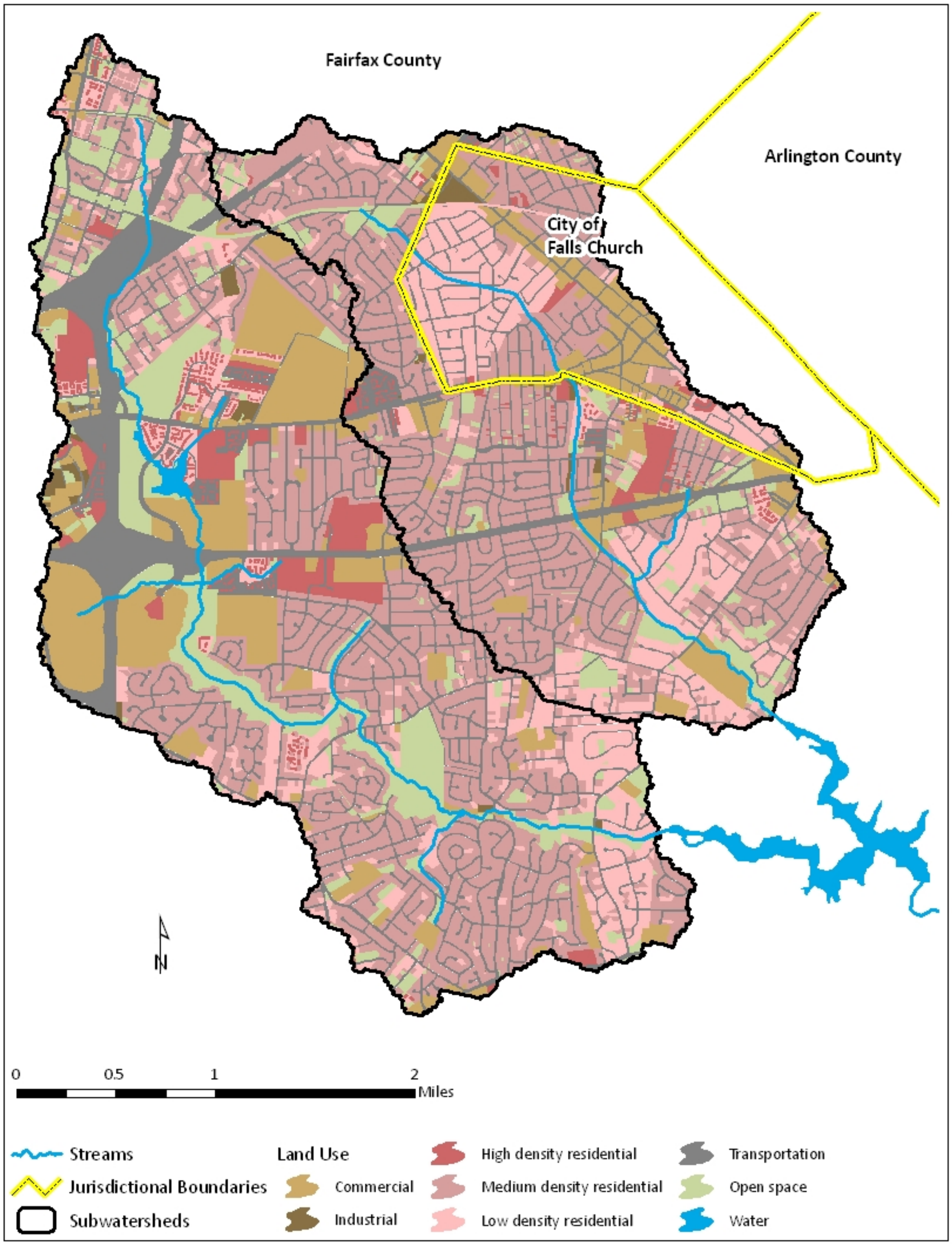

Figure 2-2: Land Use in the Holmes Run and Tripps Run Watersheds

Table 2-6: Land Use in Holmes Run Watershed					
Land Use Category	**Zoning Category**	**Acres**		**Percent of Watershed**	
Water	Water	4	4	0.1%	0.1%
Open space	Open space	361	665	7.6%	14.0%
	Vacant/underutilized	304		6.4%	
Residential	High-density	254	2,332	5.3%	48.9%
	Medium-density	1,552		32.6%	
	Low-density	526		11.0%	
Commercial	Commercial	2	758	< 0.1%	15.9%
	High-intensity commercial	53		1.1%	
	Low-intensity commercial	703		14.8%	
	Transitional/Development	0		0.0%	
Industrial	Industrial	33	33	0.7%	0.7%
Transportation	Transportation/Utilities	969	969	20.4%	20.4%
Total		**4,760**		**100%**	

Note: Numbers may not add due to rounding.

Table 2-7: Land Use in Tripps Run Watershed					
Land Use Category	**Zoning Category**	**Acres**		**Percent of Watershed**	
Water	Water	0	0	0%	0%
Open space	Open space	54	226	1.6%	6.9%
	Vacant/underutilized	172		5.2%	
Residential	High-density	95	2,083	2.9%	63.2%
	Medium-density	1,344		40.8%	
	Low-density	644		19.6%	
Commercial	Commercial	113	347	3.4%	10.5%
	High-intensity commercial	52		1.6%	
	Low-intensity commercial	137		4.2%	
	Transitional/Development	45		1.4%	
Industrial	Industrial	25	25	0.8%	0.8%
Transportation	Transportation/Utilities	613	613	18.6%	18.6%
Total		**3,294**		**100.0%**	

Note: Numbers may not add due to rounding.

An estimation of the impervious area within each watershed was based on polygon and line GIS layers representing building footprints and paved areas (e.g. roads, parking lots, driveways, and sidewalks). The layers were provided by Fairfax County (K. Bennett, DPWES. Personal communication, 2009), and Falls Church (S. Kahn, City of Falls Church. Personal communication, 2009). Using standard GIS tools and procedures, the various layers were combined to obtain a representation of the impervious area in each subwatershed, which was then apportioned by land use. **Table 2-8** shows the shapefiles provided by the jurisdictions to estimate impervious area. Details of the treatment of specific features are described below.

Roads and Parking Lots – These polygon layers show areas covered by transportation features (e.g. roads, shoulders, medians, bridges) and parking lots, and were classified as either paved or unpaved. Paved areas were deemed to be 100% impervious and unpaved areas as 50% impervious. When a classification was not provided for a polygon, it was considered to be 75% impervious.

Sidewalks – Fairfax County provided a line feature, which either represented the centerline or both edges of the sidewalks. In the former case the sidewalk length was multiplied by an average sidewalk width of four feet and in the latter case by half the sidewalk width so that the areal extent of the sidewalks could be estimated. The City of Falls Church did not provide a sidewalk shapefile, but rather a shapefile of road edges. Again, the length of the road edges was multiplied by four feet. Sidewalks were assumed to be 85% impervious.

Buildings - The buildings polygon layer contained building footprints and a description of the building types (**Table 2-9**). Buildings were presumed to be 100% impervious. When the building type was not provided, the buildings were classified according to zones in which they were located (**Table 2-10**). When building polygons overlapped road, parking lot, or sidewalk polygons, standard GIS procedures were used to subtract the overlap area in order to avoid double counting impervious area.

Not all impervious areas drain into storm sewers. For example, drainage from roofs of detached low density single family residences is often directed onto lawns rather than onto driveways or other structures hydraulically connected to storm sewers. Therefore, a fraction of roof drainage from low density zones was separate from the directly connected impervious area (DCIA) and classified as pervious area. DCIA fractions were taken from a memorandum prepared by Camp, Dresser, and McGee (2003) for Fairfax County on the use of GIS information in stormwater models. **Table 2-11** shows the fraction of buildings and other features considered DCIA.

Driveways – The areal extent of driveways was presumed to cover 1,000 square feet per single family residential building. All driveways were assumed to be 100% impervious.

Table 2-8: Shapefiles Used to Estimate Impervious Area		
Feature	**Jurisdiction**	
	Falls Church	**Fairfax County**
Building Footprints	building (p)	BuildingOutlines(p)
Roads	roads poly (p)	EoPMajor
Parking lots	parking	EoPMinor
Driveways	Estimated based on single family residences	
Sidewalks	Estimated from road edges(l)	sidewalks (l)

Table 2-9: Classification of Building Types		
Building Type	**Codes**	**Notes**
Single family residential	SFR	
Multifamily residential	A, CM, TH, MFR	Includes apartment, condominium, townhouse, multifamily residential
Public	P	e.g. schools, libraries, community centers, government centers, parking garages, hospitals
Other	M, O, R/C	Metro station, other, religious/charitable
Non enclosed	NON	Court yards and other internal spaces surrounded by a building
Commercial	C	
Industrial	I	
Not classified	NC	These were reclassified based on the zoning

Table 2-10: Reclassification of Building Types	
If in zone…	**Building classified as… (see Table 2-9)**
COM	C
Industrial	I
HDR	MFR
LDR, MDR	SFR
Open Space (OSP)	Public

Table 2-11: Directly Connected Impervious Area (DCIA) by Land Use		
Impervious Feature	**Type**	**Fraction DCIA**
Sidewalk	N/A	0.85
Buildings	Commercial	1
	Industrial	0.95
	Multifamily residential	0.9
	Other	0.85
	Public	0.85
	Single family residential	0.5
Transportation Features: Roads, shoulders, medians, parking lots, driveways	Paved	1
	Unpaved	0.5
	Not classified	0.75

2.1.4 Population and Number of Households, Sewers, and Septic Systems

Spatial data at the Virginia state level that incorporates the 2010 Census block geography and the 2010 Census population and housing unit counts were downloaded from the U.S. Census Bureau ftp site (ftp://ftp2.census.gov/geo/tiger/TIGER2010BLKPOPHU/). The aerial extent of census blocks located within or intersecting a subwatershed were determined using routine GIS analysis. The fraction of each census block within a subwatershed was calculated and then used to obtain an area-weighted number of households for each watershed. A summary of the population and household estimates for Holmes Run, and Tripps Run are presented in **Table 2-12**.

Table 2-12: 2010 Census Data Summary for Holmes Run and Tripps Run Watersheds		
Watershed	**Estimated Population**	**Estimated Households**
Holmes Run	35,097	13,330
Tripps Run	27,829	10,507

Source: U.S. Census Bureau (2010)

Although the population in Holmes Run and Tripps Run is primarily served by sanitary sewers, there are a few septic systems in each watershed. Estimates of the number of septic systems in the Holmes Run and Tripps Run watersheds in Fairfax County were supplied by the Fairfax County Health Department (A. Joye, Fairfax County Health Department. Personal communication, 2012). There are 32 septic systems in the Holmes Run watershed, and 27 septic systems in the Tripps Run watershed. There are no known septic systems in Falls

Church. There are also no known straight pipes in the watershed and it is assumed that given the density of development, there are none.

2.2 Permitted Facilities and Septic Systems

There are three types of permits issued in the Holmes Run and Tripps Run watersheds: (1) general Virginia Pollutant Discharge Elimination System (VPDES) permits; (2) municipal separate storm sewer system (MS4) permits; and (3) general construction stormwater control permits. These are discussed in subsequent sections. There are no individual VPDES permits in either the Holmes Run or Tripps Run watersheds.

2.2.1 Facilities with General Permits

There are not any facilities holding general Virginia Pollutant Discharge Elimination System (VPDES) permits, issued through the VPDES permitting program, in the Holmes Run watershed and two facilities holding general permits in the Tripps Run watershed. The permit number and type for each permit are presented in **Table 2-13** and their location is shown in **Figure 2-3**.

Table 2-13: General VPDES Permitted Facilities within the Holmes Run and Tripps Run Watersheds

Permit No	Permit Type	Facility	Receiving Stream
VAR050998	Industrial Stormwater GP	Yellow Cab Company - Falls Church	Tripps Run
VAG110010	Concrete GP	Virginia Concrete Company Inc	UT Tripps Run

*Permits listed in this table were accurate as of April 2014.

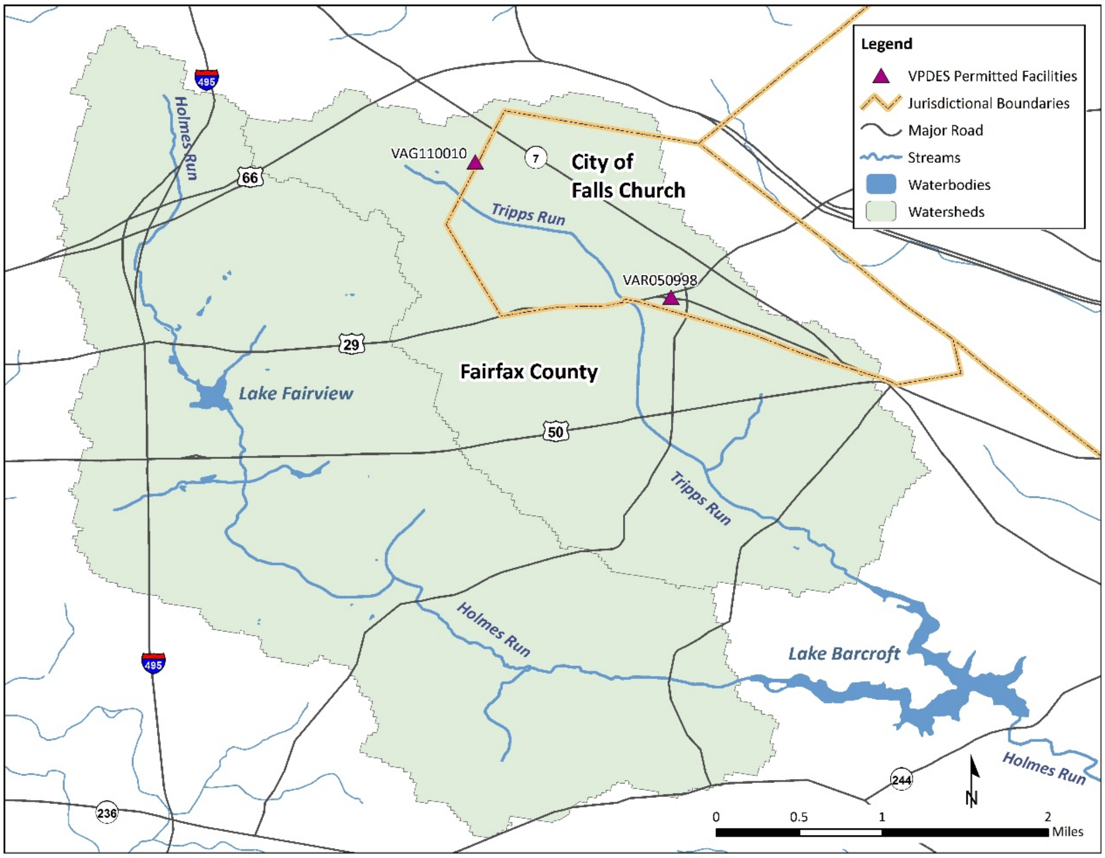

Figure 2-3: Location of General VPDES Permitted Facilities in the Holmes Run and Tripps Run Watersheds

2.2.2 Municipal Separate Storm Sewer Systems (MS4s)

As of July 1, 2013, Virginia DEQ assumed the responsibility for issuing MS4 permits under the Virginia Stormwater Management Program (VSMP). All MS4 permits in the Holmes Run and Tripps Run watersheds are listed in **Table 2-14**. Fairfax County has a Phase I permit; the Virginia Department of Transportation (VDOT), City of Falls Church and Fairfax County Schools have Phase II permits. All of these MS4s are in both watersheds, with the exception of the City of Falls Church, which is only in Tripps Run.

Table 2-14: MS4 Permits Within the Holmes Run and Tripps Run Watersheds	
Permit Number	**MS4 Permit Holder**
VA0088587	Fairfax County
VAR040115	Virginia Department of Transportation - Northern Urban Area
VAR040065	City of Falls Church*
VAR040104	Fairfax County Public Schools

*Located only in the Tripps Run watershed.

2.2.3 Construction Stormwater Permits

Under the VSMP, DEQ also issues general permits to control stormwater from construction sites. The list of active permits in the Holmes Run and Tripps Run watersheds at time of the public meeting (May 31, 2012) is shown in **Table 2-15**. Information on the permits was obtained from an on-line database on the VSMP website, which is currently available at the following:

http://www.deq.virginia.gov/Programs/Water/StormwaterManagement/VSMPPermits/ConstructionGeneralPermit.aspx

Supplementary information on construction permits issued to VDOT was obtained from the Virginia Department of Conservation and Recreation (DCR) Warrenton office, when DCR still had responsibility for the VSMP. Based on the permits at the time of the public meeting, there were 18 general construction permits in Holmes Run covering 57.4 acres, and 7 general construction permits in Tripps Run covering 11.4 acres.

Table 2-15: Construction Stormwater Permits Within the Holmes Run and Tripps Run Watersheds (May 31, 2012—Public Meeting)				
VAR Permit Number	**Nature of Project**	**Watershed**	**Disturbed Area (acres)**	**MS4 Area**
VAR10-10-100129	Sewer Capacity Improvements at Fenwick Road and Essex Avenue, Falls Church and Springfield	Holmes Run	0.2	Fairfax County
VAR10-10-100631	2900 Fairview	Holmes Run	7.9	Fairfax County
VAR10-10-100996	Graham Road	Holmes Run	0.3	Fairfax County
VAR10-10-102495	Stenwood Property	Holmes Run	7.4	Fairfax County
VAR10-10-104999	Sleepy Hollow - Residential	Holmes Run	0.71	Fairfax County
VAR10-11-100633	Minor Site Plan - Office	Holmes Run	14.6	Fairfax County
VAR10-11-100636	Residential - 3507 Slade Run Drive	Holmes Run	0.23	Fairfax County
VAR10-11-100687	Sleepy Hollow - Residential	Holmes Run	2.96	Fairfax County
VAR10-11-101371	Commercial	Holmes Run	0.9	Fairfax County
VAR10-11-101790	Falls Crest - Residential	Holmes Run	2.1	Fairfax County
VAR10-12-101117	King David Memorial Gardens Cemetery Stream Restoration	Holmes Run	0.7	Fairfax County
VAR10-12-101311	Falls Place - Residential	Holmes Run	2.3	Fairfax County
VAR10-12-103669	Project 2G40-028-011, Graham Road Improvement	Holmes Run	0.2	Fairfax County
VAR10-13-100354	National Memorial Park Remediation Plan - Cemetery	Holmes Run	5.9	Fairfax County
VAR10-10-100254	Beech Tree Elementary School	Holmes Run	3.6	Fairfax County Public Schools
VAR10-11-100616	Shrevewood Elementary Phase II - Stormwater Retrofit	Holmes Run	0.2	Fairfax County Public Schools
VAR10-11-100704	Lacey Center - Public School	Holmes Run	7	Fairfax County Public Schools
VAR10-10-9-1-11	VDOT Project	Holmes Run	0.2	VDOT
VAR10-11-101305	BB&T (Branch Bank & Trust) Falls Plaza	Tripps Run	4.6	City of Falls Church
VAR10-13-100234	Thomas Jefferson E.S. - Public Elementary School	Tripps Run	1.6	City of Falls Church
VAR10-10-101497	Jefferson Ave. Walkway	Tripps Run	0.3	Fairfax County
VAR10-11-100258	4YP201-PB033 Annandale Road Walkway - Pedestrian Improvement	Tripps Run	0.1	Fairfax County
VAR10-11-100341	Double Lee Park - Office Building - Commercial	Tripps Run	1.2	Fairfax County
VAR10-11-100530	7309 Venice Street	Tripps Run	0.1	Fairfax County
VAR10-10-100253	Westlawn Elementary School	Tripps Run	3.5	Fairfax County Public Schools
Total Holmes Run			**57.4**	
Total Tripps Run			**11.4**	

3 Analysis of Monitoring Data

This section reviews and analyzes the available monitoring data for Holmes Run and Tripps Run. **Section 3.1** discusses the biological monitoring performed by DEQ in these two watersheds. **Section 3.2** analyzes the water quality monitoring data collected by DEQ in Holmes Run and Tripps Run. **Section 3.3** discusses the results of Whole Effluent Toxicity (WET) testing performed in Holmes Run and Tripps Run. **Section 3.4** summarizes the habitat assessments DEQ conducted concurrently with biological monitoring. **Section 3.5** discusses the results of geomorphic surveys of Holmes Run and Tripps Run to determine relative stability of bed sediments. Finally, **Section 3.6** reviews the biological and water quality monitoring data collected by Fairfax County.

3.1 Analysis of Biological Monitoring Data

DEQ has performed benthic biological assessments at two sites in the Holmes Run and Tripps Run watersheds. Station 1AHOR005.48 on Holmes Run is located at the Sleepy Hollow Road bridge crossing and has been sampled seven times since 2004. Station 1ATRI001.50 on Tripps Run, is also located at the Sleepy Hollow Road bridge crossing and has been sampled seven times since 2004. **Figure 3-1** shows the location of the biological monitoring stations.

Based on the results of biological monitoring, the health of the benthic biological community is measured using the VSCI (Burton and Gerritsen, 2003). The VSCI is scored on a scale of 0 to 100, where 100 represents the best biological condition and 0 represents the worst. A score of 60 is the threshold for biological impairment. All 14 assessments in Holmes Run and Tripps Run had scores below 60.

The VSCI is a multi-metric index composed of eight biological metrics. Each of these eight metrics measures an aspect of the benthic macroinvertebrate community, such as diversity, intolerance to pollution, or a balance in the structure and function of taxa. **Table 3-1** lists the composite metrics in the VSCI and what they measure. The metrics are given scores on a scale from 0 to 100 based on a comparison with reference sites. Reference sites are sites relatively free of anthropogenic influence and are intended to represent natural conditions.

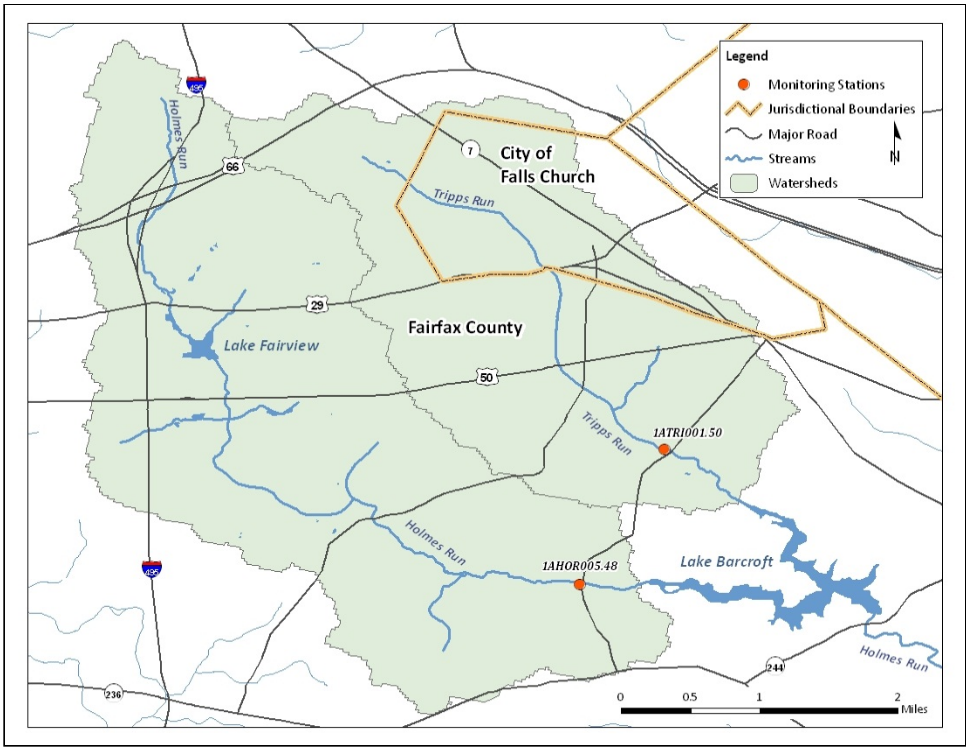

Figure 3-1: DEQ Biological and Ambient Water Quality Monitoring Stations in Holmes Run and Tripps Run

Tables 3-2 and **3-3**, respectively, show the individual metric scores for the biological assessments of Holmes Run and Tripps Run. As the metrics show, both Holmes Run and Tripps Run are marked by poor biological diversity. The total number of taxa is low compared to reference streams. Both streams are frequently dominated by no more than two taxa, as shown by the '% Top Two Dominant Taxa' metric. Holmes Run tends to be dominated by midges (*Chironomidae*) and the caddis fly *Hydropsychidae*, although riffle beetles (*Elmidae*) are also commonly found. Pollution tolerant *Chironomidae* are also one of the two dominant taxa in Tripps Run. Pollutant-tolerant aquatic earthworms (*Naididae* and *Tubficidae*), flatworms (*Tricladida*) as well as the caddis fly *Hydropsychidae* are also common in Tripps Run. Pollution-sensitive macroinvertebrates from the *Ephemeroptera* (mayfly), *Plecoptera* (stonefly), and *Trichoptera* (caddis fly) orders are generally rare or absent except for the relatively pollution insensitive net-spinning caddis fly *Hydropsychidae*, mentioned previously, and on two occasions in Tripps Run where the mayfly family *Baetidae* had a significant presence. Overall, the benthic community in both streams is relatively tolerant of pollution, as shown by the scores on the modified Hilsenhoff Biotic Index (HBI). **Tables 3-4** and **3-5** show the number of individuals identified by taxa in

Holmes Run and Tripps Run, respectively, during DEQ biological monitoring conducted from2004 to 2010. The tolerance values shown for each family are used by DEQ to calculate HBI scores. Potential tolerance values range from one to ten, with one indicating the intolerance to pollution and ten indicating tolerance to pollution.

One characteristic of the benthic communities in both Holmes Run and Tripps Run that is not captured by the biological metrics is how the number of individual macroinvertebrates found during biological monitoring is occasionally low (J. Classen, DEQ. Personal communication, 2012.).

Table 3-1: Description of VSCI Metrics

Metric	Description	Measures…	Response to Pollution
Total Taxa	Number of distinct taxa	overall variety of macroinvertebrate assemblage	Decrease
% Top Two Taxa	Percent of individuals from two most dominant taxa	diversity of benthic community	Increase
EPT Taxa	Number of Ephemeroptera, Plecoptera, and Trichoptera taxa	prevalence of pollutant-sensitive mayflies, stoneflies, and caddis flies	Decrease
%PT (excluding *Hydropsychidae*)	Percent individuals of *Plecoptera*, and *Trichoptera*, excluding *Hydropsychidae*	pollutant-sensitive stoneflies and caddis flies without counting pollution-insensitive net-spinning caddis flies	Decrease
% Ephemeroptera	Percent of individuals *Ephemeroptera*	pollutant-sensitive mayflies	Decrease
% Chironomidae	Percent of individuals *Chironomidae*	pollution-tolerant midge larvae	Increase
HBI (family level)	Family-level Hilsenhoff Biotic Index	average tolerance to pollution of benthic community, weighted by abundance	Increase
% Scrapers	Percent individuals from scraper functional feeding group	macroinvertebrates which graze on substrate- or periphyton-attached algae	Decrease

Table 3-2: VSCI Metric Scores for Holmes Run							
VSCI Metrics:	**Sample Date**						
	6/9/04	**11/29/04**	**11/8/07**	**4/7/08**	**10/1/08**	**4/15/10**	**11/9/10**
Total Taxa	31.82	45.45	31.82	22.73	31.82	31.82	27.27
EPT	9.09	9.09	9.09	0	18.18	18.18	18.18
%Ephemeroptera	0	0	0	0	4.8	7.42	0
%PT-H Score	0	0	0	0	0	0	14.78
%Scrapers	18.36	24.48	87.91	36.57	74.1	28.19	40.8
%Chironomidae	95.79	87.37	95.88	21.7	93.14	57.27	94.74
% Two Top Taxa	27.38	53.24	20.86	4.09	31.17	60.43	45.63
HBI	63.31	64.71	72.32	64.1	68.63	59.89	55.73
VSCI	30.7	35.5	39.7	18.7	40.2	32.9	37.1

Table 3-3: VSCI Metric Scores for Tripps Run							
VSCI Metrics:	**Sample Date**						
	6/9/04	**11/29/04**	**9/25/07**	**4/7/08**	**10/1/08**	**4/15/10**	**11/9/10**
Total Taxa	45.45	50	27.27	50	59.09	27.27	4.55
EPT	9.09	9.09	9.09	18.18	18.18	18.18	9.09
%Ephemeroptera	0	0	0	0	56.87	24.12	0
%PT-H Score	0	0	0	3.05	0	0	0
%Scrapers	57.73	27.69	1.85	8.43	5.33	0	0
%Chironomidae	69.15	67.86	67.62	42.39	89.91	63.48	100
% Two Top Taxa	61.49	89.46	37.16	26.7	64.96	26.39	0
HBI	35.51	40.79	46.78	50.35	63.55	50.26	58.82
VSCI	34.8	35.6	23.7	24.9	44.7	26.2	21.6

Table 3-4: Macroinvertebrates Observed at Holmes Run DEQ Sampling Site 1AHOR005.48				
Order	**Family ID**	**Functional Feeding Group**	**VA DEQ Tolerance Value[1]**	**Individuals**
Amphipoda	Gammaridae	Collector	6	7
Coleoptera	Elmidae	Scraper	4	142
Decapoda - Crayfish	Cambaridae	Shredder	5	6
Diptera	Ceratopogonidae	Predator	6	1
Diptera	Chironomidae (A)	Collector	6	155
Diptera	Chironomidae (B)	Collector	9	3
Diptera	Empididae	Predator	6	1
Diptera	Simuliidae	Filterer	6	26
Diptera	Tipulidae	Shredder	3	11
Ephemeroptera	Baetidae	Collector	4	8
Gastropoda	Planorbidae	Scraper	7	2
Isopoda	Asellidae	Collector	8	1
Lumbriculida	Lumbriculidae	Collector	8	5
Megaloptera	Corydalidae	Predator	5	4
Odonata - Zygoptera	Calopterygidae	Predator	5	4
Odonata - Zygoptera	Coenagrionidae	Predator	9	3
Trichoptera	Hydropsychidae	Filterer	6	218
Trichoptera	Philopotamidae	Collector	3	1
Tricladida	Tricladida (unknown)	Collector	8	2
Tubificida	Naididae	Collector	8	24

[1] Higher tolerance values indicate greater tolerance to pollution.

Table 3-5: Macroinvertebrates Observed at Tripps Run DEQ Sampling Site 1ATRI001.50				
Order	**Family ID**	**Functional Feeding Group**	**VA DEQ Tolerance Value[1]**	**Individuals**
Amphipoda	Gammaridae	Collector	6	6
Coleoptera	Elmidae	Scraper	4	6
Diptera	Ceratopogonidae	Predator	6	1
Diptera	Chironomidae (A)	Collector	6	186
Diptera	Chironomidae (B)	Collector	9	10
Diptera	Culicidae	Filterer	8	5
Diptera	Empididae	Predator	6	3
Diptera	Simuliidae	Filterer	6	23
Diptera	Tipulidae	Shredder	3	8
Ephemeroptera	Baetidae	Collector	4	55
Gastropoda	Physidae	Scraper	8	40
Gastropoda	Planorbidae	Scraper	7	2
Isopoda	Asellidae	Collector	8	1
Lumbriculida	Lumbriculidae	Collector	8	17
Odonata - Zygoptera	Calopterygidae	Predator	5	8
Odonata - Zygoptera	Coenagrionidae	Predator	9	28
Odonata - Zygoptera	Lestidae	Predator	9	13
Opisthopora	Lumbricidae	Collector	10	2
Pelecypoda	Sphaeriidae	Filterer	8	1
Plecoptera	Nemouridae	Shredder	2	1
Trichoptera	Hydropsychidae	Filterer	6	60
Tricladida	Tricladida (unknown)	Collector	8	54
Tubificida	Naididae	Collector	8	79
Tubificida	Tubificidae	Collector	10	6

[1] Higher tolerance values indicate greater tolerance to pollution.

3.2 The Analysis of Water Quality Monitoring Data

DEQ has conducted four water quality monitoring studies in Holmes Run and Tripps Run:

1. Since 2004, ambient water quality monitoring has been performed at the Holmes Run and Tripps Run biological monitoring locations, 1AHOR005.48 and 1ATRI001.50, respectively, shown in **Figure 3-1**. Twenty ambient samples have been collected at each station; 15 of the 20 samples at each station have been collected since 2010.
2. Continuous monitoring for temperature, DO, pH, salinity, and specific conductance was conducted in both Holmes Run and Tripps Run from 6/16/10 to 6/18/10 and again in Holmes Run from 8/17/11 to 8/31/11.

3. Samples targeting storm flows were collected in Holmes Run and Tripps Run at the biological monitoring station locations in February and March, 2012; four samples were collected at each station.
4. A special study was conducted at four locations on Tripps Run in April and May of 2012 to determine whether there was a geographically-specific source of high nitrate concentrations in Tripps Run. Two samples were collected at each location. Samples were also analyzed for a full suite of nutrients as well as *E. coli* bacteria, dissolved solids, and other constituents.

Table 3-6 summarizes the sampling performed for each monitoring study.

Table 3-6: Summary of DEQ Monitoring Studies in Holmes Run and Tripps Run

Monitoring Study	Holmes Run 1AHOR005.48	Tripps Run 1ATRI001.50
Ambient Monitoring	20 sampling dates 6/9/2004-11/17/2011	20 sampling dates 6/9/2004-11/17/2011
Continuous Monitoring	6/16/2010-6/18/2010 8/17/2011-8/31/2011	6/16/2010-6/18/2010
Storm Event Monitoring	4 sampling dates 2/9/2012-3/1/2012	4 sampling dates 2/9/2012-3/1/2012
Tripps Run Special Study		2 sampling dates 4/26/2012, 5/3/2012

Sections 3.2.2 through **3.2.6** discuss monitoring results from all four studies for individual constituents at stations 1AHOR005.48 and 1ATRI001.50. When Virginia's water quality standards contained in 9VAC25-260 et seq. (State Water Control Board, 2011) have numerical criteria for a constituent, those criteria will be discussed. For nutrients and other constituents without numerical criteria, monitoring results will be compared to the 90th percentile concentrations observed in the DEQ Probabilistic Monitoring (ProbMon) program dataset from 2001-2008 (Dail et al., 2006). Sample sites for the ProbMon program are chosen at random, so that the collection of sample sites constitutes a random sample of Virginia's streams. ProbMon Stations are typically sampled once in the spring and once in the fall, and are not usually sampled during or right after major weather events (e.g. rain or snow). A biological assessment and habitat assessment is performed at each sample site. Not only are conventional pollutants monitored, but metals and organic chemicals are monitored as well, both in the sediments and in the water column. Any observed

concentration in excess of the 90th percentile concentration of ProbMon samples is, therefore, high relative to concentrations found in the rest of the state.

The ProbMon program has also adopted condition thresholds for six potential biological stressors that do not have water quality criteria: (1) total nitrogen (TN), (2) total phosphorus (TP), (3) total dissolved solids (TDS), (4) the cumulative impact of dissolved metals (using the Cumulative Criterion Unit (CCU) Metals Index), (5) habitat degradation, and (6) sedimentation (using the $\log_{10}$ Relative Bed Stability Index (LRBS)). These thresholds are used in evaluating the data collected in the ProbMon program and are included in the Freshwater Probabilistic Monitoring chapter in Virginia's Integrated Water Quality Reports (DEQ, 2010 and 2012a). The thresholds are also shown in **Table 3-7**. For each of the six thresholds, ProbMon data was used to estimate the relative risk of a site receiving a failing VSCI score when the stressor has a suboptimal value at that site. **Table 3-7** also shows the relative risk for each stressor. The relative risk calculated by ProbMon is based on a state-wide data, without regard to ecoregion or the land use in the catchment upstream the monitoring sites. Relative risk will be discussed further in **Section 4** on Stressor Identification.

Table 3-7: ProbMon Thresholds for Stressor Indicators with Relative Risk for Suboptimal Scores

Parameter	Optimal	Suboptimal	Relative Risk
TN	< 1 (mg/l)	> 2 (mg/l)	3.4
TP	< 0.02 (mg/l)	> 0.05 (mg/l)	3.9
TDS	< 100 (mg/l)	> 350 (mg/l)	5.1
CCU Metals Index	< 1 (unitless)	> 2 (unitless)	4.3
Habitat	> 150 (of 200)	< 120 (of 200)	4.1
LRBS	> - 0.5 (unitless)	< -1.0 (unitless)	2.8

3.2.1 Flow

The U. S. Geological Survey (USGS) does not maintain a gage measuring flow in either Tripps Run or Holmes Run. There is a USGS gage on Cameron Run (01653000) downstream of the confluence of Holmes Run and Backlick Run. **Figure 3-2** shows the location of the gage in relation to the Holmes Run and Tripps Run watersheds. This gage is below Lake Barcroft. Lake Barcroft is managed to maintain a constant surface water elevation; there is no flood storage in the lake. Storm flows entering Lake Barcroft should be transmitted downstream and hydrologic conditions at the gage on Cameron Run should reflect conditions upstream of Lake Barcroft.

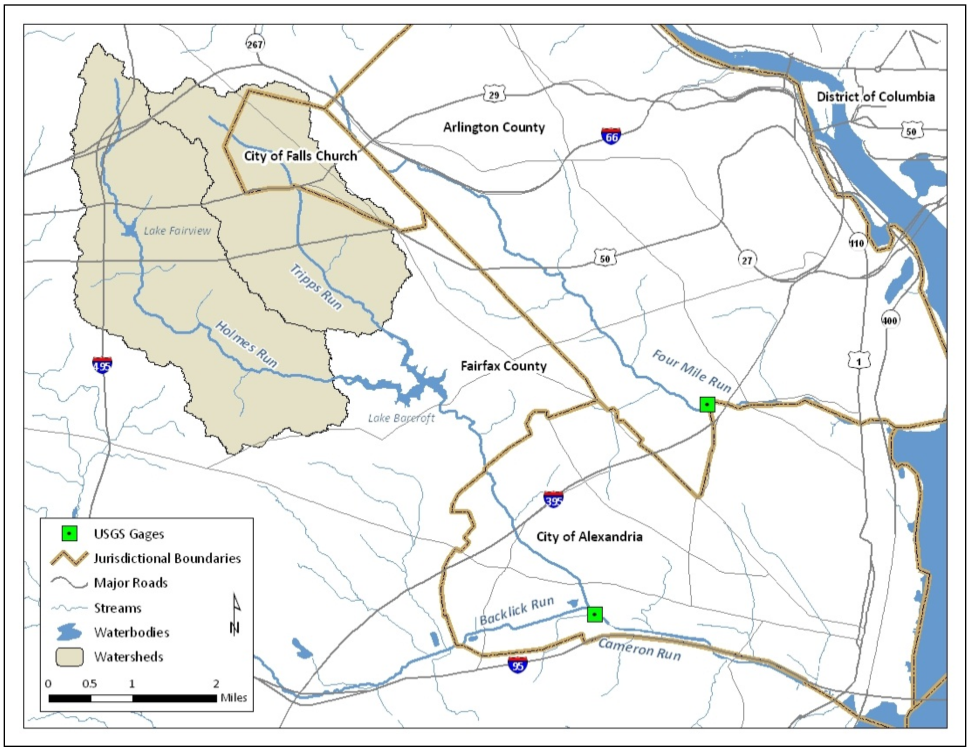

Figure 3-2: Location of USGS Gages in the Vicinity of Holmes Run and Tripps Run

Average daily flows from the Cameron Run gage were used to construct an index of hydrological conditions for the Holmes Run and Tripps Run watersheds. The index is the percentile of the daily average flow from the Cameron Run gage, 1986-2012. **Figure 3-3** shows the percentiles of average daily flows. Storm conditions generally occur at 90th or greater flow percentiles. The boundary between ambient and storm conditions is approximate, however, and small summer storms can have lower percentiles than ambient winter flows.

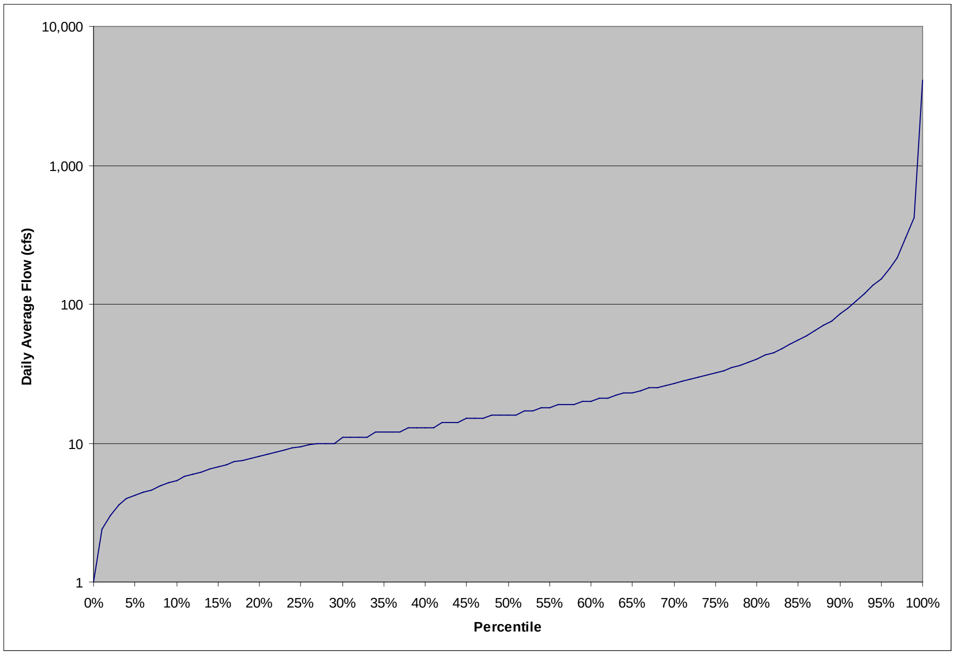

Figure 3-3: Flow Percentiles for Daily Average Flow in Cameron Run

There is also a USGS gage on Fourmile Run (01652500), which is located in the watershed adjacent to Tripps Run. **Figure 3-2** shows the location of this gage in relation to the Holmes Run and Tripps Run watersheds. The USGS also maintains a precipitation gage at the Fourmile Run site. Flow percentiles from the Cameron Run gage were checked against the flow percentiles of the Fourmile Run gage to confirm that the presence of Lake Barcroft had minimal impact on flow dynamics.

DEQ sampling dates from ambient monitoring, storm monitoring, and the Tripps Run special study were correlated with flow percentiles on those dates from the Cameron Run gage. **Figure 3-4** shows the flow percentile on each sampling date at each site. As **Figure 3-4** shows, several ambient monitoring samples were collected on dates with storm events, so storm flow monitoring is not confined to the storm flow samples explicitly collected.

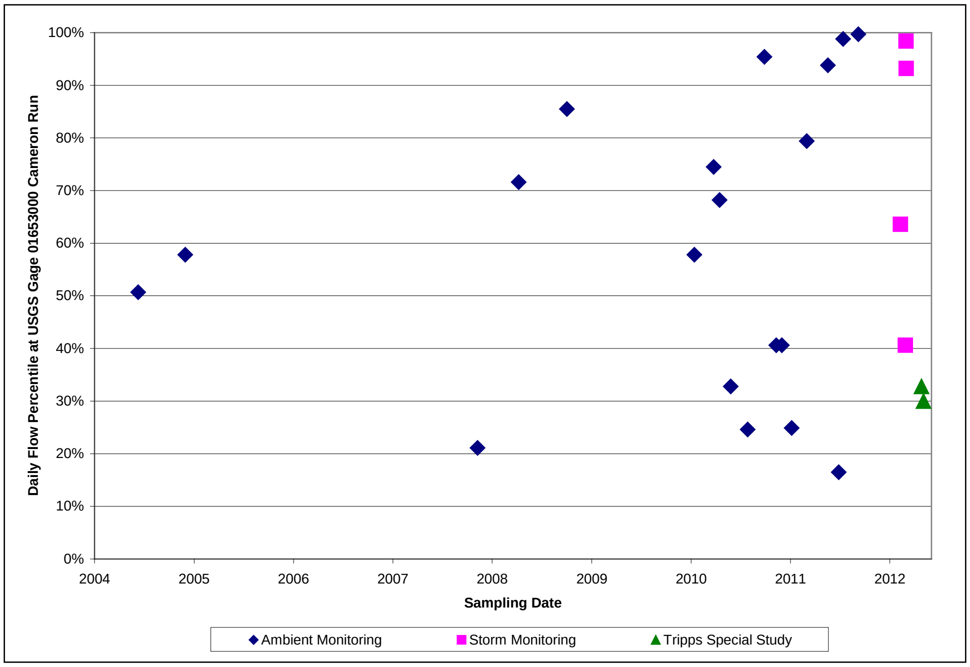

Figure 3-4: Cameron Run Daily Flow Percentiles on Sampling Dates in Holmes Run and Tripps Run

3.2.2 Temperature

Water temperature measurements are made in the field when water quality samples are collected. **Figure 3-5** shows the temperature measurements of the samples from Tripps Run and Holmes Run. Virginia water quality standards for Class III waters (both Holmes Run and Tripps Run are Class III waters) specify that water temperature should not be greater than 32° C (9VAC-25-260-50). No sample in either Holmes Run or Tripps Run exceeded this criterion.

Temperature was also measured during the continuous monitoring studies of Holmes Run and Tripps Run. **Figures 3-6** and **3-7** show temperature values for the June 2010 and August 2011 continuous monitoring of Holmes Run, respectively. **Figure 3-8** shows values for the June 2010 continuous monitoring of Tripps Run. There are no exceedances of the maximum temperature criterion. Virginia's water quality standards also specify that the maximum hourly temperature change should not exceed 2^{0}C (9VAC25-260-70). No hourly temperature change recorded during continuous monitoring of Holmes Run or Tripps Run exceeds the maximum criterion. Virginia's water quality standards also specify that any rise above natural temperature shall not exceed 3⁰C (9VAC25-260-60). **Figures 3-6, 3-7**, and **3-8** do not show any rise in temperature greater than 3⁰C.

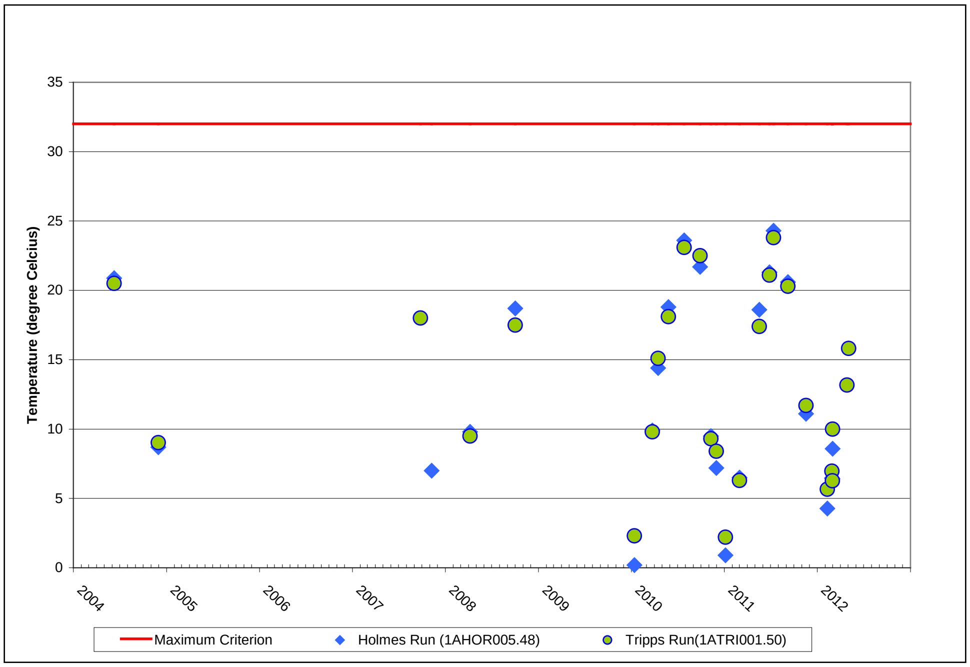

Figure 3-5: Observed Temperature in Holmes Run and Tripps Run

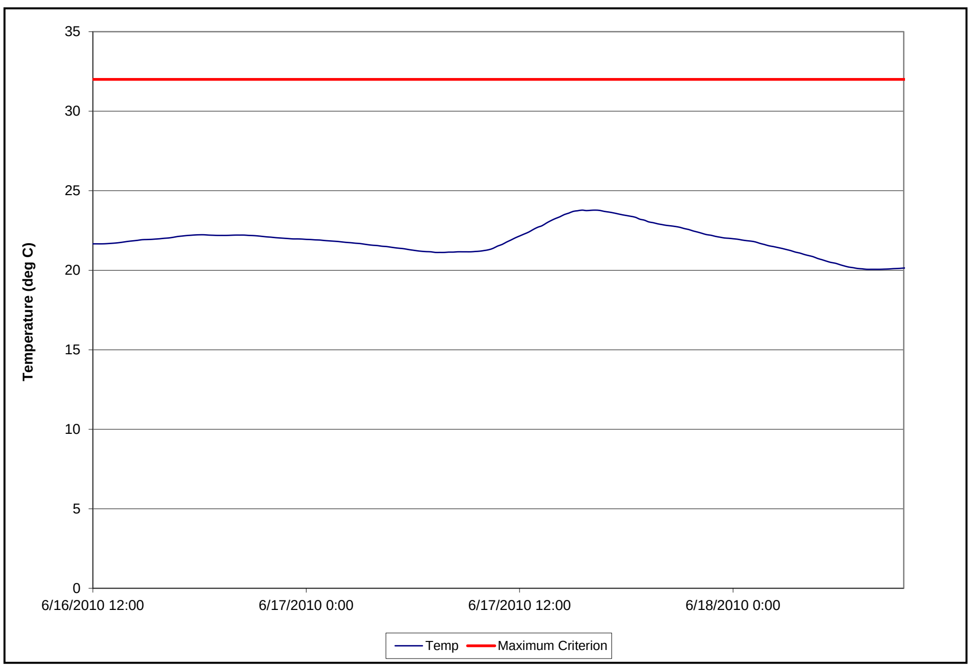

Figure 3-6: Observed Temperature, Continuous Monitoring, June 2010, Holmes Run

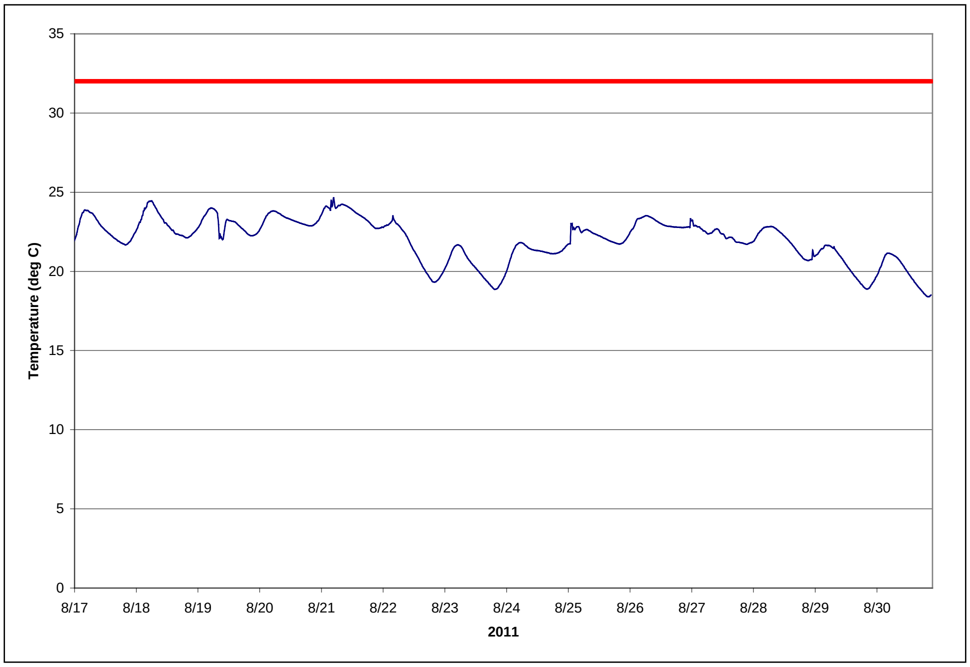

Figure 3-7: Observed Temperature, Continuous Monitoring, August 2011, Holmes Run

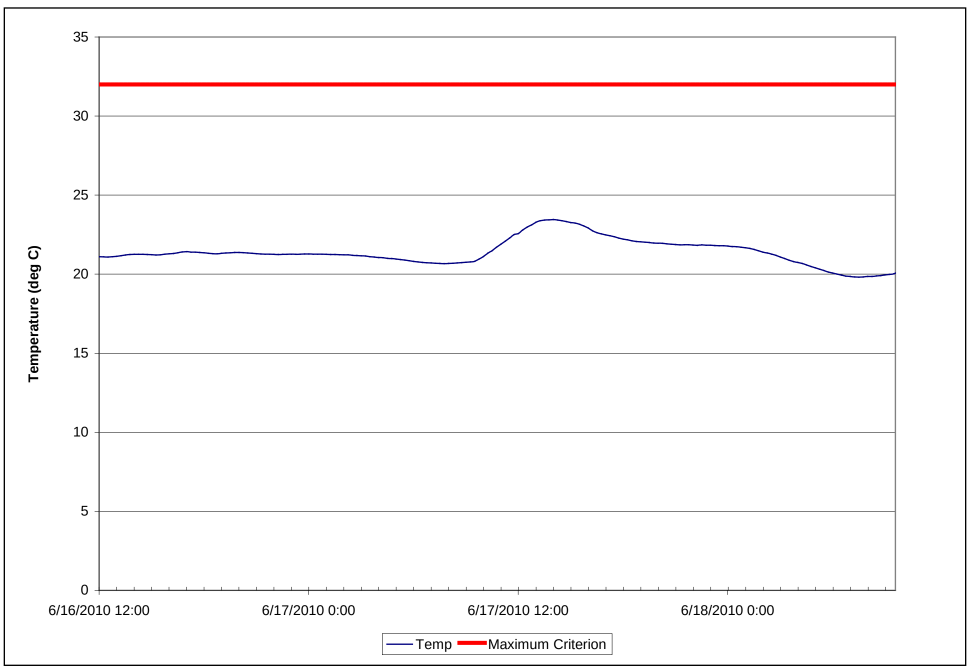

Figure 3-8: Observed Temperature, Continuous Monitoring, June 2010, Tripps Run

3.2.3 pH

pH measurements are made in the field when water quality samples are collected. **Figure 3-9** shows the pH measurements of the samples from Tripps Run and Holmes Run. Virginia water quality standards specify that for Class III waters, pH should not be less than 6.0 or greater than 9.0 (9VAC-25-260-50). All samples have pH values between the minimum and maximum criteria.

pH was also measured during the continuous monitoring studies of Holmes Run and Tripps Run. **Figures 3-10** and **3-11** show pH values for the June 2010 and August 2011 continuous monitoring of Holmes Run, respectively. **Figure 3-12** shows values for the June 2010 continuous monitoring of Tripps Run. All observed pH values are between the minimum and maximum criteria.

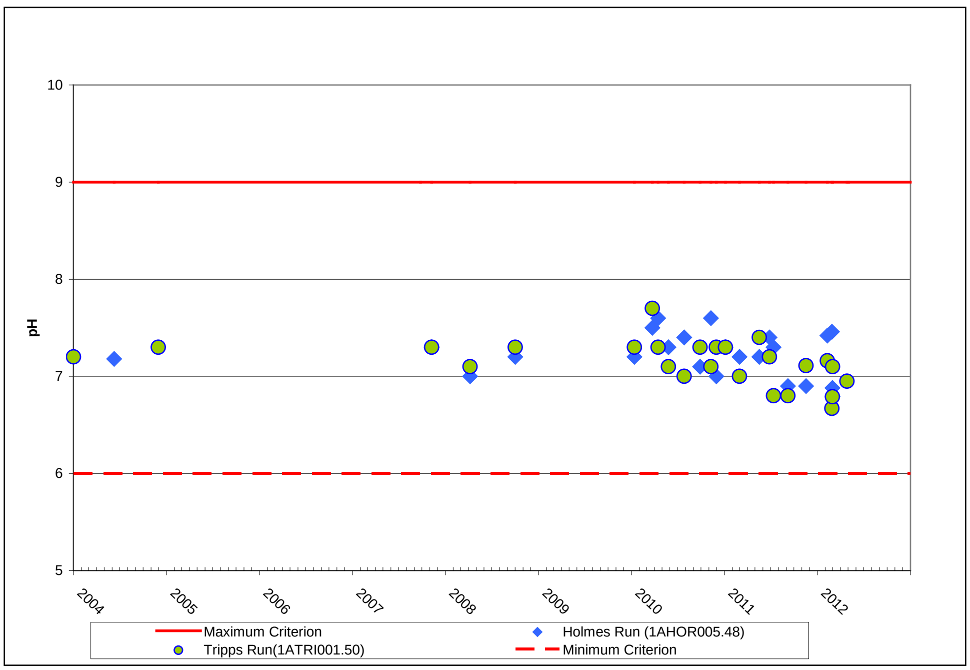

Figure 3-9: Observed pH, Holmes Run and Tripps Run

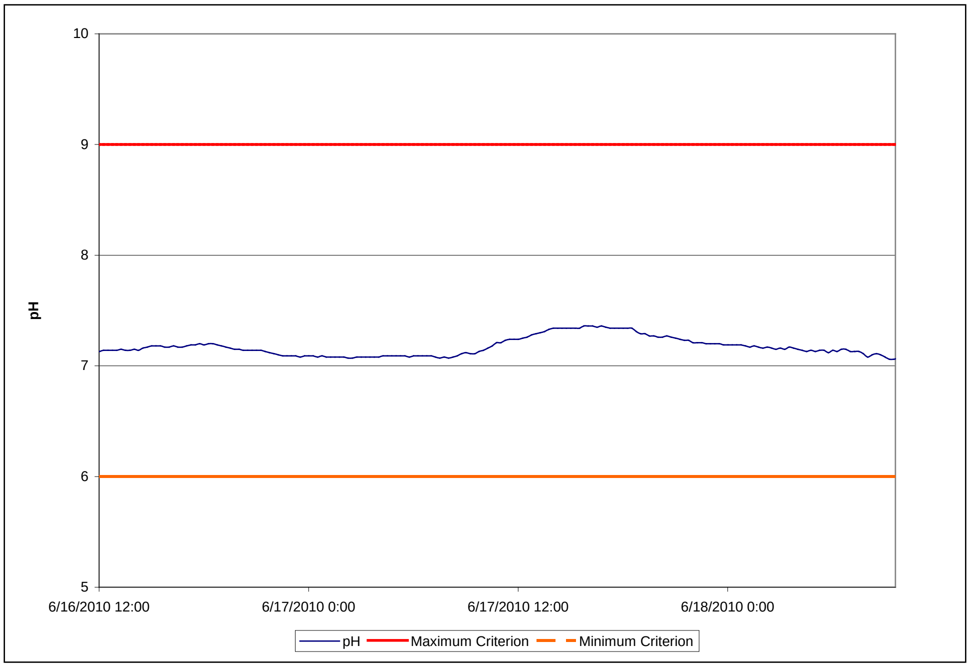

Figure 3-10: Observed pH , Continuous Monitoring, June 2010, Holmes Run

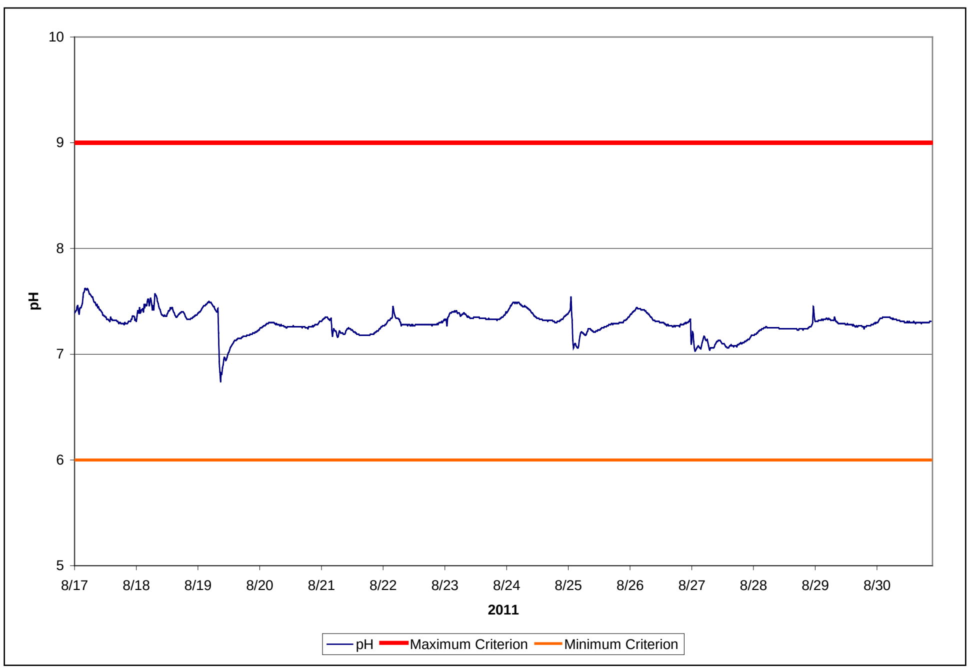

Figure 3-11: Observed pH, Continuous Monitoring, August 2011, Holmes Run

Figure 3-12: Observed pH, Continuous Monitoring, June 2010, Tripps Run

3.2.4 Dissolved Oxygen

Dissolved oxygen (DO) measurements are also made in the field when water quality samples are collected. **Figure 3-13** shows DO concentrations observed in samples from Holmes Run and Tripps Run. Virginia water quality standards specify that for Class III waters the minimum instantaneous DO concentration should not be less than 4.0 mg/l (9VAC-25-260-50). None of the observed concentrations in Holmes Run or Tripps Run are less than the minimum concentration.

DO was also measured during the continuous monitoring studies of Holmes Run and Tripps Run. **Figures 3-14** and **3-15** show DO concentrations and percent DO saturation for the June 2010 and August 2011 continuous monitoring of Holmes Run, respectively. **Figure 3-16** shows DO concentrations and percent DO saturation for the June 2010 continuous monitoring of Tripps Run. No observed concentration is below the 4.0 minimum DO criterion. Virginia's standards also require Class III waters to have a daily average DO concentration no less than 5.0 mg/l (9VAC-25-260-50). Since the minimum DO concentration does not drop below 6.0 mg/l, both the Holmes Run and Tripps Run DO observations in the continuous monitoring data met the daily average DO criterion. Percent

DO saturation ranged between 70% and 98% in Holmes Run and 73% and 96% in Tripps Run.

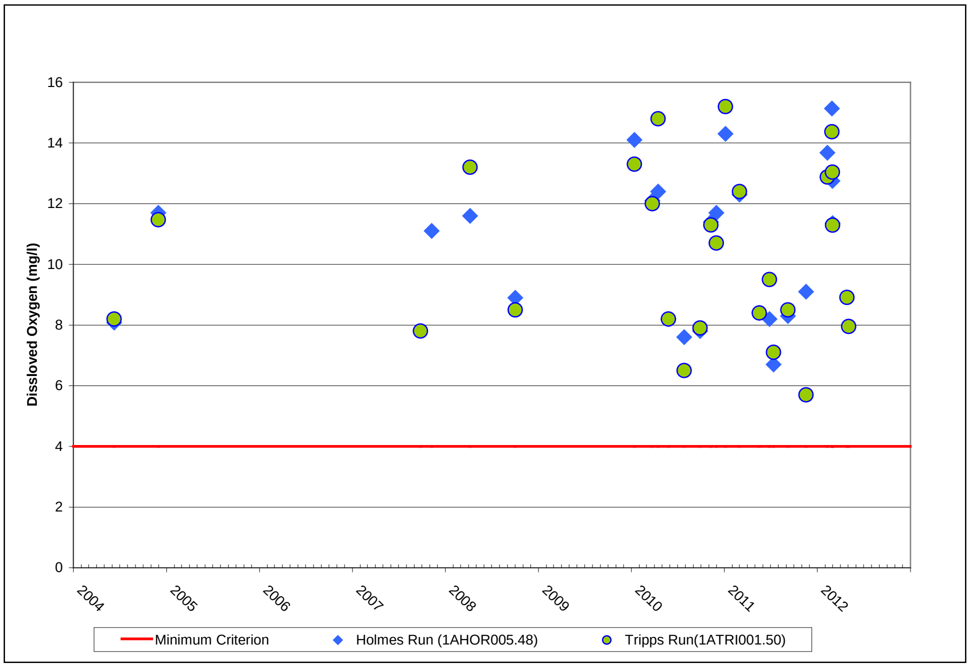

Figure 3-13: Observed Dissolved Oxygen (mg/l) in Holmes Run and Tripps Run

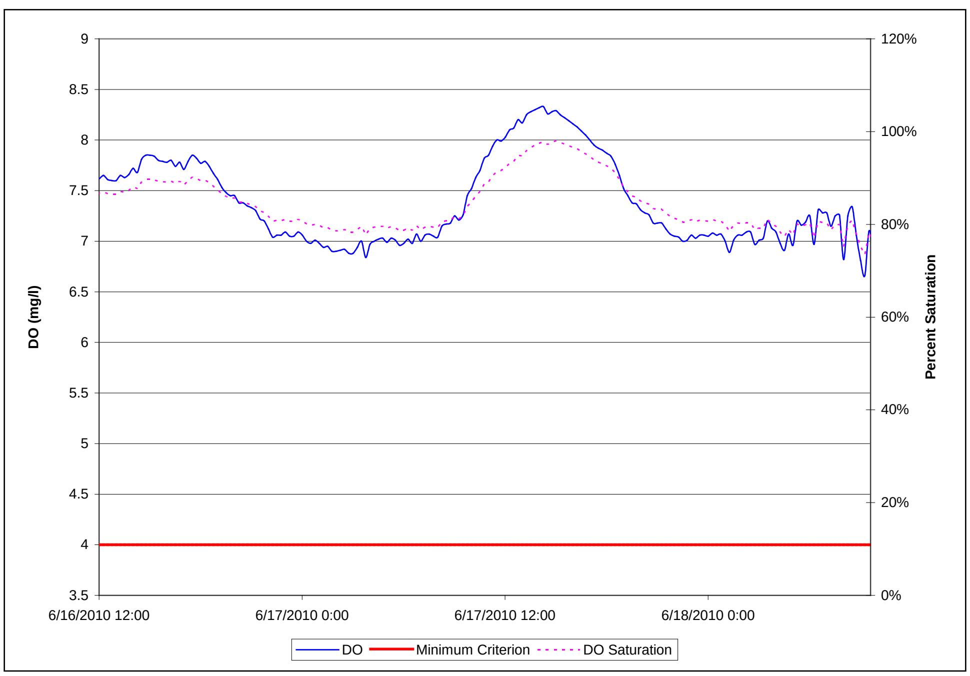

Figure 3-14: Observed Dissolved Oxygen (mg/l) and Percent Dissolved Oxygen Saturation, Continuous Monitoring, June 2010, Holmes Run

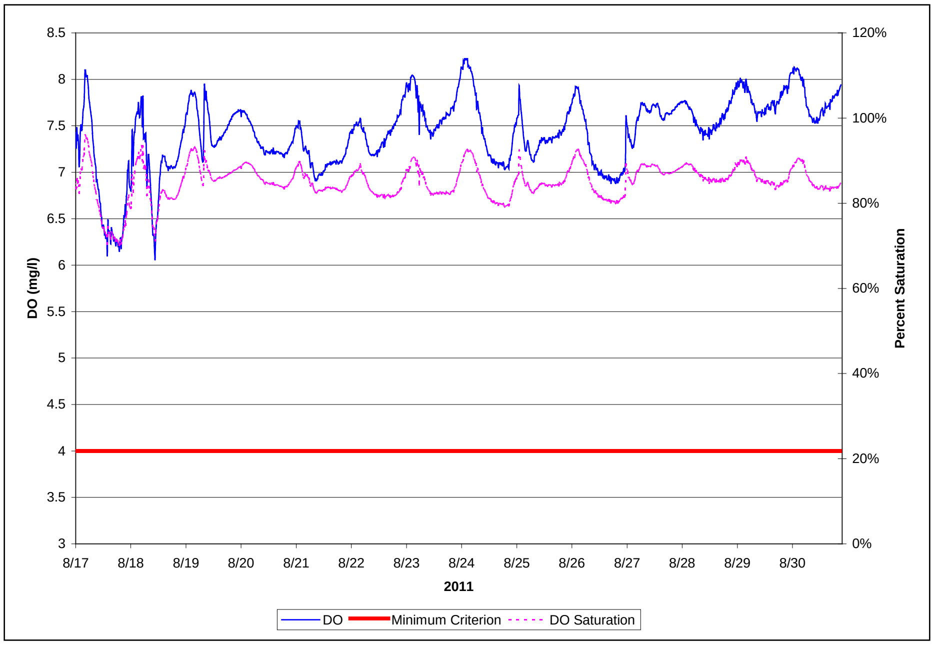

Figure 3-15: Observed Dissolved Oxygen (mg/l) and Percent Dissolved Oxygen Saturation, Continuous Monitoring, August 2011, Holmes Run

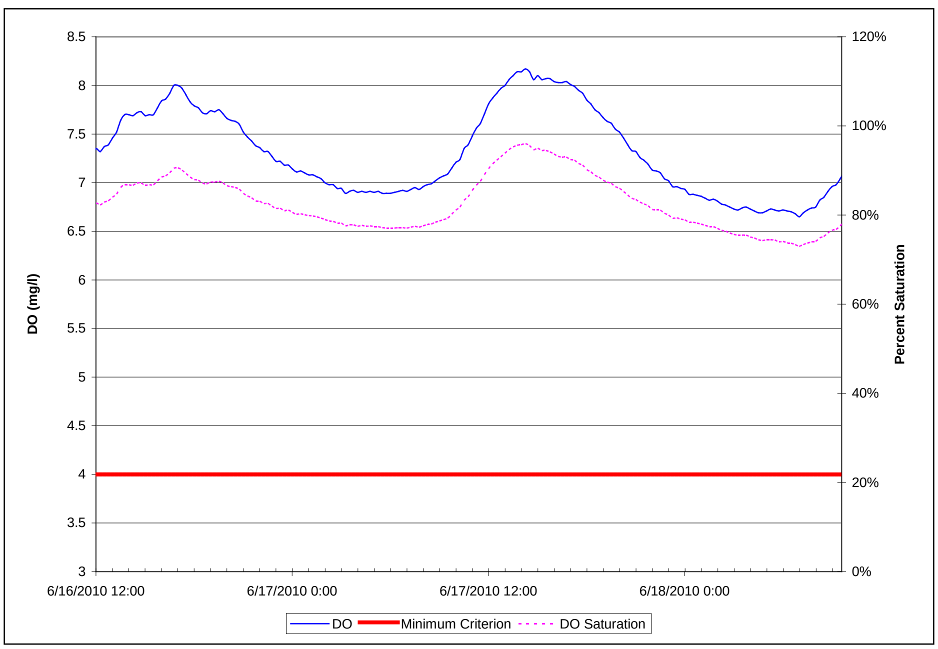

Figure 3-16: Observed Dissolved Oxygen (mg/l) and Percent Dissolved Oxygen Saturation, Continuous Monitoring, June 2010, Tripps Run

3.2.5 Specific Conductance

Specific conductance (SC) is measured in the field concurrently with water quality sampling. It was also measured during the continuous monitoring studies in Holmes Run and Tripps Run. There are no standards in Virginia for specific conductance. The 90th percentile concentration of state-wide ProbMon samples is 348 µmho/cm. **Figure 3-17** shows the specific conductance observed in samples from Holmes Run and Tripps Run. **Figures 3-18** and **3-19** show specific conductance values for the June 2010 and August 2011 continuous monitoring of Holmes Run, respectively. **Figure 3-20** shows values for the June 2010 continuous monitoring of Tripps Run. As judged by the 90th percentile ProbMon concentration, specific conductance tends to be high in both Holmes Run and Tripps Run. About half the concentrations in Holmes Run and a quarter of the concentrations in Tripps Run are above the 90th percentile ProbMon concentration.

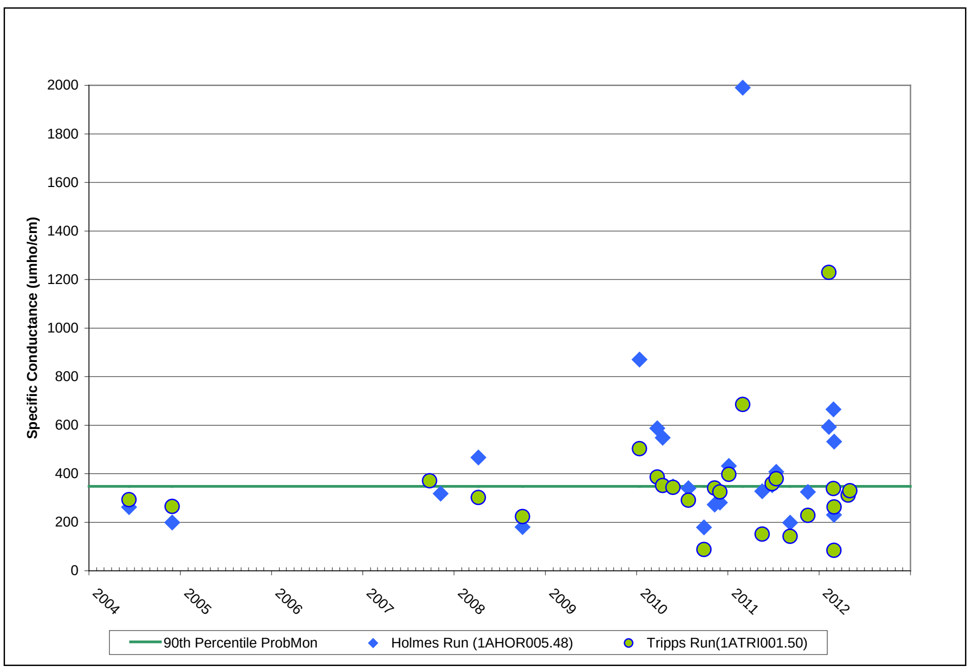

Figure 3-17: Observed Specific Conductance (µmhos/cm) in Holmes Run and Tripps Run

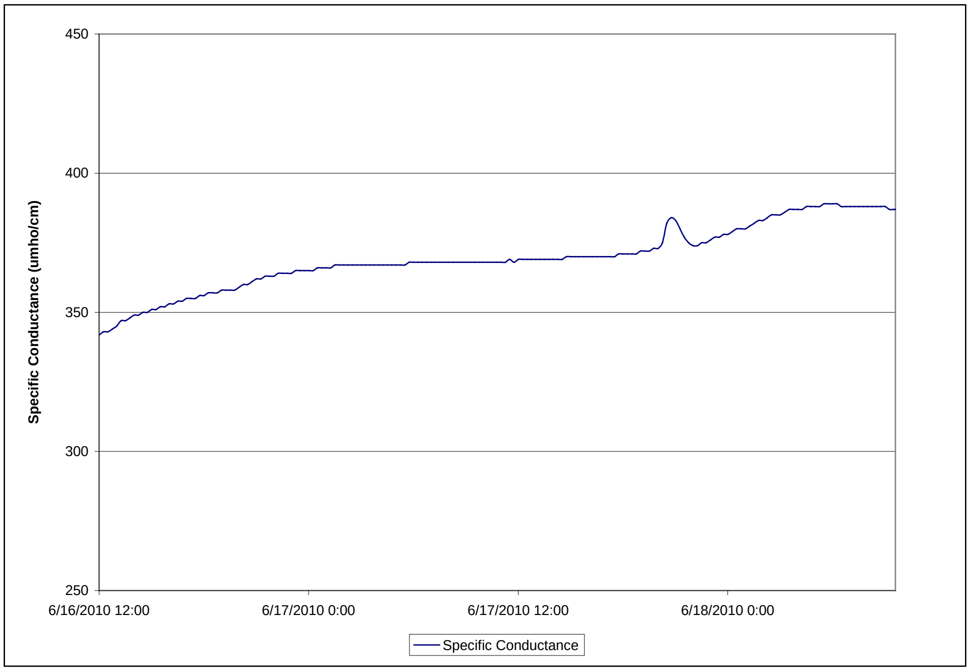

Figure 3-18: Observed Specific Conductance (µmhos/cm), Continuous Monitoring, June 2010, Holmes Run

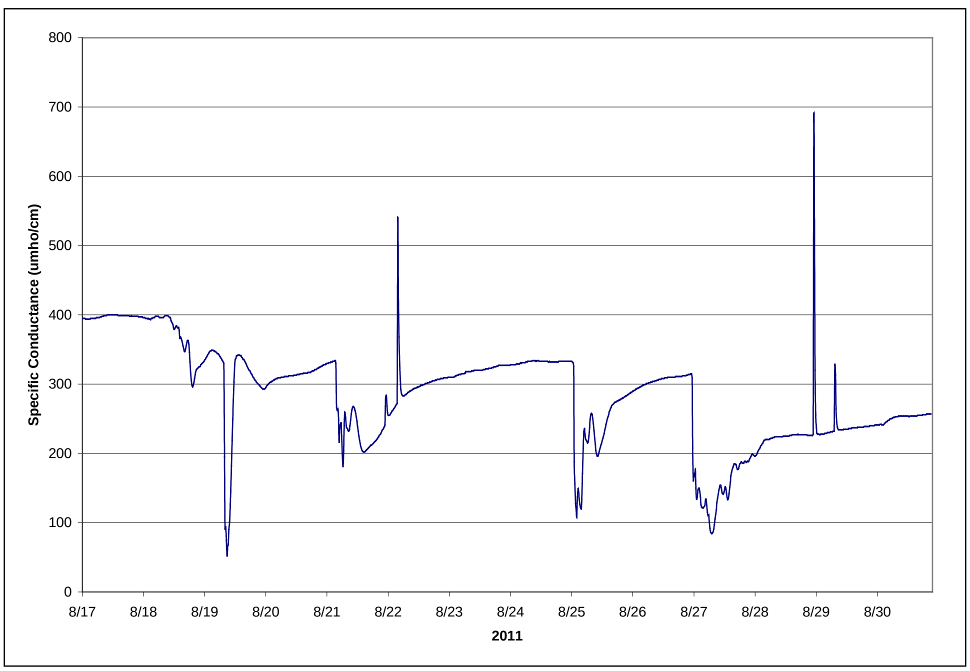

Figure 3-19: Observe Specific Conductance (µmhos/cm), Continuous Monitoring, August 2011, Holmes Run

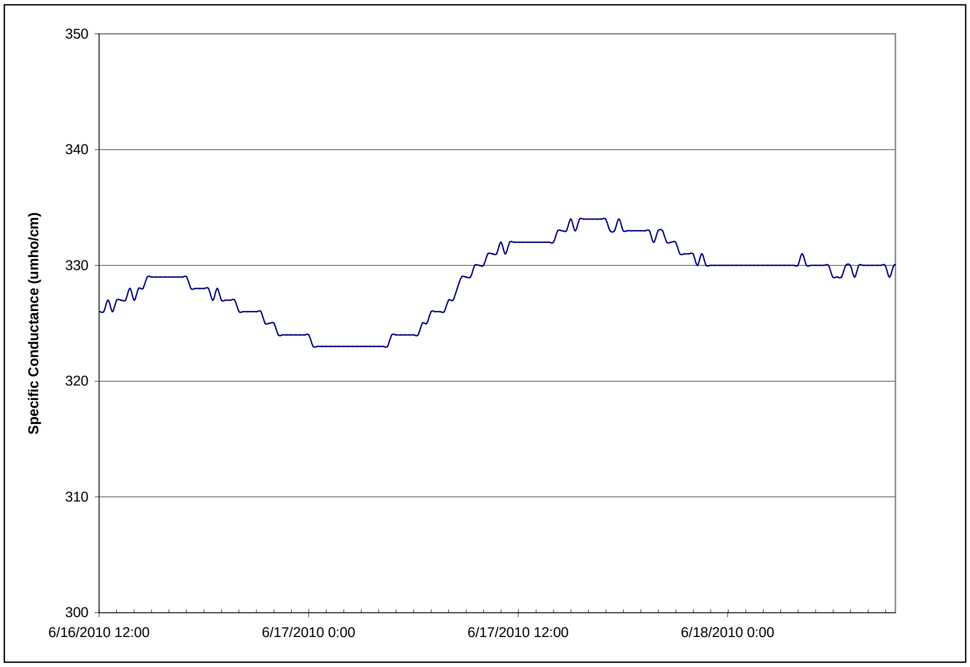

Figure 3-20: Observed Specific Conductance (µmhos/cm), Continuous Monitoring, June 2010, Tripps Run

3.2.6 Total Dissolved Solids

Figure 3-21 shows the concentrations of total dissolved solids (TDS) observed in water quality samples from Holmes Run and Tripps Run. Virginia's water quality standards include a criterion of a maximum concentration of 500 mg/l for drinking water intakes, which is not relevant for Holmes Run or Tripps Run. Less than 12% of the concentrations observed in either Holmes Run or Tripps Run are above the ProbMon condition threshold of 350 mg/l for suboptimal conditions. More than half of the observed concentrations in Holmes Run and Tripps Run, however, are above the 90th percentile ProbMon concentration of 215 mg/l.

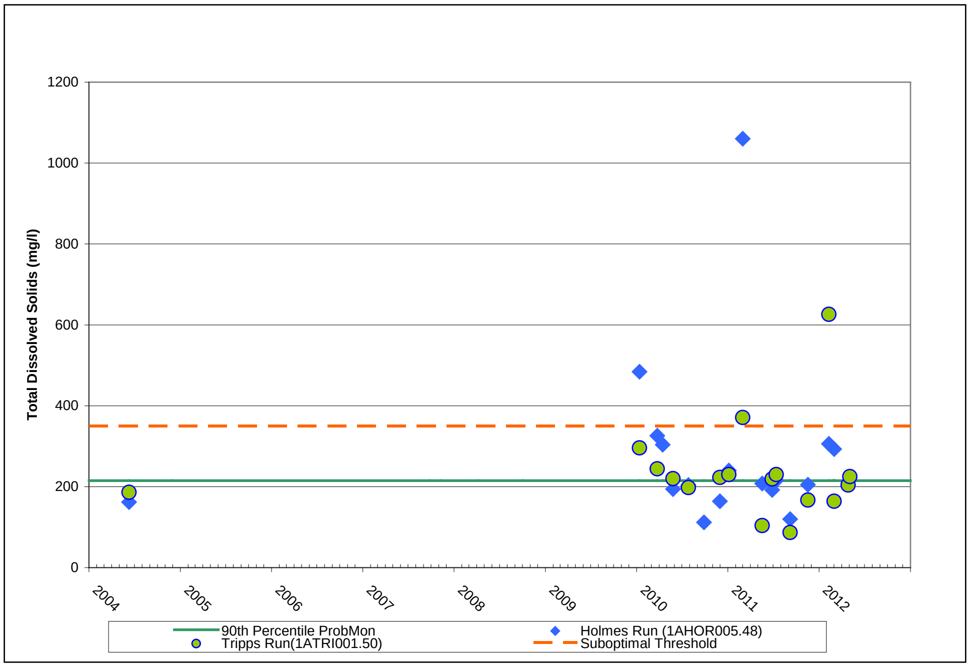

Figure 3-21: Observed Total Dissolved Solids (mg/l) in Holmes Run and Tripps Run

3.2.7 Total Chloride

Virginia's water quality standards include an acute maximum chloride (Cl) concentration criterion of 860 mg/l and a chronic maximum concentration criterion of 230 mg/l to protect aquatic life. The acute criterion is for a one-hour average not to be exceeded more than once every three years; the chronic criterion applies to a four-day average, which is also not to be exceeded more than once every three years (on average) (9VAC25-260-140). No concentrations exceed the acute criterion threshold. The 4-day average chronic criterion cannot be compared to instantaneous concentration data, although two instantaneous concentrations are above the threshold. The 90th percentile concentration of ProbMon data for chloride is only 17 mg/l. All observations from Holmes Run and all but one observation from Tripps Run exceed this value. **Figure 3-22** compares the total chloride concentrations observed in water quality samples from Holmes Run and Tripps Run to the 90th percentile ProbMon concentration. The acute criterion is not shown for reasons of scale.

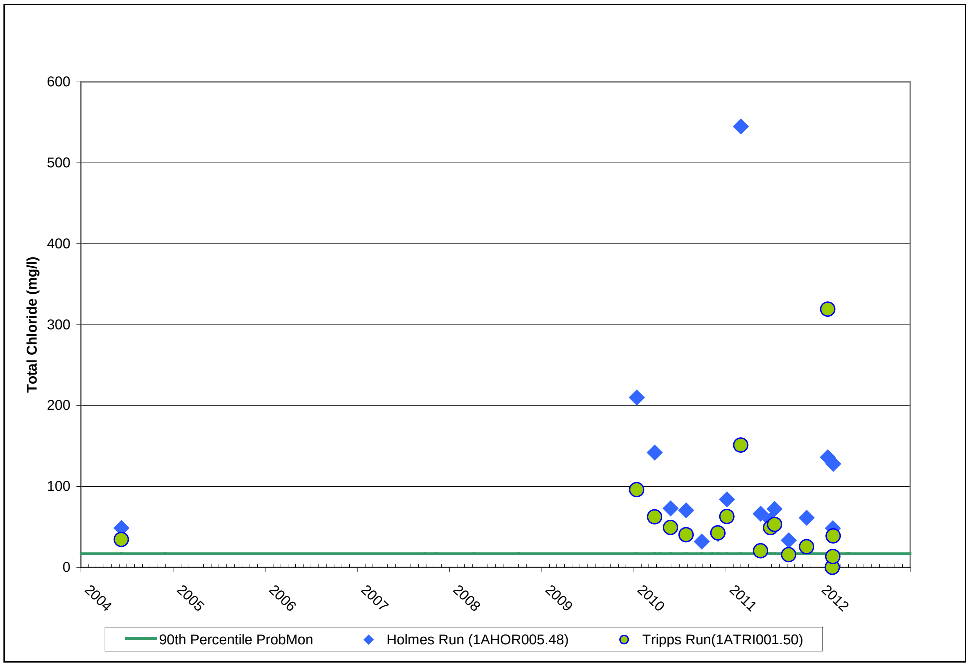

Figure 3-22: Observed Total Chloride (mg/l) in Holmes Run and Tripps Run

3.2.8 Turbidity

Figure 3-23 shows turbidity as measured in the laboratory from water quality samples in Holmes Run and Tripps Run. Virginia does not have water quality standards for turbidity. The 90th percentile turbidity measurement from the ProbMon data is 14.5 NTU. About two-thirds of the data from Holmes Run and three-quarters of the data in Tripps Run are below the 90th percentile of the ProbMon data. All but one of the observed values above 14.5 NTU occurred under storm flow conditions. Turbidity was measured during the continuous monitoring of Holmes Run in August 2011. **Figure 3-24** shows the results. The spikes in the turbidity correspond to storm events, as indicated by changes in measured depth at the monitoring station shown in **Figure 3-25**.

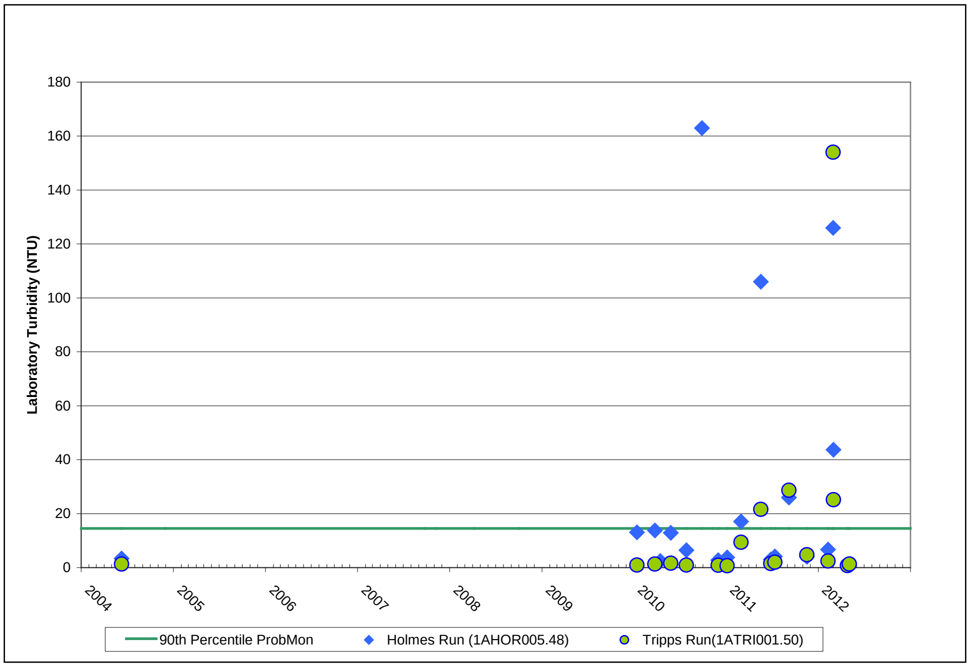

Figure 3-23: Observed Turbidity (NTU) in Holmes Run and Tripps Run

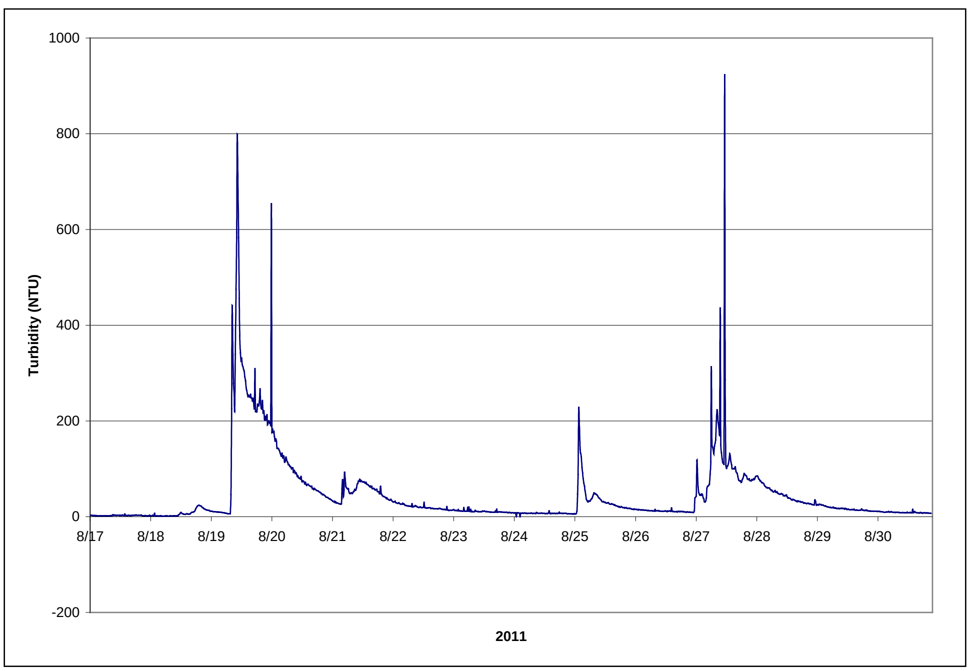

Figure 3-24: Observed Turbidity (NTU), Continuous Monitoring, August 2011, Holmes Run

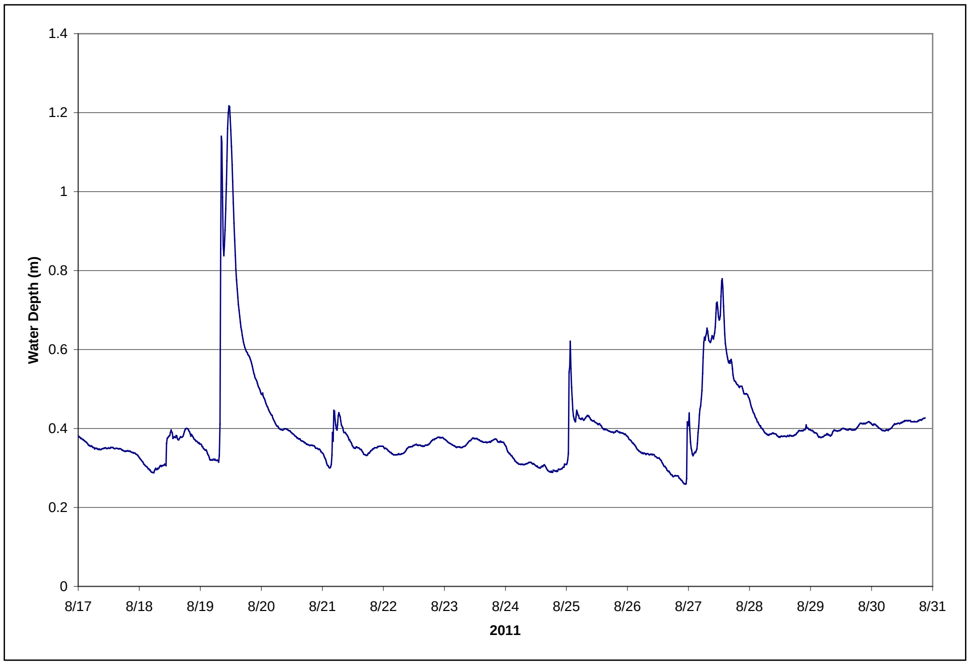

Figure 3-25: Observed Water Depth (m), Continuous Monitoring, August 2011, Holmes Run

3.2.9 Total Suspended Solids

Figure 3-26 shows the total suspended solids (TSS) concentrations observed in water quality samples in Holmes Run and Tripps Run. There are no water quality criteria for TSS in Virginia. High concentrations generally occur during storm events. The 90th percentile TSS concentration in the ProbMon data is 14 mg/l. TSS concentrations in Holmes Run and Tripps Run are generally below the 90th percentile ProbMon concentration, except during storm events.

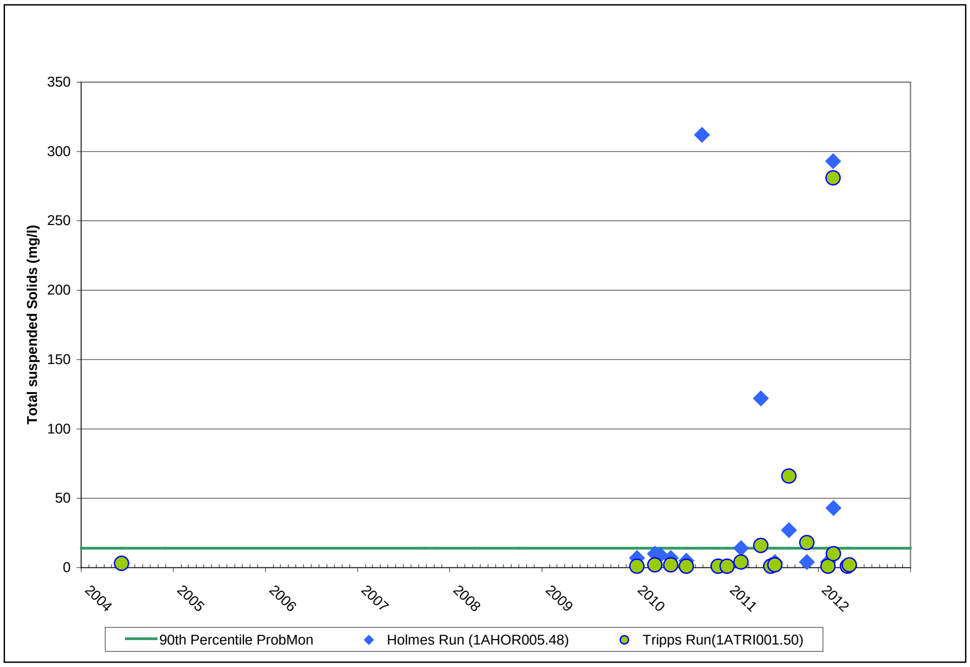

Figure 3-26: Observed Total Suspended Solids (mg/l), Holmes Run and Tripps Run

3.2.10 Total Orthophosphate

Figure 3-27 shows the total orthophosphate (PO_4) concentrations (in phosphorus) observed in water quality samples in Holmes Run and Tripps Run. Virginia has no water quality criteria for orthophosphate. The 90th percentile orthophosphate concentration in the ProbMon data is 0.05 mg/l. Less than 5% of the concentrations observed in Holmes Run and about a 10% of the concentrations observed in Tripps Run are greater than the 90th percentile of the ProbMon data.

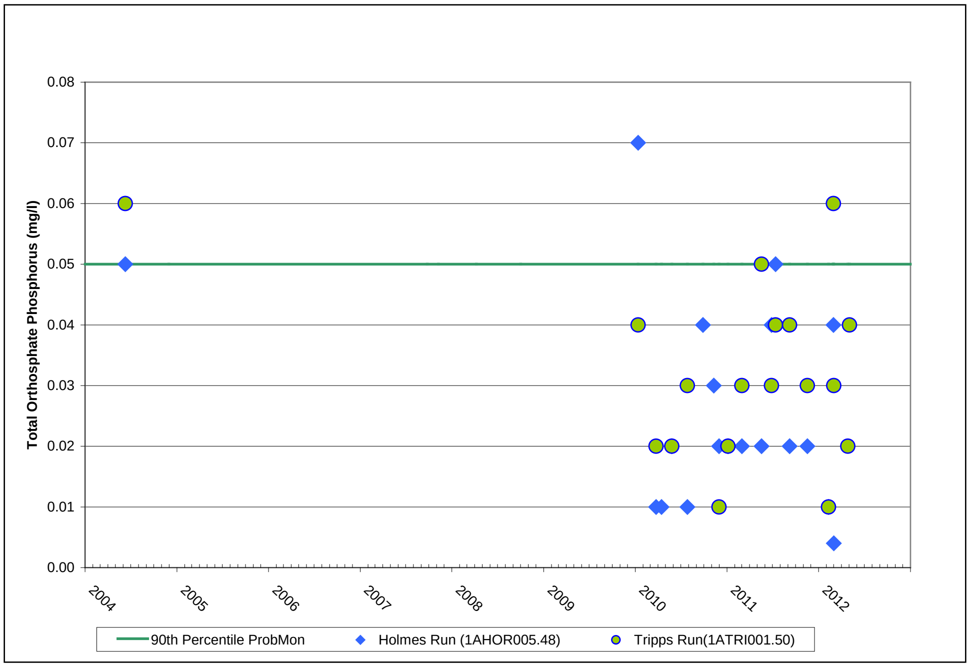

Figure 3-27: Observed Total Orthophosphate (mg/l P), Holmes Run and Tripps Run

3.2.11 Total Phosphorus

Figure 3-28 shows the total phosphorus (TP) concentrations observed in water quality samples in Holmes Run and Tripps Run. There are no water quality criteria for TP in Virginia for free-flowing streams. High concentrations of TP generally occur during storm events. The 90th percentile TP concentration in the ProbMon data is 0.07 mg/l. TP concentrations in Holmes Run and Tripps Run are generally below the 90th percentile ProbMon concentration, except during storm events. Forty-two percent of the TP observations in Holmes Run and 44% of the observations in Tripps Run are above the 0.05 mg/l ProbMon condition threshold for suboptimal conditions.

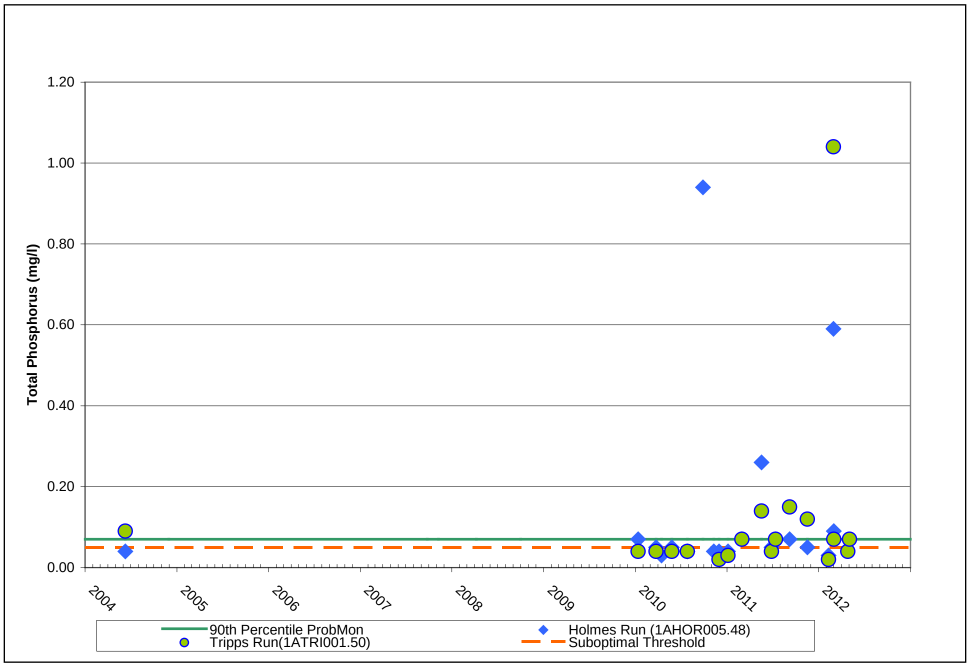

Figure 3-28: Observed Total Phosphorus (mg/l), Holmes Run and Tripps Run

3.2.12 Ammonia

Figure 3-29 shows the ammonia (NH_4) concentrations (in nitrogen) observed in water quality samples in Holmes Run and Tripps Run. Virginia has acute and chronic criteria for ammonia to protect aquatic life. The acute criteria are a function of pH, while the chronic criteria are a function of pH and temperature (9VAC25-260-140). There are no exceedances of the acute criteria in either Holmes Run or Tripps Run, and the observed concentrations are all below the range of the chronic criteria. The 90th percentile ammonia concentration in the ProbMon data is 0.06 mg/l. About a third of the concentrations observed in Holmes Run and about a tenth of the concentrations observed in Tripps Run are greater than the 90th percentile of the ProbMon data.

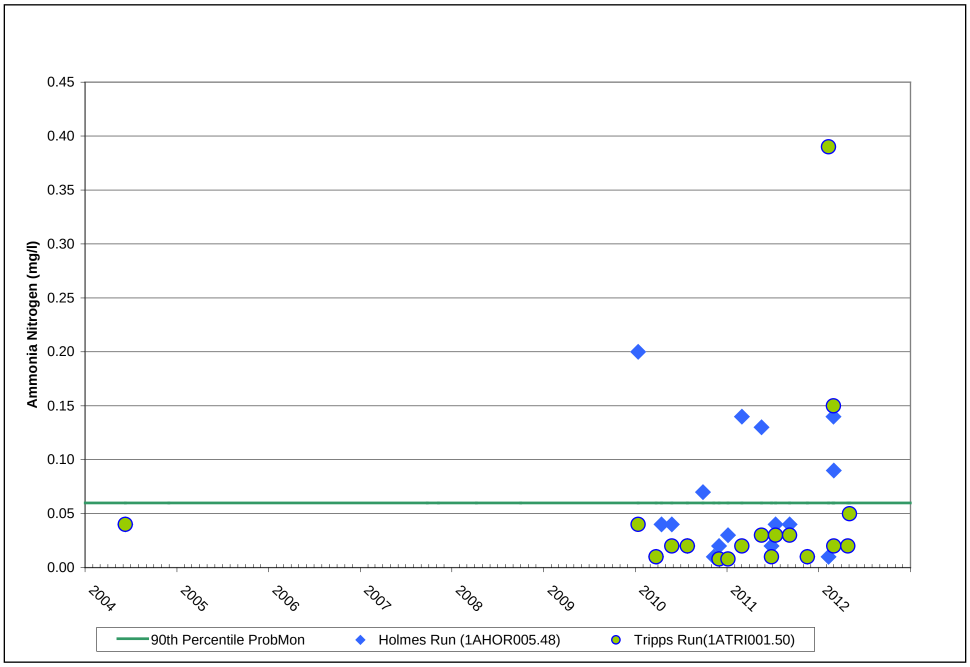

Figure 3-29: Observed Ammonia Concentrations (mg/l N), Holmes Run and Tripps Run

3.2.13 Nitrate

Figure 3-30 shows the nitrate (NO_3) concentrations (in nitrogen) observed in water quality samples in Holmes Run and Tripps Run. Virginia has no water quality criteria for nitrate to protect aquatic life. The 90th percentile nitrate concentration in the ProbMon data is 0.98 mg/l. While all but one of the observed concentrations in Holmes Run are less than the 90th percentile of the ProbMon data, in contrast, about three-quarters of the concentrations observed in Tripps Run are greater than the 90th percentile of the ProbMon data.

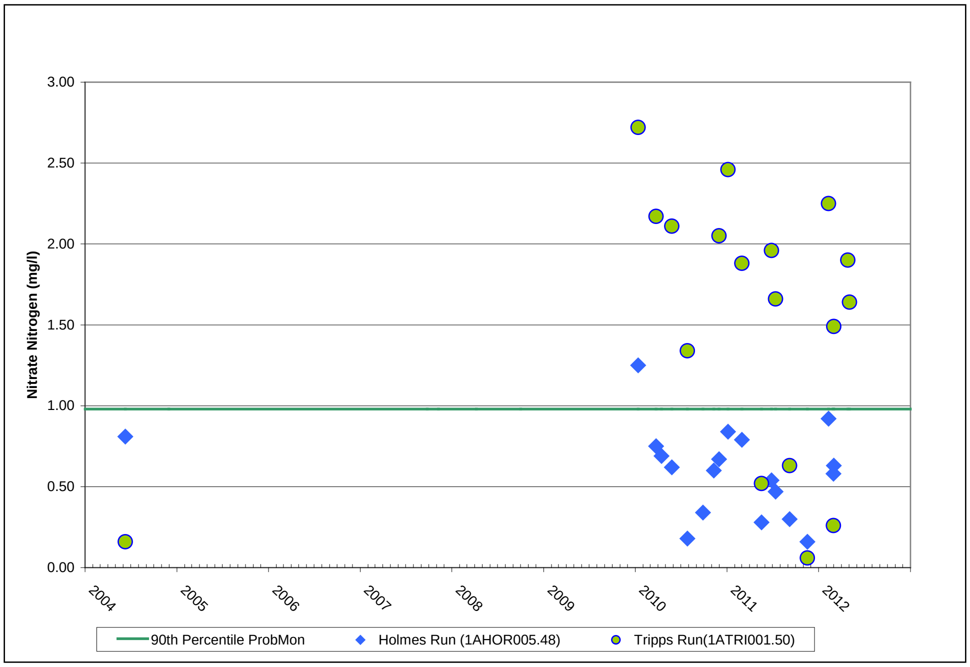

Figure 3-30: Observed Nitrate Concentrations (mg/l N), Holmes Run and Tripps Run

3.2.14 Total Kjeldahl Nitrogen

Figure 3-31 shows the total Kjeldahl nitrogen (TKN) concentrations observed in water quality samples in Holmes Run and Tripps Run. Virginia has no water quality criteria for TKN. The 90th percentile nitrate concentration in the ProbMon data is 0.7 mg/l. About a third of the concentrations observed in Holmes Run and about a quarter of the concentrations observed in Tripps Run are greater than the 90th percentile of the ProbMon data.

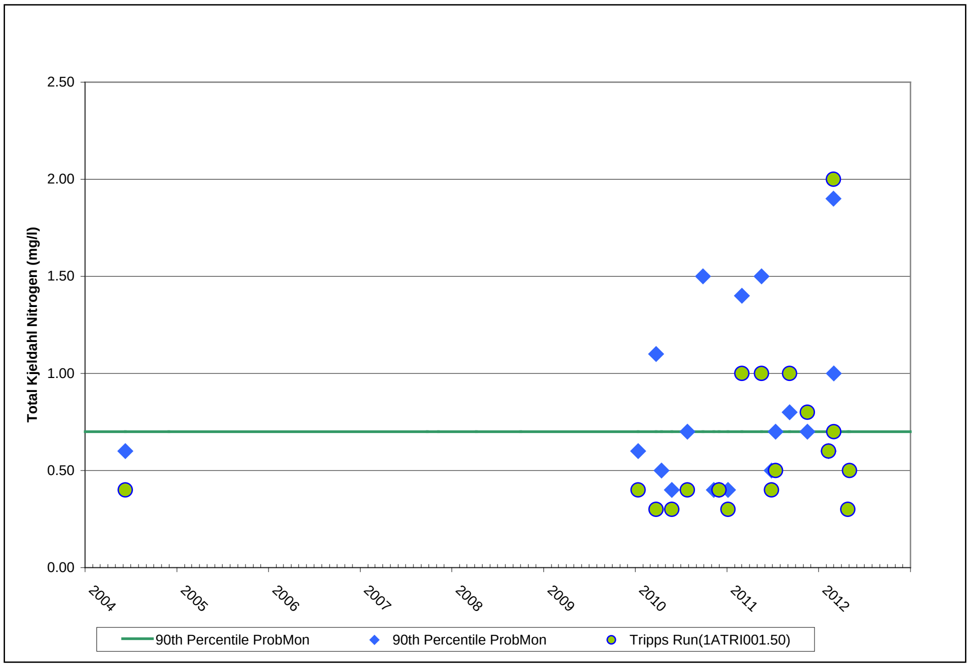

Figure 3-31: Observed Total Kjeldahl Nitrogen (mg/l), Holmes Run and Tripps Run

3.2.15 Total Nitrogen

Figure 3-32 shows the total nitrogen (TN) concentrations observed in water quality samples in Holmes Run and Tripps Run. Virginia has no water quality criteria for TN. The 90th percentile nitrate concentration in the ProbMon data is 1.35 mg/l. About half of the concentrations observed in Holmes Run are greater than the 90th percentile of the ProbMon data. All but one of the TN concentrations observed in Tripps Run are greater than the 90th percentile of the ProbMon data, primarily because of the high nitrate concentrations observed in Tripps Run. Only about 10% of the observed TN concentrations in Holmes Run are above the 2.0 mg/l ProbMon condition threshold for suboptimal conditions. In contrast, over three-quarters of the TN observations in Tripps Run are above the condition threshold.

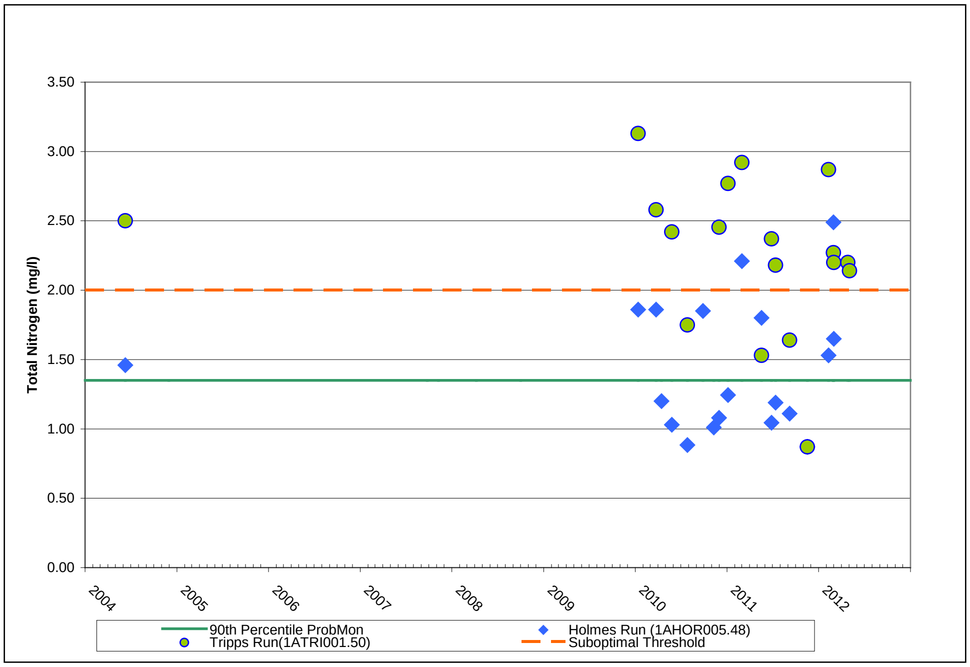

Figure 3-32: Observed Total Nitrogen Concentrations (mg/l), Holmes Run and Tripps Run

3.2.16 Metals

Tables 3-8 and **3-9** list all metal concentrations observed in water quality monitoring in Holmes Run and Tripps Run, respectively. All observations are from the water column. No sediment samples were analyzed for metals in either Holmes Run or Tripps Run.

Nine metals have acute and/or chronic criteria to protect aquatic life (9VAC25-260-140). Most of these criteria are expressed as functions of hardness and apply only to the dissolved form of the metal. Observed hardness concentrations are also listed in **Tables 3-8** and **3-9**. The acute and/or chronic criteria for metals are shown in **Table 3-10,** based on the average hardness concentration of 76 mg/l $CaCO_3$ (calcium carbonate) observed in Holmes Run and Tripps Run. There are no exceedances of the acute criteria for metals in Holmes Run or Tripps Run. Observed concentrations of dissolved metals are all below the chronic criteria as well, so there is no evidence that chronic criteria are exceeded in Holmes Run or Tripps Run. Four metals—barium, iron, manganese, and thallium—also have criteria for drinking water. While these criteria are not applicable in Holmes Run or Tripps Run, observed concentrations of these metals are below the drinking water criteria.

As mentioned in **Section 3.2**, ProbMon uses the Cumulative Criterion Unit (CCU) Metals Index (Clements et al., 2000) to screen ProbMon sampling sites for the cumulative chronic biological impact of dissolved metals. A CCU is the ratio of the observed dissolved metals concentration to the EPA chronic criterion concentration; the CCU Index is the sum of the CCU's for each metal analyzed. ProbMon classifies an index score less than one as optimal and a score greater than two as sub-optimal.

The CCU Metals Index was calculated for each sampling date on which samples of dissolved metals were collected in Holmes Run or Tripps Run. **Table 3-11** shows the results. All calculated index values are below 1.0 and therefore in the ProbMon range for optimal conditions.

Table 3-8: Observed Water Column Metals , Holmes Run						
	4/15/10	**9/27/10**	**6/27/11**	**2/9/12**	**2/29/12**	**3/1/12**
HARDNESS, CA MG CALCULATED (MG/L AS CACO3)	79	42	85	87	53	66
HARDNESS, CA MG CALCULATED (MG/L AS CACO3) AS DISSOLVED	66	32	87			
ALUMINUM, DISSOLVED (UG/L AS AL)	3.65	5.6	2.79			
ALUMINUM, TOTAL (UG/L AS AL)	72.8	5700	52	104	5320	1190
ANTIMONY, DISSOLVED (UG/L AS SB)	0.273	0.4	0.18			
ANTIMONY, TOTAL (UG/L AS SB)	0.241	0.5	0.17	0.524	0.545	0.352
ARSENIC, DISSOLVED (UG/L AS AS)	0.44	0.6	0.43			
ARSENIC, TOTAL (UG/L AS AS)	0.307	1.1	0.7	0.3	1.36	0.644
BARIUM, DISSOLVED (UG/L AS BA)	30.6	18.4	31.3			
BARIUM, TOTAL (UG/L AS BA)	38.2	82	31.9	40.7	59.1	40
BERYLLIUM, DISSOLVED (UG/L AS BE)	0.011	0.02	0.04			
BERYLLIUM, TOTAL (UG/L AS BE)	0.011	0.5	0.04	0.08	0.37	0.08
CADMIUM, DISSOLVED (UG/L AS CD)	0.06	0.02	0.03			
CADMIUM, TOTAL (UG/L AS CD)	0.013	0.2	0.03	0.04	0.082	0.04
CHROMIUM, DISSOLVED (UG/L AS CR)	1.75	1	1.37			
CHROMIUM, TOTAL (UG/L AS CR)	2.05	11.9	1.27	2.77	14.7	4.68
COPPER, DISSOLVED (UG/L AS CU)	1.5	2.4	1.36			
COPPER, TOTAL (UG/L AS CU)	1.82	17.9	1.63	2.22	13.4	5.28
IRON, DISSOLVED (UG/L AS FE)	146	108	19.4			
IRON, TOTAL (UG/L AS FE)	531	7720	370	526	8420	2130
LEAD, DISSOLVED (UG/L AS PB)	0.044	0.2	0.02			
LEAD, TOTAL (UG/L AS PB)	0.12	17.8	0.19	0.321	10.7	2.67
MANGANESE, DISSOLVED (UG/L AS MN)	45.5	87.6	61.2			
MANGANESE, TOTAL (UG/L AS MN)	72.2	750	65.2	122	534	190
NICKEL, DISSOLVED (UG/L AS NI)	1.49	1	0.97			
NICKEL, TOTAL (UG/L AS NI)	1.4	7.4	1.1	2.42	7.64	2.96
SELENIUM, DISSOLVED (UG/L AS SE)	0.651	0.2	0.41			
SELENIUM, TOTAL (UG/L AS SE)	0.538	0.4	0.52	0.358	0.3	0.3
SILVER, DISSOLVED (UG/L AS AG)	0.006	0.004	0.03			
SILVER, TOTAL (UG/L AS AG)	0.008	0.1	0.03	0.3	0.3	0.3
THALLIUM, DISSOLVED (UG/L AS TL)	0.007	0.01	0.03			
THALLIUM, TOTAL (UG/L AS TL)	0.007	0.1	0.02	0.046	0.105	0.027
ZINC, DISSOLVED (UG/L AS ZN)	1.49	2.6	1.08			
ZINC, TOTAL (UG/L AS ZN)	2.9	66.5	1.53	5.88	60	19.8

Yellow: Analyte detected above the MDL but below the method quantification limit (QQ).
Orange: Material analyzed for, but not detected. Value stored is the limit of detection for the process in use (U).

Table 3-9: Observed Water Column Metals , Tripps Run					
	4/15/10	**6/27/11**	**2/9/12**	**2/29/12**	**3/1/12**
HARDNESS, CA MG CALCULATED (MG/L AS CACO3)	105	121	116	22	65
HARDNESS, CA MG CALCULATED (MG/L AS CACO3) AS DISSOLVED	90	122			
ALUMINUM, DISSOLVED (UG/L AS AL)	7.43	3.1			
ALUMINUM, TOTAL (UG/L AS AL)	49.8	28.2	35.4	5180	523
ANTIMONY, DISSOLVED (UG/L AS SB)	0.141	0.16			
ANTIMONY, TOTAL (UG/L AS SB)	0.154	0.16	0.531	1.03	0.336
ARSENIC, DISSOLVED (UG/L AS AS)	0.241	0.36			
ARSENIC, TOTAL (UG/L AS AS)	0.171	0.62	0.3	1.71	0.768
BARIUM, DISSOLVED (UG/L AS BA)	28.2	33.9			
BARIUM, TOTAL (UG/L AS BA)	33.3	34.5	48.6	44.2	26.3
BERYLLIUM, DISSOLVED (UG/L AS BE)	0.011	0.04			
BERYLLIUM, TOTAL (UG/L AS BE)	0.011	0.04	0.08	0.301	0.08
CADMIUM, DISSOLVED (UG/L AS CD)	0.013	0.03			
CADMIUM, TOTAL (UG/L AS CD)	0.013	0.03	0.04	0.161	0.04
CHROMIUM, DISSOLVED (UG/L AS CR)	2.1	1.95			
CHROMIUM, TOTAL (UG/L AS CR)	3.24	1.18	3.2	12.7	5.22
COPPER, DISSOLVED (UG/L AS CU)	1.97	1.77			
COPPER, TOTAL (UG/L AS CU)	2.29	1.85	3.26	26.6	6.38
IRON, DISSOLVED (UG/L AS FE)	70.7	23.7			
IRON, TOTAL (UG/L AS FE)	211	117	105	8190	837
LEAD, DISSOLVED (UG/L AS PB)	0.017	0.06			
LEAD, TOTAL (UG/L AS PB)	0.087	0.14	0.191	21.6	1.68
MANGANESE, DISSOLVED (UG/L AS MN)	55.1	24.5			
MANGANESE, TOTAL (UG/L AS MN)	66.8	28.3	38.8	290	31.8
NICKEL, DISSOLVED (UG/L AS NI)	1.53	1.08			
NICKEL, TOTAL (UG/L AS NI)	1.54	1.02	3.18	6.93	2.28
SELENIUM, DISSOLVED (UG/L AS SE)	0.37	0.32			
SELENIUM, TOTAL (UG/L AS SE)	0.351	0.47	0.3	0.3	0.3
SILVER, DISSOLVED (UG/L AS AG)	0.006	0.03			
SILVER, TOTAL (UG/L AS AG)	0.01	0.03	0.3	0.3	0.3
THALLIUM, DISSOLVED (UG/L AS TL)	0.007	0.02			
THALLIUM, TOTAL (UG/L AS TL)	0.007	0.02	0.161	0.142	0.02
ZINC, DISSOLVED (UG/L AS ZN)	7.91	5.2			
ZINC, TOTAL (UG/L AS ZN)	11.3	6.01	34.4	112	31.3

Yellow: Analyte detected above the MDL but below the method quantification limit (QQ).
Orange: Material analyzed for, but not detected. Value stored is the limit of detection for the process in use (U).

Table 3-10: Aquatic Life Criteria for Dissolved Metals (µg/l) (9VAC25-260-140) (Based on Average Hardness of 76 mg/l CaCO3 Observed in Holmes Run and Tripps Run)		
Constituent	**Acute**	**Chronic**
Arsenic	340	150
Cadmium	2.9	0.9
Chromium	455	59.2
Copper	10.4	7.1
Lead	83.8	9.5
Nickel	144.6	16.1
Selenium	20	5.0
Silver	2.2	
Zinc	92.9	93.6

Table 3-11: CCU Metals Index1 for Dissolved Metal Samples in Holmes Run and Tripps Run		
Sample Date	**Holmes Run**	**Tripps Run**
4/15/2010	0.35	0.38
9/27/2010	0.79	0.28
6/27/2010	0.26	

[1] <1.0, Optimal; 1.0-2.0, Fair; >2.0, Suboptimal

3.2.17 Summary of Conventional Water Quality Data

Table 3-12 gives the summary statistics for nutrients and some conventional constituents observed in Holmes Run. **Table 3-13** gives summary statistics for Tripps Run. The statistics are based on all samples (ambient, storm, and the Tripps Run special study) collected at stations 1AHOR005.48 and 1ATRI001.50. The median of the observations is above the 90th percentile of the ProbMon data for chlorides in both Holmes Run and Tripps Run. The median of nitrate observations is above the 90th percentile of the ProbMon data for Tripps Run and the median of TKN observations is approximately at the 90th percentile of the ProbMon data for Holmes Run.

Tables 3-14 and **3-15** give the Spearman rho correlation coefficients among these constituents for Holmes Run and Tripps Run, respectively. The tables also show the correlation of these constituents with flow percentiles for sampling dates from Cameron Run. The tables show that the constituents could be divided into two groups, depending on whether their correlations with the flow percentiles are positive or negative. TKN, TP, TSS, and turbidity are positively correlated with flow and with each other. (The calculated

Spearman rho correlation between flow and turbidity confirms the visual evidence of their correlation shown in **Figures 3-24** and **3-25.**) Higher concentrations of these constituents occur during storm flow. Ammonia also can be included in this group, though its correlation with flow and the other members of the group is somewhat weaker. Other the other hand, nitrate, specific conductivity, TDS, and total chlorides are negatively correlated with flow but positively correlated with each other. Higher concentrations of these constituents occur under baseflow conditions.

DEQ collected a single sample in Holmes Run (4/15/10) with a full suite of dissolved ions. In this sample the major ions in road salt --sodium, calcium, and chloride-- accounted for over 80% of fixed total dissolved solids observed in the sample. Given the degree of development in Holmes Run and Tripps Run, it is likely that road salt accounts for the elevated levels of total chloride observed in these watersheds.

Table 3-12: Summary Statistics for Selected Water Quality Constituents in Holmes Run

Statistic	CL	NO_3	NH_4	TKN	TN	TP	TSS	SC	Turbidity	TDS
Count	17	19	19	19	19	19	18	24	18	17
Minimum	31.9	0.2	0.01	0.4	0.4	0.03	1	179	2.4	112
1st Quartile	48.6	0.4	0.02	0.5	0.5	0.04	4	270	3.8	192
Median	70.6	0.6	0.04	0.7	0.7	0.05	7	344	9.8	208
3rd Quartile	128.0	0.8	0.08	1.1	1.1	0.07	24	536	23.8	304
Maximum	545.0	1.3	0.20	1.9	2.0	0.94	312	1990	163.0	1060
Average	108.9	0.6	0.06	0.8	0.9	0.14	48	454	31.0	282
Standard Deviation	121.8	0.3	0.06	0.4	0.5	0.23	97	370	48.5	220
90^{th} Percentile ProbMon Data	17	0.98	0.06	0.7	1.35	0.07	14	348	14.5	215

Table 3-13: Summary Statistics for Selected Water Quality Constituents in Tripps Run

Statistic	CL	NO_3	NH_4	TKN	TN	TP	TSS	SC	Turbidity	TDS
Count	16	18	18	18	18	18	18	26	18	17
Minimum	13.4	0.1	0.01	0.3	0.3	0.02	1	84	0.7	87
1st Quartile	32.2	0.8	0.01	0.4	0.4	0.04	1	264	1.1	186
Median	45.8	1.8	0.02	0.5	0.5	0.06	2	328	1.5	220
3rd Quartile	62.4	2.1	0.04	0.8	0.9	0.09	9	368	8.2	230
Maximum	319.0	2.7	0.39	2.0	2.2	1.04	281	1229	154.0	626
Average	67.1	1.5	0.05	0.6	0.7	0.12	23	345	14.4	235
Standard Deviation	75.2	0.8	0.09	0.4	0.5	0.23	66	218	36.0	120
90th Percentile ProbMon Data	17	0.98	0.06	0.7	1.35	0.07	14	348	14.5	215

Table 3-14: Spearman Rho Correlations among Selected Water Quality Constituents, Holmes Run										
	CL	**FLOW**	**NH_4**	**NO_3**	**SC**	**TDS**	**TKN**	**TP**	**TSS**	**Turbidity**
CL	1.00	-0.14	0.07	0.59	0.94	0.96	-0.01	-0.16	-0.04	0.05
FLOW	-0.14	1.00	0.39	-0.27	-0.21	-0.17	0.73	0.67	0.67	0.68
NH_4	0.07	0.39	1.00	-0.04	-0.07	-0.03	0.36	0.72	0.50	0.50
NO_3	0.59	-0.27	-0.04	1.00	0.64	0.57	-0.40	-0.45	-0.40	-0.30
SC	0.94	-0.21	-0.07	0.64	1.00	0.99	-0.10	-0.25	-0.21	-0.14
TDS	0.96	-0.17	-0.03	0.57	0.99	1.00	-0.03	-0.19	-0.14	-0.06
TKN	-0.01	0.73	0.36	-0.40	-0.10	-0.03	1.00	0.67	0.85	0.81
TP	-0.16	0.67	0.72	-0.45	-0.25	-0.19	0.67	1.00	0.79	0.75
TSS	-0.04	0.67	0.50	-0.40	-0.21	-0.14	0.85	0.79	1.00	0.98
Turbidity	0.05	0.68	0.50	-0.30	-0.14	-0.06	0.81	0.75	0.98	1.00

Green: rho> 0.5; Yellow: rho< 0.0

Table 3-15: Spearman Rho Correlations among Selected Water Quality Constituents, Tripps Run										
	CL	**FLOW**	**NH_4**	**NO_3**	**SC**	**TDS**	**TKN**	**TP**	**TSS**	**Turbidity**
CL	1.00	-0.29	-0.20	0.83	0.97	1.00	-0.42	-0.72	-0.64	-0.42
FLOW	-0.29	1.00	0.55	-0.40	-0.29	-0.31	0.73	0.67	0.74	0.72
NH_4	-0.20	0.55	1.00	-0.38	-0.21	-0.23	0.59	0.50	0.42	0.59
NO_3	0.83	-0.40	-0.38	1.00	0.81	0.83	-0.59	-0.83	-0.72	-0.52
SC	0.97	-0.29	-0.21	0.81	1.00	0.98	-0.41	-0.68	-0.63	-0.36
TDS	1.00	-0.31	-0.23	0.83	0.98	1.00	-0.43	-0.72	-0.66	-0.44
TKN	-0.42	0.73	0.59	-0.59	-0.41	-0.43	1.00	0.69	0.68	0.85
TP	-0.72	0.67	0.50	-0.83	-0.68	-0.72	0.69	1.00	0.92	0.74
TSS	-0.64	0.74	0.42	-0.72	-0.63	-0.66	0.68	0.92	1.00	0.81
Turbidity	-0.42	0.72	0.59	-0.52	-0.36	-0.44	0.85	0.74	0.81	1.00

Green: rho> 0.5; Yellow: rho< 0.0

3.2.18 Tripps Run Special Study

To investigate the nature of the high observed nitrate concentrations in Tripps Run, DEQ performed additional water quality monitoring in the Tripps Run watershed on two dates at four locations, including the primary DEQ monitoring station at 1ATRI001.50. The goal was to determine whether there were geographic differences in nitrate concentrations in Tripps Run and if the high nitrate concentrations could be correlated with bacteria concentrations, which might suggest sewer leaks or failing septic systems, or with some other indicator of the source of the high concentrations.

Figure 3-33 shows the sampling locations, and **Table 3-16** gives the monitoring results for nutrients and a select number of other constituents. As the table shows, observed nitrate concentrations do not vary significantly by location. If high nitrate concentrations were due to a specific source, such as a sewer leak, one would expect to see an increase in concentration between monitoring locations upstream and downstream of the source. Observed nitrate concentrations on these two sampling dates, which took place under ambient flow conditions, were within the 1st and 3rd quartiles of observed values at 1ATRI001.50. Although several observed *E. coli* concentrations are above the 235 cfu/100 ml threshold used to screen for exceedances of Virginia's bacteria standards, the observed bacteria concentrations are typical of urban streams and do not indicate a specific source of bacteria, such as a sewer leak, which could also be a source of high nitrate concentrations. Bacteria concentrations in streams contaminated by sewage are typically an order of magnitude higher in the immediate vicinity of the source than the concentrations observed in Tripps Run (J. Beckley, Personal communication, 2012).

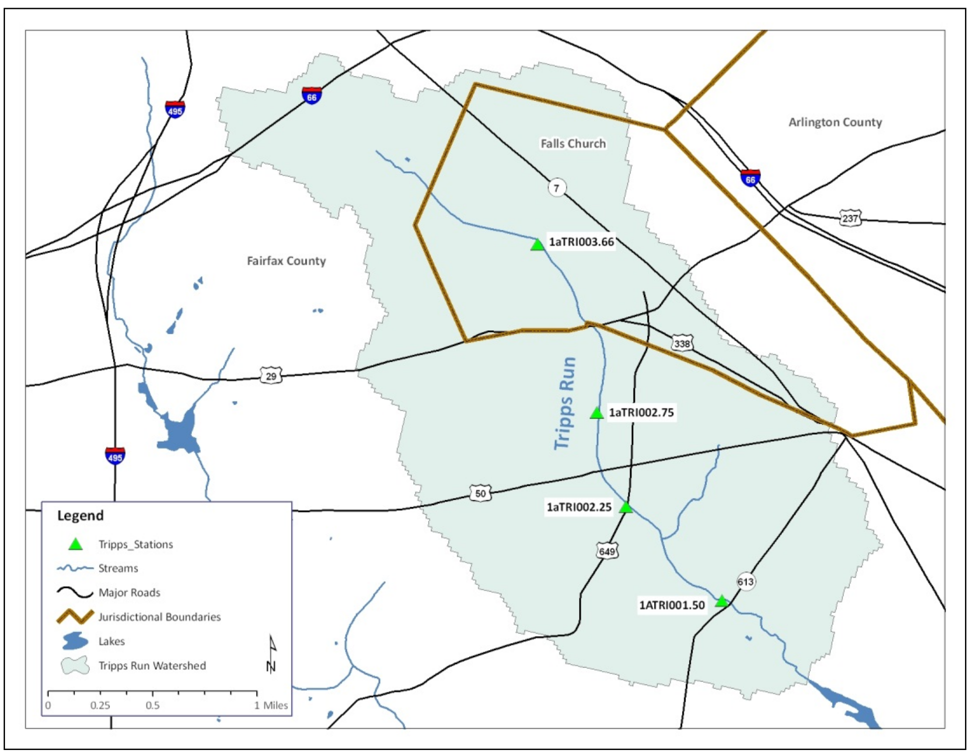

Figure 3-33: Monitoring Stations for Tripps Run Special Study

Table 3-16: Selected Water Quality Monitoring Results from DEQ Tripps Run Special Study								
	1ATRI001.50		**1ATRI002.25**		**1ATRI002.75**		**1ATRI003.66**	
	4/26/12	5/3/12	4/26/12	5/3/12	4/26/12	5/3/12	4/26/12	5/3/12
Temperature (°C)	13.17	15.81	14.01	17.55	13.27	15.43	12.79	13.82
pH	7.1	6.95	7.71	8.75	7.56	7.27	7.54	7.26
DO (mg/l)	8.91	7.95	11.35	14.15	10.43	10.01	10.53	9.8
SC	312	330	317	344	333	401	327	423
Salinity	0.15	0.16	0.15	0.17	0.16	0.19	0.16	0.2
E. Coli (cfu/ 100 ml)	200	300	425	100	200	375	100	275
NH_4 (mg/l-N)	0.02	0.05	0.01	0.008	0.01	0.03	0.03	0.05
NO_2 (mg/l-N)	0.02	0.02	0.02	0.02	0.01	0.02	0.01	0.01
NO_3 (mg/l-N)	1.9	1.64	2.1	1.81	2.01	1.88	1.75	1.77
TKN (mg/l)	0.3	0.5	0.4	0.4	0.3	0.4	0.3	0.3
TP (mg/l)	0.04	0.07	0.05	0.05	0.04	0.06	0.03	0.05
PO_4 (mg/l-P)	0.02	0.04	0.02	0.03	0.03	0.04	0.02	0.03
TSS (mg/)	1	2	2	2	1	1	1	2
Turbidity (NTU)	0.76	1.31	1.62	0.75	0.53	1.01	0.63	1
TDS (mg/l)	204	225	212	233	221	267	237	258

Yellow: Analyte detected above the MDL but below the method quantification limit (QQ).
Orange: Material analyzed for, but not detected. Value stored is the limit of detection for the process in use (U).

3.3 Whole Effluent Toxicity (WET) Tests

Whole Effluent Toxicity (WET) testing was performed using samples collected from Holmes Run and Tripps Run on February 27, 2012. WET tests compare the response of test species to the water from sampled streams against the response from a control sample with no toxic substances present. In this case, the test species were water fleas (*Ceriodaphnia dubia*) and fathead minnows (*Pimephales promelas*). The biological response of water fleas to the stream samples was measured in terms of the survival rate and number of young produced. The response of minnows was measured in terms of survival rate and change in biomass. The tests are run for seven days, using tests samples diluted to a range of strengths from 0% sample water (control) to 100% sample water. The tests assume that there is a monotonically increasing dose-response relationship between the percent sample water and adverse biological impacts. Based on test results, a variety of statistical measures of the impact of the sample water on the test organisms can be determined, including IC25, or the concentration of the sample that cause a 25% reduction in growth or reproduction; LOEC (lowest-observable-effects-concentration), the lowest concentration of the sample at which there is a statistically significant biological impact; or NOEC (No-observable-effect-concentration), the highest concentration of the sample at which there is no statistically significant biological impact.

No statistically significant biological impacts were observed on either fathead minnows or water fleas from the sample from Holmes Run. There were also no statistically significant impacts observed on water fleas from the sample from Tripps Run, but statistically significant differences were observed when fathead minnows were exposed to the sample water from Tripps Run. There was not a monotonically-increasing dose-response relation in the response of fathead minnows, leading the Coastal Bioanalysts, Inc., the laboratory performing the tests, to conclude:

"Sporadic mortality in effluent treatments, but not controls, nonmonotonic dose-response and observations of growth on fish suggest the presence of a fish pathogen, as opposed to chemical toxicants, as the cause of fish mortality. Lack of effect in the concurrent chronic Ceriodaphnia test supports this hypothesis."

This conclusion is in accordance with EPA (2000) guidance on analyzing the results of WET tests, *Method Guidance and Recommendations for Whole Effluent Toxicity (WET) Testing (40 CFR Part 136)*.

3.4 Habitat Assessment

DEQ routinely performs a habitat assessment of the biological monitoring site as part of its biological assessment. **Tables 3-17** and **3-18** show the habitat assessment scores for Holmes Run and Tripps Run, respectively, corresponding to the biological assessments at the sites shown in **Figure 3-1**. There are ten habitat metrics, each scored on a scale from 0 to 20. Scores from 0 to 5 are considered poor, between 6 and 10 are marginal, 11 to 15 are sub-optimal, and 16 through 20 are optimal.

Poor or marginal riparian vegetation stands out as a problem in Holmes Run. Since leaf litter is a primary source of energy in small order streams, poor riparian vegetation can deprive macroinvertebrates of their source of food. Poor riparian vegetation also means that the stream is poorly shaded, which in turn can lead to higher stream temperatures and greater algal growth than under natural conditions. Embeddedness measures the extent to which substrate, which is the prime habitat for desirable macroinvertebrates, is covered by sediment. Sediment deposition measures the extent to which sediment has filled in pools or formed bars. Since 2007, both embeddedness and sediment scores in Holmes Run have been consistently marginal.

Embeddedness and sediment deposition have also been consistently marginal in Tripps Run since 2008. Poor or marginal riparian vegetation has also been a problem in Tripps Run, though less so in recent years. The quality and quantity of epifaunal substrate, which includes the quality and diversity of areas in the stream where aquatic fauna can live and breed, is also frequently found to be marginal in Tripps Run.

The ProbMon condition threshold for suboptimal conditions is 120 for the total habitat score. The last five habitat assessments of Holmes Run, and four of the last five habitat assessments of Tripps Run, have had total habitat scores below 120.

Table 3-17: Habitat Scores for Holmes Run

Habitat Metrics:	Assessment Date						
	6/9/04	11/29/04	11/8/07	4/7/08	10/1/08	4/15/10	11/9/10
ALTER	19	20	7	9	8	12	11
BANKS	18	18	11	14	12	12	13
BANKVEG	16	8	9	16	15	14	13
EMBED	13	12	9	8	10	8	6
FLOW	17	14	9	18	17	14	8
RIFFLES	17	15	14	16	16	14	12
RIPVEG	10	4	6	2	2	7	4
SEDIMENT	14	13	10	7	6	7	6
SUBSTRATE	17	17	10	15	12	8	8
VELOCITY	14	12	10	10	15	9	12
TOTAL	155	133	95	115	113	105	93

Yellow: Marginal; Red: Poor

Table 3-18: Habitat Scores for Tripps Run							
Habitat Metrics:	**Assessment Date**						
	6/9/04	**11/29/04**	**9/25/07**	**4/7/08**	**10/1/08**	**4/15/10**	**11/9/10**
ALTER	19	20	15	13	15	16	13
BANKS	18	18	12	12	10	16	6
BANKVEG	18	14	13	14	13	16	8
EMBED	10	9	12	5	8	8	7
FLOW	18	17	6	14	14	13	10
RIFFLES	16	15	15	16	15	14	15
RIPVEG	8	4	13	13	9	14	14
SEDIMENT	13	13	12	6	4	10	8
SUBSTRATE	17	17	8	14	6	13	8
VELOCITY	14	13	10	10	14	13	13
TOTAL	151	140	116	117	108	133	102

Yellow: Marginal; Red: Poor

3.5 The Log_{10} Relative Bed Stability Index (LRBS)

The Log_{10} Relative Bed Stability Index (LRBS) measures the relative stability of the bed substrate in a stream and how it is altered by anthropogenic impacts. Streams that have an excess supply of sediment from upland erosion tend to have more mobile beds with finer substrate like silts and clays. This finer substrate can bury the coarser substrate, which forms the habitat of pollutant-sensitive macroinvertebrates or the spawning ground of sensitive fish species like trout. On the other hand, some bed mobility is part of the natural geomorphic processes in streams and is necessary to maintain variety in habitat and to clean coarser substrate of sediment (Kaufman et al., 1999). Streams are reworked during bankfull flow events that have a return period of approximately 1.5 to 2 years. A stream can be too stable, however. Streams subject to persistent high flows, such as the tailwater below a dam, have beds dominated by coarser substrate which cover the bed and prevent finer particles from scouring. This process is called armoring, and it represents the other extreme from excessively mobile beds dominated by fine sediment.

The LRBS postulates that under natural conditions, long term sediment supply is in equilibrium with the sediment transport capacity in a stream (Kaufman et al., 1999). The LRBS is the $\log_{10}$ of the ratio of the observed median diameter of the substrate in a stream (D_{50}) to the diameter of the largest substrate that is mobilized during bankfull flow (D_{cbf}). D_{50} can be approximated by the geometrical mean of observed substrate diameters. D_{cbf} can be calculated from the hydraulic radius under bankfull flows (R_{bf}) and the water surface slope, S (which can be approximated by the channel slope), using the following two equations:

$\tau_{bf} = \rho_w * g * R_{bf} * S$

where
τ_{bf} = average bottom shear stress at bankfull flow (kg-m/s^2)
ρ_w = density of water (kg/m^3)
g = gravitational acceleration (m/s^2)

$\tau_c = \theta * (\rho_s - \rho_w) * g * D$

where
θ = Shields parameter (0.044 for non-cohesive particles under turbulent flow)
τ_c = minimum shear stress required to move particle of size D (kg-m/s^2)
ρ_s = density of sediment (kg/m^3)
ρ_w = density of water (kg/m^3)
g = gravitational acceleration (m/s^2)
D = particle size (m)

By equating the critical shear stress, τ_c, to τ_{bf}, D_{cbf}, the largest substrate size mobilized by bankfull flow, can be determined. R_{bf} is corrected to take into account the roughness contributed by woody debris, riffles, and other channel structures.

If D_{cbf} equals D_{50}, LRBS is equal to zero. If D_{50} is less than D_{cbf}, LRBS is negative. This implies that flows less than bankfull flow can move more than half the substrate in the bed. The more negative the LRBS is, the more unstable the bed. On the other hand, large positive values of LRBS can indicate a bed that is armored.

Table 3-19 shows the LRBS scores for Holmes Run and Tripps Run, based on geomorphic data from monitoring stations 1AHOR005.48 and 1ATRI001.50, respectively. The percentile ranking of the LRBS scores among statewide measurements from the ProbMon program is also shown. ProbMon, in the Integrated Report assessments, classifies LRBS scores less than -1.0 as suboptimal and scores greater than -0.5 as optimal. DEQ has adopted the interpretation that LRBS scores below -1.0 indicate that a stream is carrying excessive sediment, while scores above -0.5 have a normal sediment load (DEQ, 2012). Since the LRBS scores for both Holmes Run and Tripps Run are above -0.5, they are not carrying excessive sediment loads. **Table 3-19** also shows the geometric mean substrate diameter, slope, percent of sands and fine particles, and percent embeddedness (without fines or bedrock) and the percentile of these scores among statewide results.

Table 3-19: LRBS Scores and Geomorphic Characteristics, Holmes Run and Tripps Run (11/9/2010)

	1AHOR005.48		1ATRI001.50	
	Value	**Percentile**	**Value**	**Percentile**
LRBS	0.236	91%	0.208	90%
Geometric Mean Substrate Diameter (mm)	11.38	63%	18.01	71%
Substrate Class	Fine Gravel		Coarse Gravel	
Slope	0.236	17%	0.354	23%
Percent Sands+Fines	0.305	34%	0.238	29%
Percent Embeddedness (without fines or bedrock)	50%		46%	

3.6 Fairfax County Biological Monitoring and Stream Assessment

Fairfax County Department of Public Works and Environmental Services (DPWES) supports its own biological monitoring program which samples both fish and benthic macroinvertebrates. Sampling results are assessed according to fish and benthic indices of biological integrity (IBIs) developed by the DPWES. **Table 3-20** shows the location of monitoring locations and water quality ratings from IBI results within the Holmes Run and Tripps Run watersheds. The ratings range from very poor to fair. **Tables 3-21** and **3-22** summarize the benthic macroinvertebrates found in Holmes Run and Tripps Run, respectively. Pollution-tolerant *Oligochaeta* and *Chironomidae* are the dominant taxa found at DPDES sampling sites. **Table 3-23** shows the field measurements of water quality parameters concurrent with biological monitoring. Generally the results are consistent with DEQ monitoring except that field measurements of DO are supersaturated. This may be indicative of primary production by algae occurring in early spring. DEQ personnel have observed benthic algae growing in early spring before leaves on trees have grown (B. Thomas, DEQ. Personal communication, 2012). Generally, with the exception of observation at CA0701, the levels of supersaturation are modest and not a cause for concern.

CH2MHill (2005) conducted a physical assessment of Fairfax County streams. The Stream Physical Assessment (SPA) had four components. The first component was a habitat assessment, based on EPA visual assessment protocols similar to those used in the DEQ habitat assessment discussed in **Section 3.4**. The second component was an infrastructure inventory. The infrastructure inventory identified the following items and assessed their impact on the streams: deficient buffer vegetation, ditches, dump sites, head cuts, obstructions, pipes, road crossings, and utility lines. The third component is a geomorphic assessment based on a channel evolution model (CEM). The CEM describes the successive stages of a stream's response to urbanization, starting with a stable system (Stage I), and proceeding to incision and head cuts (Stage II), widening stream channels with substantial stream bank sloughing (Stage III), stabilizing stream channel with aggregating bed (Stage IV), and returning to a stable channel with a well-defined flood plain that has adjusted to urbanized conditions (Stage V). The final component is a stream characterization with combines the previous elements with an assessment of the need and feasibility of stream restoration.

According to CH2MHill's SPA, 38% (by linear feet) of the assessed streams in Holmes Run had poor or very poor habitat and 43% had fair habitat; only 19% had good habitat. Inadequate riparian buffers affected 93,950 linear feet of stream and eroded stream banks affected 4,590 linear feet (as reported in Versar, 2007). In the Tripps Run watershed, 58% of the assessed stream length had poor habitat and 29% had fair habitat, with only 13% of the habitat rated good (C2MHill, 2005). Inadequate riparian buffers affected 37,850 linear feet of stream in the Tripps Run watershed (reported in Versar, 2007). The SPA reports that three-quarters of the streams in the Cameron Run watershed, where Holmes Run and Tripps Run are located, are in Stage III of the CEM and 25% are in Stage IV (C2MHill, 2005).

Table 3-20: Fairfax County DPWES Biological Ratings

Site ID	Watershed	Year	Benthic	Fish
CAHR01	Holmes	1999	Very Poor	Fair
CAHR02	Holmes	1999	Very Poor	Very Poor
CATR01	Tripps	1999	Very Poor	Very Poor
CA0602	Holmes	2006	Very Poor	Very Poor
CA0701	Holmes	2007	Fair	
CA0704	Holmes	2007	Poor	Fair
CAHR02	Holmes	2007	Poor	Very Poor
CA0901	Holmes	2009	Poor	
CA0902	Holmes	2009	Poor	
CA1001	Tripps	2010	Poor	Very Poor

Table 3-21: Macroinvertebrates Observed at Holmes Run Sampling Sites, Fairfax County DPWES

Class	Order	Family	Count
Insecta	Diptera	Chironomidae	1102
Oligochaeta			679
Insecta	Trichoptera	Hydropsychidae	28
Insecta	Coleoptera	Elmidae	10
Crustacea	Amphipoda	Crangonyctidae	6
Insecta	Coleoptera	Dytiscidae	5
Insecta	Lepidoptera	Pyralidae	5
Insecta	Diptera	Simuliidae	4
Hydrozoa	Hydroida	Hydridae	3
Bivalvia	Pelecypoda	Corbiculidae	3
Insecta	Odonata	Coenagrionidae	3
Arachnida	Acariformes	Sperchonidae	2
Insecta	Diptera	Tipulidae	2
Insecta	Hemiptera	Veliidae	2
Gastropoda	Limnophila	Physidae	2
Arachnida	Acariformes	Torrenticolidae	2
Insecta	Odonata	Calopterygidae	1
Bivalvia	Pelecypoda	Sphaeriidae	1
Crustacea	Isopoda	Asellidae	1
Crustacea	Decapoda	Cambaridae	1
Gastropoda	Limnophila	Ancylidae	1
Arachnida	Acariformes	Lebertiidae	1
Insecta	Lepidoptera		1
Insecta	Odonata	Corduliidae	1
Insecta	Plecoptera	Nemouridae	1
Insecta	Diptera		1

Table 3-22: Macroinvertebrates Observed at Tripps Run Sampling Sites, Fairfax County DPWES			
Class	**Order**	**Family**	**Count**
Insecta	Diptera	Chironomidae	233
Oligochaeta			176
Insecta	Odonata	Coenagrionidae	4
Insecta	Diptera	Empididae	4
Gastropoda	Limnophila	Physidae	3
Nematomorpha (phylum)		2	
Insecta	Lepidoptera		1
Hirudinea	Pharyngobdellida	Erpobdellidae	1
Hirudinea			1
Crustacea	Amphipoda	Crangonyctidae	1

Table 3-23: Fairfax County DPWES Water Quality Field Data from Tripps Run and Holmes Run							
Site ID	**Watershed**	**Date**	**Temperature**	**pH**	**DO**	**% DO Saturation**	**Specific Conductance**
CA0602	Holmes	3/28/06	8	7.3	12.5	105.6	421
CA0701	Holmes	3/26/07	11.3	6.6	14.9	136.4	288
CAHR02	Holmes	3/27/07	12.2	7.3	12.1	112.5	577
CA0704	Holmes	3/29/07	14.4	6.8	10.8	106	746
CA0901	Holmes	3/31/09	7.3	7.1	12.1	100.3	328
CA0902	Holmes	3/31/09	10.7	7.2	12.7	114.3	259
CA1001	Tripps	4/6/10	15	7.5	10.3	101.9	416

4 Stressor Identification Analysis

Biological monitoring in Holmes Run and Tripps Run has determined that these waterbodies are not supporting their aquatic life use, but the biological monitoring does not determine the causes of the biological impairments in these waterbodies. Until the cause(s) of the biological impairments have been determined, it is not possible to take any action to address the impairments. The purpose of Stressor Identification Analysis is to determine the stressor(s) to the biological community. Once the stressors have been identified, Total Maximum Daily Loads (TMDLs) for the stressors can be developed, assuming that the identified stressors are pollutants. TMDLs can only be developed for pollutants. If the identified stressor(s) are not pollutants, alternative approaches can be developed to address the water quality impairment.

The stressor identification (SI) analysis for Holmes Run and Tripps Run follows the steps outlined in the EPA's guidance document, *Stressor Identification Guidance Document* (EPA, 2000). The first step is to list candidate stressors. The stressors which were considered for Holmes Run and Tripps Run are listed below:

Temperature	Metals
pH	Toxics
Dissolved Oxygen	Nutrients
Total Dissolved Solids	Sediment
Specific Conductivity	Riparian Buffers and Other Habitat Modifications
Chlorides	Hydromodification

The second step is to analyze existing monitoring data to determine the evidence for each candidate cause. The existing monitoring data has been reviewed in **Section 3**. The third step is to use a weight-of-evidence approach to determine the strength of the causal link between the candidate stressor and the biological impairment.

The result of the SI is a classification of candidate stressors into one of the following three categories:

1. **Non-Stressors**: Stressors with data indicating normal conditions, without water quality exceedances, or without any observable impacts usually associated with stressors.
2. **Possible Stressors**: Stressors with evidence indicating possible link to the biological impairment, but the evidence is inconclusive.
3. **Most Probable Stressors**: Stressor(s) with the most consistent evidence linking them to the biological impairment.

Each category of stressor will be discussed in the sections below.

Both Holmes Run and Tripps Run suffer from what has been called "the urban stream syndrome," (Meyer et al., 2005; Walsh et al., 2005) which is characterized by the following symptoms:

- Flashier flows
- Elevated nutrient and/or contaminant concentrations
- Fewer smaller streams and lower stream density
- Altered channel morphology
- Reduction in biological diversity with increases in pollution-tolerant taxa

The goal of the stressor identification analysis is to determine the causes of these symptoms.

4.1 Non-Stressors

An examination of water quality monitoring data shows that all of the candidate stressors that can be directly compared to a Virginia water quality standard protecting aquatic life are meeting that standard. The stressors are included in the non-stressor category are: temperature, pH, DO, and metals. Toxics, whose impact to biota can be determined by laboratory tests, have also been placed in the non-stressor category.

4.1.1 Temperature

Elevated temperatures can cause increased mortality and other stresses in aquatic organisms. Streams in urbanized watersheds like Holmes Run and Tripps Run are particularly vulnerable to temperature-induced stresses. Stormwater sewers transport water with elevated temperatures from contact with hot pavement in the summer and urban streams with poor riparian buffers frequently lack a developed tree canopy to shade them from direct sunlight. As shown in **Section 3.2.2**, however, DEQ performed continuous monitoring of both Holmes Run and Tripps Run and found no violations of the temperature criteria to protect aquatic life. No violations of temperature criteria were observed in any ambient monitoring samples. The maximum observed temperature in Holmes Run was 25°C and the maximum observed temperature in Tripps Run was 24°C, both well below the 32°C maximum criterion. There is, therefore, no evidence that temperature is a stressor in Holmes Run or Tripps Run.

4.1.2 pH

Aquatic organisms have a tolerance range for pH that is reflected in Virginia water quality standards, which set a maximum pH criterion of 9.0 and a minimum criterion of 6.0. As shown in **Figures 3-9** through **3-12** in **Section 3.2.3**, the ranges of pH observed in Holmes Run and Tripps Run are narrower than the criterion: observed pH ranges from 6.7 to 7.6 in Holmes Run and 6.7 to 7.7 in Tripps Run. These ranges include data from both ambient monitoring and continuous monitoring. There is, therefore, no evidence that pH is a stressor in Holmes Run or Tripps Run.

4.1.3 Dissolved Oxygen

Aquatic organisms need a minimum dissolved oxygen concentration to survive. Virginia's water quality standards set a minimum instantaneous concentration of 4 mg/l and a minimum daily average concentration of 5 mg/l to protect aquatic life. As illustrated by **Figures 3-13** through **3-16** in **Section 3.2.4**, dissolved oxygen concentrations are never observed to fall below 6 mg/l in Holmes Run in either ambient monitoring or continuous monitoring. One sample in Tripps Run had a DO concentration of 5.7 mg/l; the next lowest observation was 6.5 mg/l. There is, therefore, no evidence that low DO concentrations are a stressor in Holmes Run or Tripps Run.

4.1.4 Metals

As reported in **Section 3.2.16**, there are no exceedances in samples taken from either Holmes Run or Tripps Run of the maximum criteria for individual metals to protect aquatic life. There is no evidence, therefore, that metals toxicity is a stressor in either Holmes Run or Tripps Run.

4.1.5 Toxics

Section 3.3 discussed the results of whole effluent toxicity (WET) tests performed on water fleas and fathead minnows using water samples from Holmes Run and Tripps Run. No evidence of chemical toxicity was detected by the WET tests.

4.2 Possible Stressors

Virginia's water quality standards do not have numerical criteria for nutrients and sediments in free-flowing streams to assess the aquatic life use. Nutrients and sediment are categorized as possible stressors, because there may be some evidence implicating them in the biological impairments in Holmes Run and Tripps Run; however the weight of evidence suggests they are not the primary causes of the impairments.

4.2.1 Nutrients

In Holmes Run and Tripps Run, the concentrations of some nutrient species are high relative to concentrations found in other Virginia streams.

- The sub-optimal threshold total phosphorus concentration in Virginia's Integrated Report is 0.05 mg/l. About half the observed concentrations in both Holmes Run and Tripps Run are in the sub-optimal range. The ProbMon program calculated that the relative risk of a biological impairment associated with sub-optimal total phosphorus concentrations was 2.5.
- The sub-optimal threshold total nitrogen concentration is set in Virginia's Integrated Report at 2.0 mg/l. Only about 10% of the observed TN concentrations in Holmes Run are in the sub-optimal range, however all but one observed TN concentration in Tripps Run is in the sub-optimal range, primarily because of high nitrate concentrations. About three-quarters of the observed nitrate concentrations in Tripps Run are above the 90th percentile of ProbMon data. The

ProbMon program calculated that the relative risk of a biological impairment associated with sub-optimal TN concentrations was 3.1.

The presence of high nutrient concentrations by themselves does not establish a causal connection between excess nutrients and biological impairments. According to Meyer et al., (2005), reduced nutrient uptake is associated with streams in urban environments. Since both Holmes Run and Tripps Run are characterized by reduced populations of benthic invertebrates, it is likely that nutrient uptake is also reduced in these streams. Therefore, higher nutrient concentrations in Holmes Run and Tripps Run may be a result of reduced nutrient uptake and altered ecosystem function.

Diurnal DO and pH measurements also indicate that excess primary production is not impacting the biological communities in Holmes Run and Tripps Run. Excess primary production usually results in wide diurnal swings in DO concentrations, as algae and plants release oxygen in the daytime during photosynthesis and consume it through respiration in the night. As **Figures 3-14** through **3-16** show, diurnal DO swings are modest at best. No super-saturated DO concentrations were observed by DEQ, and Fairfax County monitoring showed very limited super-saturated concentrations in early spring. Photosynthesis also tends to increase pH; no evidence of significant swings in pH was detected by DEQ's continuous monitoring, shown in **Figures 3-10** through **3-12**.

To summarize, though nutrient concentrations reach high levels in Holmes Run and Tripps Run, there is no corroborating evidence that these high concentrations are impacting the biological community. The high nutrient concentrations observed in Holmes Run and Tripps Run may be not a cause, but a result of the poor state of the aquatic ecosystems in these streams.

4.2.2 Sediment

Two lines of evidence suggest that excess sediment may present a problem in Holmes Run and Tripps Run:

- In the habitat assessments performed by DEQ biologists, Holmes Run and Tripps Run consistently received marginal embeddedness scores and frequently received marginal sedimentation scores.

- CH2MHILL, in their physical assessment of Fairfax County streams, measured over 4,500 linear feet of eroded stream banks in Holmes Run, though none in Tripps Run, probably because most of Tripps Run is channelized.

In contrast, the LRBS scores for Homes Run and Tripps Run are above the -0.5 threshold for optimal conditions, indicating both streams are geomorphically stable. Since DEQ is using the LRBS as a quantitative measure of excessive sedimentation in TMDLs, the LRBS carries greater weight than the habitat scores. Staff from DEQ and the Interstate Commission on the Potomac River Basin (ICPRB) visited several sites in the Holmes Run and Tripps Run watershed in March 2012. One goal of these visits was to try to reconcile the habitat assessments with the LRBS scores. ICPRB staff observed many examples of cobble habitat lying on top of cobble habitat, where embeddedness was not an issue; nevertheless, the cobble habitat had not been colonized by benthic macroinvertebrates (A. Griggs, ICPRB. Personal communication, 2012). These observations support the hypotheses that Holmes Run and Tripps Run have relatively stable beds and that sediment is not a major cause in the biological impairments in Holmes Run and Tripps Run.

4.2.3 Total Dissolved Solids, Specific Conductance, and Chlorides

As shown in **Section 3.2.17**, total dissolved solids (TDS), specific conductance, and chlorides are highly correlated. Chloride, sodium, and calcium—the major ions constituting road salt—are likely major constituents of both TDS and specific conductivity. Elevated concentrations of ions can disrupt the osmotic regulation of aquatic organisms. The primary negative impact on biota of elevated TDS, specific conductance, or chloride occurs in this manner. Since they are highly correlated and have similar impacts, these candidate stressors will be discussed together.

Chloride and other ions occur naturally in waters as a function of mineral composition of soils and bedrock. In urban watersheds, however, road salt is the primary source of chloride (Paul and Meyer, 2001). Given the strength of the correlation between chloride, on the one hand, and TDS and specific conductivity, on the other, as described in **Section 3.2.17**, it is likely that elevated levels of the latter two are also derived from road salt.

Virginia has no water quality criteria for TDS or specific conductance to protect aquatic life. There are acute and chronic criteria for chloride. These criteria are based on EPA recommendations derived from toxicological studies on a wide variety of aquatic organisms (EPA, 1988; Siegel, 2007). As shown in **Section 3.2.7**, no observed concentrations in Holmes Run or Tripps Run violate the acute criterion. The chronic criterion of 230 mg/l applies to a four-day average, so it cannot be compared directly to instantaneous concentrations measured in ambient monitoring data.

TDS concentrations above 350 mg/l are considered suboptimal according to ProbMon classification for Virginia's Integrated Report. According to ProbMon data, the relative risk of a biological impairment is 4.5, which means that a VSCI score below 60 is 4.5 times more likely when TDS concentration is in the suboptimal range. In both Holmes Run and Tripps Run, 12% (2 of 17) samples are in the suboptimal range. It therefore cannot be ruled out that elevated TDS concentrations are contributing to the impairment of the benthic communities in Holmes Run and Tripps Run.

In addition, as discussed in **Sections 3.2.5**, **3.2.6**, and **3.2.7** (for specific conductance, TDS, and chloride, respectively), specific conductance values as well as TDS and chloride concentrations tend to be high compared to 90th percentile of ProbMon data. About half of the observed TDS and specific conductance observations are above the 90th percentile of the ProbMon data, while almost all of the observed chloride concentrations in Holmes Run and Tripps Run are above the 90th percentile of the ProbMon data. Therefore, it cannot be ruled out that TDS, specific conductance, or chloride are stressors to the aquatic life in Holmes Run and Tripps Run. It is also possible that TDS, specific conductance, and chloride have seasonal impacts but there is currently not enough monitoring data to evaluate this.

Even if the elevated chloride concentrations observed in Holmes Run and Tripps Run turn out not to be current causes of biological impairment, it is still a cause for concern. Kaushal et al. (2005) studied the increase in chloride concentrations in urbanized watersheds in the Northeast for the National Academy of Sciences. They found that chloride concentrations in the Northeast can reach 25% of the concentration of sea water, and they warn that if the trends in increasing chloride concentrations continue unabated, many streams in the Northeast would be toxic to aquatic life by the next century.

4.3 Most Probable Stressors

The most probable stressors in Holmes Run and Tripps Run are hydromodification and poor riparian habitat.

4.3.1 Hydromodification

Hydromodification in this context means the wholesale modification, not only of the stream channel, but of the entire drainage network. Hydromodification is most obvious in Tripps Run, where the natural channel has been replaced by a concrete-lined channel over much of its length. Holmes Run, although not lined with concrete, also shows signs of having been artificially straightened (J. Classen, DEQ. Personal communication, 2012), a practice that is common in urban areas. Artificially straightening channels negatively impacts aquatic life by decreasing habitat diversity. Channelization disrupts the alternating pattern of pools and riffles which are critical to habitat in healthy streams.

More importantly, in Holmes Run and Tripps Run, the drainage network of small-order streams that feed into the mainstem of Holmes Run and Tripps Run has almost entirely been replaced by a storm sewer drainage system. This has many detrimental environmental consequences, among which the alteration of flow may be the most widely recognized, but not necessarily the most severe. Meyer and Wallace (2001) and Meyer et al. (2007) document the environmental benefits and services of small headwater streams. One of the most important ecological functions of headwater streams is the processing of organic carbon. Under natural conditions, small-order streams in Virginia are heterotrophic systems. The primary source of carbon or energy is terrestrial plant litter. This litter decomposes through the leaching of dissolved organic carbon compounds, bacterial or fungi colonization, and shredding by macroinvertebrates. Bacteria, fungi, and shredder macroinvertebrates, in turn, support higher-order secondary consumers and higher levels of the food web (Allan, 1995). The carbon cycle is truncated when smaller-order streams are lost (Meyer et al., 2007). As a consequence, the food web is disrupted, reducing biological diversity (Freeman et al., 2007). In addition, organic matter retention is lower in urbanized streams, resulting in a reduction in the biological uptake of nutrients (Meyer et al., 2005), previously mentioned in **Section 4.2**. Storm sewer systems may, in some cases, effectively convey leaf litter to urban streams, but the breakdown of litter occurs by flow abrasion, not by biologically-based processes (Walsh et al., 2005).

Drift is another important process in aquatic ecosystems, which is disrupted by the replacement of headwater streams with storm sewers. Benthic macroinvertebrates and other aquatic organisms have a tendency to drift downstream. This process provides both a source of food to predators and a source of colonists to restock populations depleted by disturbances (Meyer et al., 2007).

It is within this context that the flow alterations typical of urbanized watersheds should be understood. As is well-known, the increase in impervious area and the conveyance of the associated overland flow by storm sewers increases both the peak flow during storm events and the frequency at which storm flows occur capable of scouring periphyton assemblages or dislocating benthic invertebrates. The extent of impervious area and the consequent reduction in groundwater recharge can also result in unusually low baseflows, a condition observed in Holmes Run and Tripps Run (J. Classen, DEQ. Personal communication, 2012). The lack of colonists in drift from headwater streams makes it more difficult for the biological community to recover from flow-related disturbances. Therefore, not only are disturbances more frequent, but the recovery time is probably longer, because of the lack of colonists from headwater streams. This is the most likely cause of the fact that benthic macroinvertebrate populations of Holmes Run and Tripps Run are low.

4.3.2 Riparian Habitat

Just as the storm sewer system in effect cuts Holmes Run and Tripps Run off from the ecological benefits and services of headwaters, the poor riparian habitat cuts Holmes Run and Tripps Run off from the benefits and services of the landscape. According to CH2MHill (2005 reported in Versar, 2007), 93,950 linear feet of Holmes Run and 37,850 linear feet of Tripps Run were affected by inadequate riparian buffers. Riparian vegetation scores from DEQ's habitat assessment on Holmes Run at 1AHOR05.48 are either marginal or poor.

Forested riparian buffers have two environmental benefits that are connected with biological impairments in Holmes Run and Tripps Run. They contribute the leaf litter which is the primary source of energy for aquatic ecosystems in small Piedmont streams like Holmes Run or Tripps Run. They also provide large woody debris (LWD), which is a key component of habitat diversity in undisturbed streams. LWD can help form pools, dissipate stream energy, and trap sediment and detritus (Center for Watershed Protection, 2003).

Riparian buffers have other environmental benefits, which may not directly address the biological impairments in Holmes Run and Tripps Run. Forest buffers provide shade which moderates temperature in streams. Riparian buffers also reduce overland flow and sediment transport. Vegetative buffers can remove nutrients from groundwater discharging to streams.

4.3.3 Causal Model of Most Probable Stressors

Hydromodification and poor riparian habitat have been identified as the most probable stressors of the biological communities in Holmes Run and Tripps Run. Hydromodification in this context refers to channelization and the replacement of natural headwater streams and tributaries by storm sewers. Hydromodification and poor riparian habitat are the products of urbanization of these watersheds. Channelization leads to a reduction of pool and riffle structure and of the diversity of stream habitat. Poor riparian buffers lead to a shortage of large woody debris and a reduction of the diversity of habitat. The reduction in habitat diversity contributes to a reduction of diversity in macroinvertebrate taxa.

The reduction of diversity in taxa is also caused by the lack of environmental benefits and services from headwater streams and small tributaries, including a truncation of the processing of terrestrial plant litter, to which poor riparian habitat also contributes. The degraded supply of energy sources cannot support macroinvertebrates.

Increasing peak flows and frequency of flow disturbances, which are the most noticeable results of hydromodification, reduce the overall number of macroinvertebrates. This problem is exacerbated by the lack of macroinvertebrate colonists drifting downstream from headwaters and tributaries.

These results are summarized in **Figure 4-1**. Hydromodification and poor riparian habitat are jointly sufficient to account for the biological impairments in Holmes Run and Tripps Run, though some of the possible stressors discussed in the previous section—nutrients, sediment, and chloride—may also be making a contribution to the impairment of the benthic communities in Holmes Run and Tripps Run. The disturbance of the biological community by alteration of flow is only one element among the impacts of hydromodification. Regulating flow by itself cannot make up for the loss of upstream environmental benefits and services caused by replacing the small-order steams in these watersheds with storm sewers.

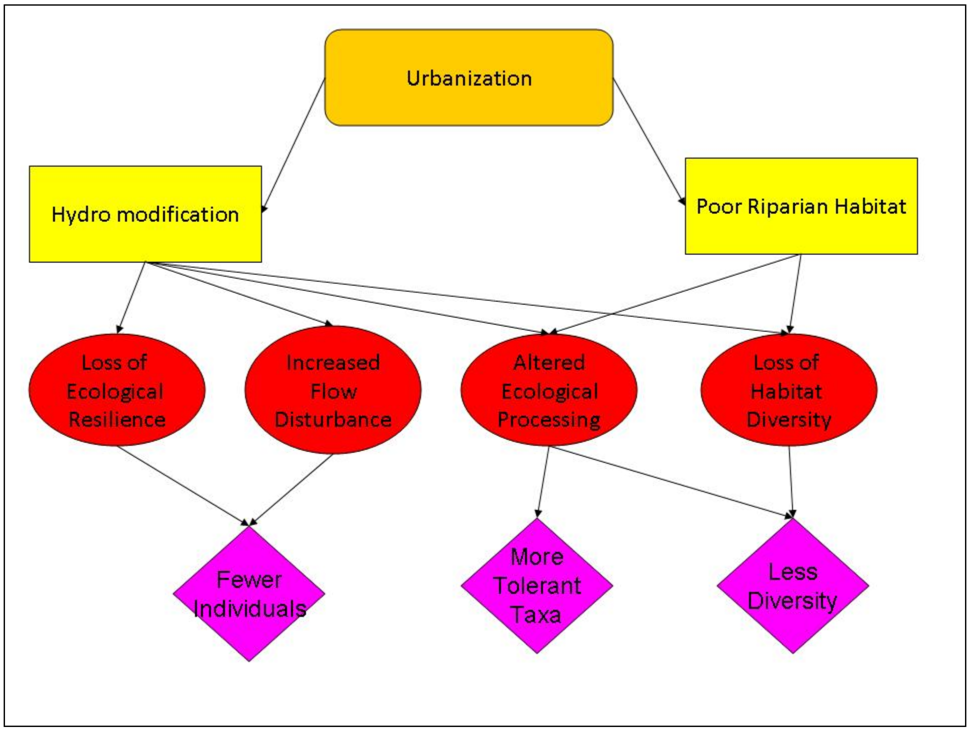

Figure 4-1: Causal Model of Biological Impairments in Holmes Run and Tripps Run

5 Conclusion

The stressor identification analysis for Holmes Run and Tripps Run examined twelve potential stressors to determine the strength of the evidence linking them to the biological impairments in these streams. Based on an evaluation of the monitoring data and the scientific literature, the potential stressors were divided into three categories: (1) non-stressors; (2) possible stressors; and (3) most-probable stressors. The results are shown in **Table 5-1**.

Table 5-1: Categorization of Potential Stressors in Holmes Run and Tripps Run

Category	Stressor	
Non-Stressors	Temperature	pH
	Dissolved Oxygen	Toxics
	Metals	
Possible Stressors	Nutrients	Sediment
	Total Dissolved Solids	Specific Conductance
	Chloride	
Most Probable Stressors	Hydromodification	Poor Riparian Habitat

For temperature, dissolved oxygen, pH, and metals, the monitoring data showed no violations of Virginia's water quality standards protecting aquatic life. WET tests on water fleas and fathead minnows did not indicate that toxics were a stressor in either Holmes Run or Tripps Run.

While there is some evidence that nutrients or sediment may be biological stressors in Holmes Run or Tripps Run, the weight of evidence indicates that neither nutrients nor sediment are the most probable stressors. According to LRBS Index, Holmes Run and Tripps Run have relatively stable stream beds. Nutrient concentrations in Holmes Run and Tripps Run are high, relative to other streams in Virginia, but these high concentrations may be the result, not the cause, of the impaired biological communities in these streams. Similarly, while chloride concentrations and concentrations of TDS and specific conductance, which are associated with chlorides, are high relative to other streams in Virginia, there are no violations of the chronic chloride criterion for support of aquatic life. Therefore, chlorides, TDS, and specific conductance were not identified among the most probable stressors.

The most probable stressors are hydromodification and poor riparian habitat. Hydromodification, including the straightening of the main channel, as well as the wholesale replacement of headwater and small-order streams by storm sewers, is the dominant stressor in both Holmes Run and Tripps Run. The loss of small-order streams leads to the disruption of the food web on the main channel. By removing the upstream source of colonists from the mainstem, the loss of small-order streams reduces the resilience of the mainstem biological community and its ability to respond to disturbances, such as the flow-related disturbances commonly associated with urbanized watersheds. The extent of poor condition of the riparian habitat in Holmes Run and Tripps Run has been documented in Fairfax County's physical assessment of their streams (CH2MHill, 2005). Poor riparian habitat contributes to a disruption of the food web by reducing the input of plant litter, the major source of energy to the aquatic community. Poor riparian habitat also reduces the input of large woody debris, a key component of habitat diversity in streams.

Although ten common pollutants were evaluated in the stressor identification analysis, not any of the pollutants have been identified as the most probable stressors. Hydromodification and poor riparian buffers have been identified as the most probable stressors; they are forms of pollution, but not pollutants. Therefore, according to the CWA and EPA guidance (2005), TMDLs are not the appropriate method for addressing the benthic impairments in these streams.

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