Benthic TMDL Development for the Beaverdam Creek, Fryingpan Creek, Pigg River, and Poplar Branch Watersheds
Located in Bedford, Franklin, and Pittsylvania Counties

Prepared by:

Wetland Studies and Solutions, Inc.
and
James Madison University

Prepared for:

Virginia Department of Environmental Quality
July 2022

Acknowledgements

Project Personnel

Wetland Studies and Solutions, Inc.

Katie Shoemaker, PE, CFM, Environmental Engineer
Thomas Schubert, EIT, Environmental Engineer
Jeremy Bradley, GISP, CFM, GIS Specialist

James Madison University

Dr. Robert Brent, Associate Professor

Virginia Department of Environmental Quality (VADEQ)

Lucy Smith

Technical Advisory Committee

Gabriel Irigaray, Eddie Wells – Roanoke Valley Alleghany Regional Commission
Kevin Dawson, Leslie Mace, Mark Winebemel – Virginia Department of Forestry
Paul Chapman, Cynthia Martel, Ben Newbill, Ronald Wilson – Franklin County
Allen Jackson, Michael Tabor – Blue Ridge SWCD
Terri Bollinger, Tracy Culbertson – Peaks of Otter SWCD
Amber Eanes, Jessy Lacks – Pittsylvania SWCD
Tony Capuco, Charlie Hamilton, Deborah Oliver, Dave Waterman – Leesville Lake Association
Liz Parcell – Appalachian Electric Power
Bill Tanger – Friends of Rivers of Virginia

For additional information, please contact:

Virginia Department of Environmental Quality

Blue Ridge Regional Office, Salem: Lucy Smith, (540) 988-6152

Table of Contents

Figures

Figures in Appendices

Tables

<u>Tables in Appendices</u>

Acronyms

AllForX	All-Forest Load Multiplier
CADDIS	Causal Analysis Diagnosis Decision Information System
CBP	Chesapeake Bay Program
CREP	Conservation Reserve Enhancement Program
CV	Coefficient of Variation
EQIP	Environmental Quality Incentive Program
GWLF	Generalized Watershed Loading Function
HSG	Hydrologic Soil Group
JMU	James Madison University
LA	Load Allocation
LTA	Long-Term Average
MDL	Maximum Daily Load
MOS	Margin of Safety
NPDES	National Pollutant Discharge Elimination System
NPS	Nonpoint Source
NRCS	Natural Resource Conservation Service
POC	Pollutant(s) of Concern
SCS-CN	Soil Conservation Service Curve Number
SSURGO	Soil Survey Geographic database
SWCB	State Water Control Board
SWCD	Soil and Water Conservation District
TAC	Technical Advisory Committee
TMDL	Total Maximum Daily Load
TSS	Total Suspended Sediment
USEPA	United States Environmental Protection Agency
USLE	Universal Soil Loss Equation
VADCR	Virginia Department of Conservation and Recreation
VADEQ	Virginia Department of Environmental Quality
VGIN	Virginia Geographic Information Network
VLCD	Virginia Land Cover Dataset
VPDES	Virginia Pollutant Discharge Elimination System
VSCI	Virginia Stream Condition Index
VSMP	Virginia Stormwater Management Program
WLA	Wasteload Allocation
WQMIRA	Water Quality Monitoring, Information and Restoration Act

1.0 EXECUTIVE SUMMARY

1.1. Background

The Beaverdam Creek, Fryingpan Creek, Pigg River, and Poplar Branch watersheds are in Bedford, Pittsylvania, and Franklin Counties, Virginia. Beaverdam Creek is situated in Bedford County and drains the area east of the City of Roanoke, including the town of Stewartsville. Beaverdam Creek flows into upper Smith Mountain Lake (Roanoke River), and is largely a mosaic of cropland, forest, and pasture. Fryingpan Creek is situated in Pittsylvania County and flows northwest into the Pigg River, just before it joins Leesville Lake. The study portion of Fryingpan Creek runs from its headwaters for 2.5 miles, ending roughly a mile after it crosses under route 40. Fryingpan Creek's watershed consists mostly of cropland, forest, and pasture. The study portion of the Pigg River lies in Franklin County, and its watershed consists primarily of cropland, pasture and forested land. The impaired reach extends from the junction of the Pigg River and Turners Creek upstream 2.95 miles. Poplar Branch is situated in Franklin County, running from its confluence with Snow Creek upstream 2.56 miles. Poplar Branch's watershed, like the other study watersheds, consists of primarily of cropland, pasture, and forested land. All study reaches are either direct or indirect tributaries to the Roanoke River, (also referred to as the Staunton River in some areas), which flows southeast through North Carolina and into the Albemarle Sound and the Atlantic Ocean.

Definition:

Watershed – All of the land area that drains to a particular point or body of water.

Beaverdam Creek, Fryingpan Creek, Pigg River, and Poplar Branch are listed as impaired on Virginia's 2020 Section 305(b)/303(d) Water Quality Assessment Integrated Report due to water quality violations of the general aquatic life (benthic) standard. The impaired segments addressed in this document are shown in **Table 1-1**. The watersheds of the impaired streams are show in **Figure 1-1**.

Table 1-1. Impaired segments addressed in this TMDL study.

TMDL Watershed	305(b) Segment ID	Cause Group Code 303(d) Impairment ID	Listing Station	Year Initially Listed
Beaverdam Creek	VAW-L07R_BDA01A00 (4.98 miles) VAW-L07R_BDA02A00 (5.35 miles)	L07R-01-BEN	4ABDA006.72	2010
Fryingpan Creek	VAW-L18R_FRY01A06 (2.56 miles)	L18R-01-BEN	4AFRY006.08	2006
Pigg River	VAW-L14R_PGG05B12 (1.48 miles) VAW-L14R_PGG06A02 (1.01 miles) VAW-L14R_PGG06B12 (1.94 miles)	L14R-01-BEN	4APGG076.93 4APGG077.15	2012
Poplar Branch	VAW-L17R_PAA01A04 (2.56 miles)	L17-01-BEN	4APAA000.24 4APAA000.71	2008

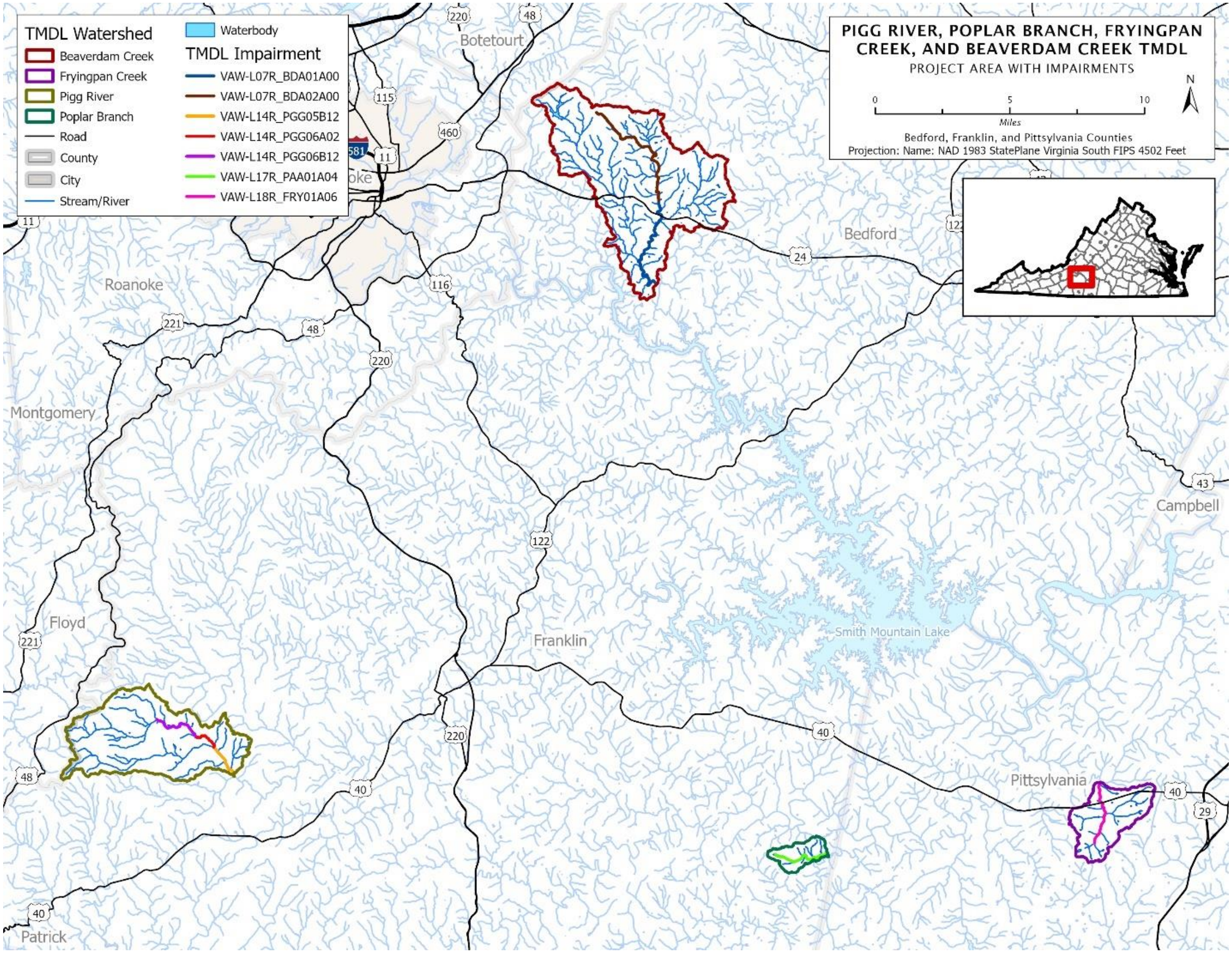

Figure 1-1. Location of the Beaverdam Creek, Fryingpan Creek, Pigg River, and Poplar Branch watersheds and impairments.

1.2. The Problem

1.2.1. Impaired Aquatic Life

The Commonwealth of Virginia sets standards for all the waters in the state. One of those standards is the expectation that every stream will support a healthy and diverse community of bugs and fish (the aquatic life standard). The Virginia Department of Environmental Quality (VADEQ) determines whether this standard is met by measuring the diversity and pollution sensitivity of benthic macroinvertebrates (bugs that live on the bottom of the stream). The health and diversity of these bugs are assessed using the Virginia Stream Condition Index (VSCI), which is measured on a scale from 0 to 100, with scores greater than 60 being acceptable. **Figure 1-2** shows the various monitoring stations throughout the watershed, color-coded by the average score at each site. Red and yellow icons indicate that the streams do not support a healthy and diverse community of bugs and fish. This shows that the various impaired streams in this study fail the aquatic life standard, and pollutants within the watershed need to be identified and reduced.

A benthic stressor analysis study was conducted in 2021 to determine the reason for the benthic impairments in the Beaverdam Creek, Fryingpan Creek, Pigg River, and Poplar Branch watersheds (**Appendix D**). The study found that the main cause of all impairments was too much sediment.

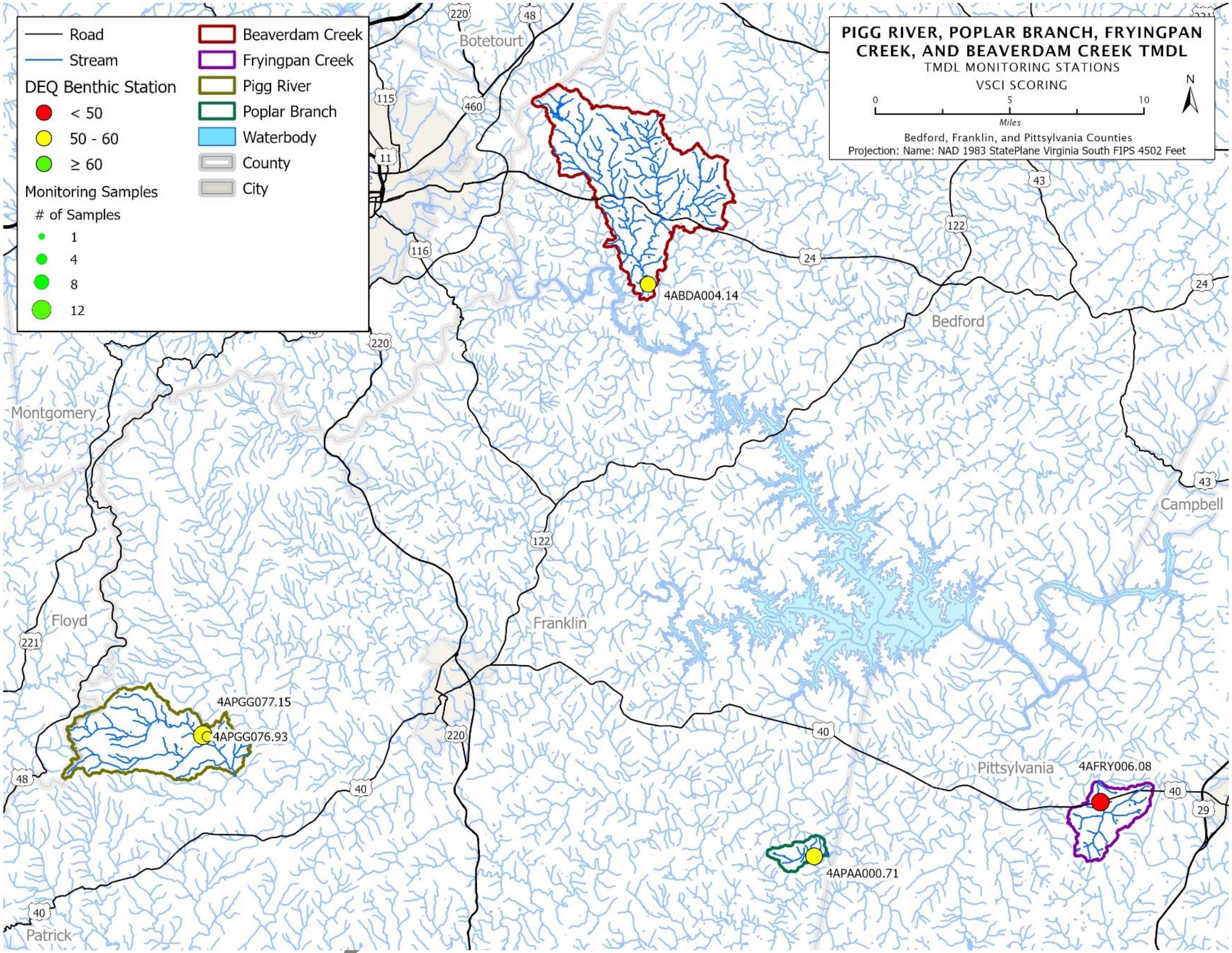

Figure 1-2. Stream health score summaries in the Beaverdam Creek, Fryingpan Creek, Pigg River, and Poplar Branch Watersheds.

1.2.2. Excess Sediment

Excess sediment was identified as the primary stressor in all TMDL watersheds. When it rains, sediment is washed off the land surface into nearby creeks and rivers. The amount of soil that is washed off depends upon how much it rains and the type of land that the rain falls on. Some land types, like a freshly plowed farm field or a construction site, can yield large amounts of sediment when it rains, while other land types, like forests and well-maintained pasture, yield only a small amount. When that soil gets into nearby streams, it falls to the bottom as sediment and can smother certain aquatic insects that live on the bottom of the stream, limiting the diversity of aquatic life.

1.3. The Study

To study the problem of excess sediment in the Beaverdam Creek, Fryingpan Creek, Pigg River, and Poplar Branch watersheds, a combination of monitoring and computer modeling was utilized. Monitoring was used to determine how much sediment is in the streams at any given time and how aquatic life conditions have changed over time. The computer model was used to estimate where the sediment is coming from and make predictions about how stream conditions would change if those sources were reduced.

Frequently Asked Question:

Why use a computer model?
Sampling and testing tell you a lot about the present and the past, but nothing about the future. A computer model is a tool that can help you make predictions about the future. This is necessary to figure out how much effort is needed to clean up a stream.

For this purpose, a computer model, the Generalized Watershed Loading Function model (or GWLF), was used. GWLF considers the slope, soils type, land cover, soil erodibility, and runoff to estimate the amount of soil eroded from the watershed and deposited in the stream. The model was calibrated against real-world flow measurements taken from the stream to ensure that it was producing accurate results. The tested model was then used to estimate the sediment reductions that would be needed to restore a healthy condition for aquatic life in the impaired streams.

Definition:

<u>TMDL</u> – Total Maximum Daily Load. This is the amount of a pollutant that a stream can receive and still meet water quality standards. The term TMDL is also used more generally to describe the state's formal process for cleaning up polluted streams.

This report summarizes the study and sets goals for a clean-up plan. The study is called a Total Maximum Daily Load (TMDL) because it determines the maximum daily amount of sediment that can get into a certain stream without harming the stream or the creatures living in it.

1.4. Current Conditions

For this report, the Virginia Geographic Information Network (VGIN) 2016 Virginia Land Cover Dataset (VLCD) was used to represent the current land use (**Section 3.4**). The land cover distribution for each impaired watershed is shown in **Figure 1-3** to **Figure 1-6.** Most of the land cover in all study watersheds is forest, ranging from 57 to 76%, followed by pasture, ranging from 15 to 26%. Except for Beaverdam creek, cropland is the third most common land cover type, ranging from 5 to 7%. None of the watersheds are significantly developed.

Definition:

<u>Point Source</u> – pollution that comes out of a pipe (like at a sewage treatment plant).
<u>Nonpoint Source</u> – pollution that does not come out of a pipe but comes generally from the landscape (usually as runoff).

This land cover dataset combined with an accounting of the permitted discharges represent the major pollutant sources in the watershed. The GWLF model was used to figure out the relative contribution of sources of sediment in the impaired watersheds. **Figure 1-3** through **Figure 1-6** show the distribution of sediment contributions from various sources in the watersheds. The permitted sources include one Virginia Pollutant Discharge Elimination System (VPDES) individual permit and two domestic sewage permits, all in Beaverdam Creek. The sediment loads from permitted sources were calculated based on the permit language, reported discharge data, and land cover type and area (detailed in **Section 4.3.2**). In all TMDL watersheds, pasture or cropland were the primary sources of sediment.

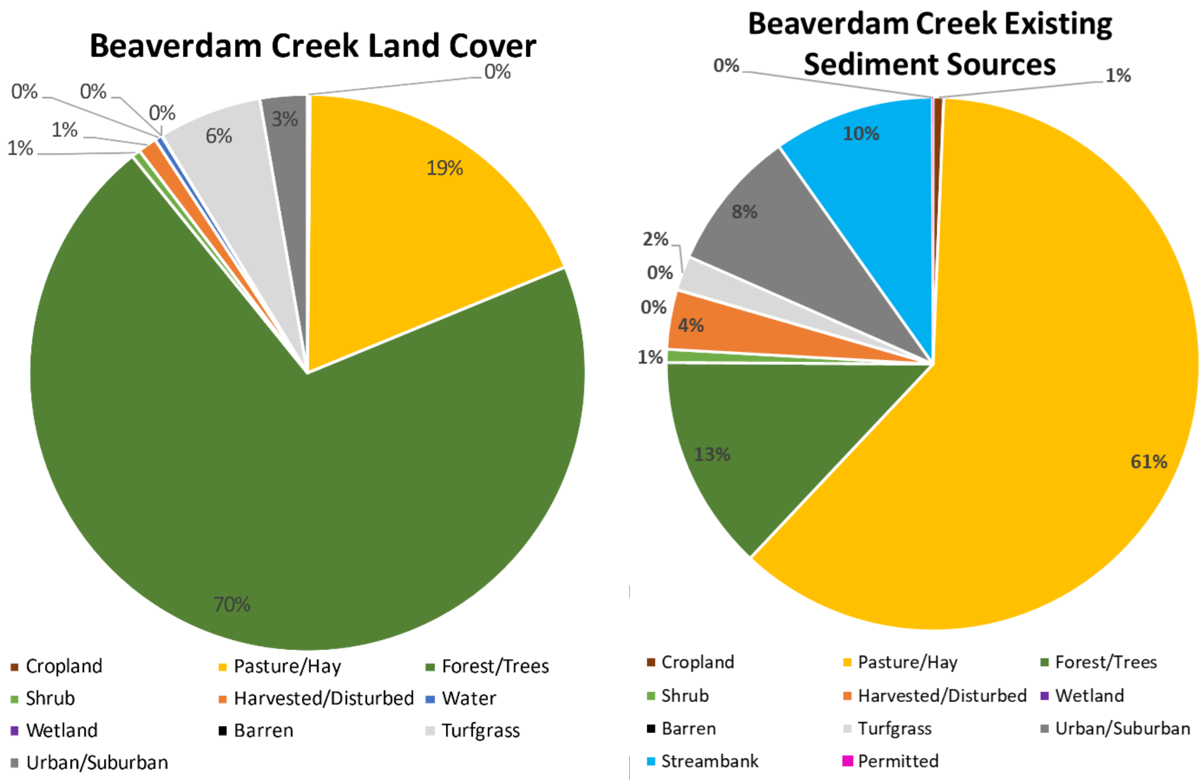

Figure 1-3. Land cover and existing source load distributions in the Beaverdam Creek watershed.

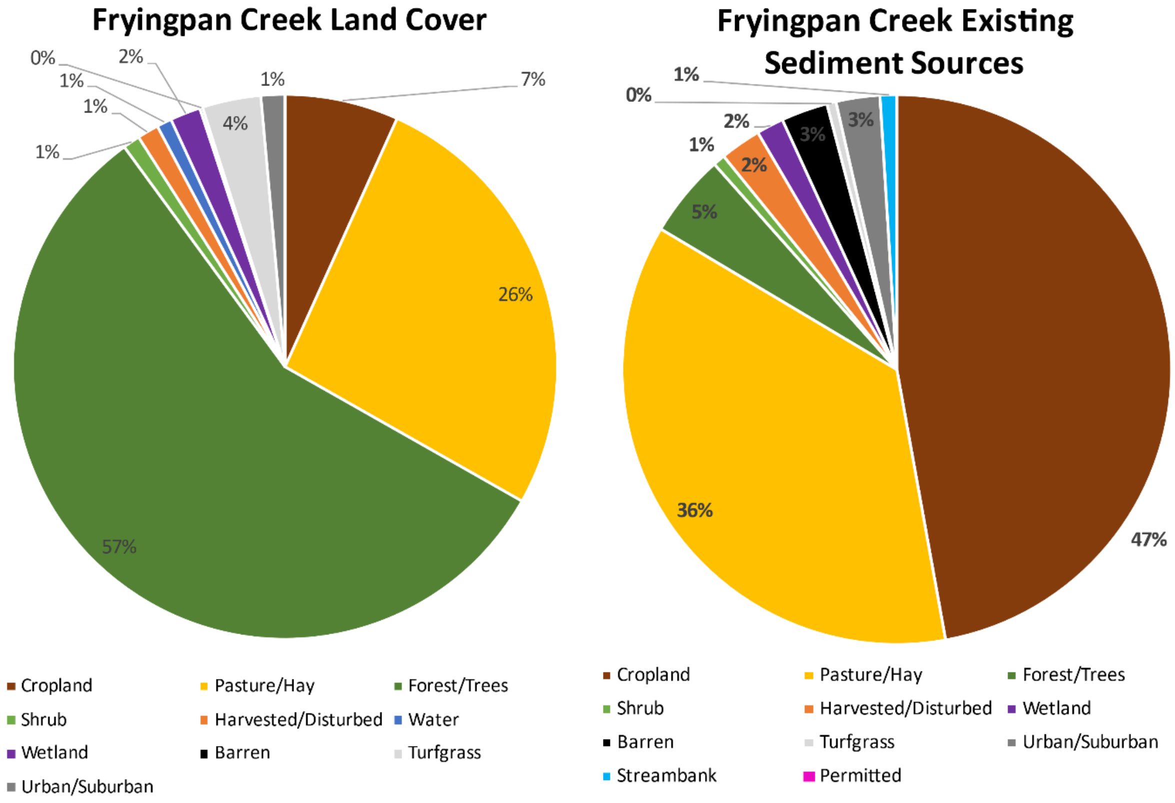

Figure 1-4. Land cover and existing source load distributions in the Fryingpan Creek watershed.

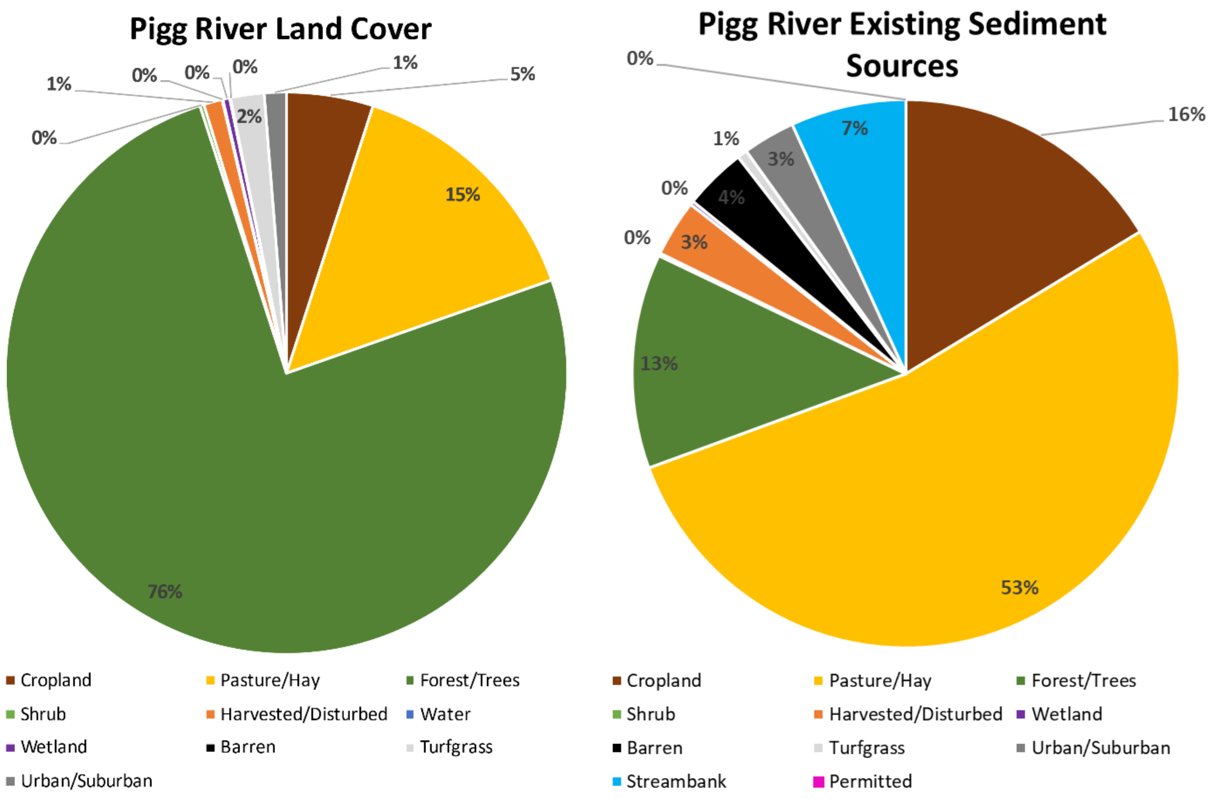

Figure 1-5. Land cover and existing source load distribution in the Pigg River watershed.

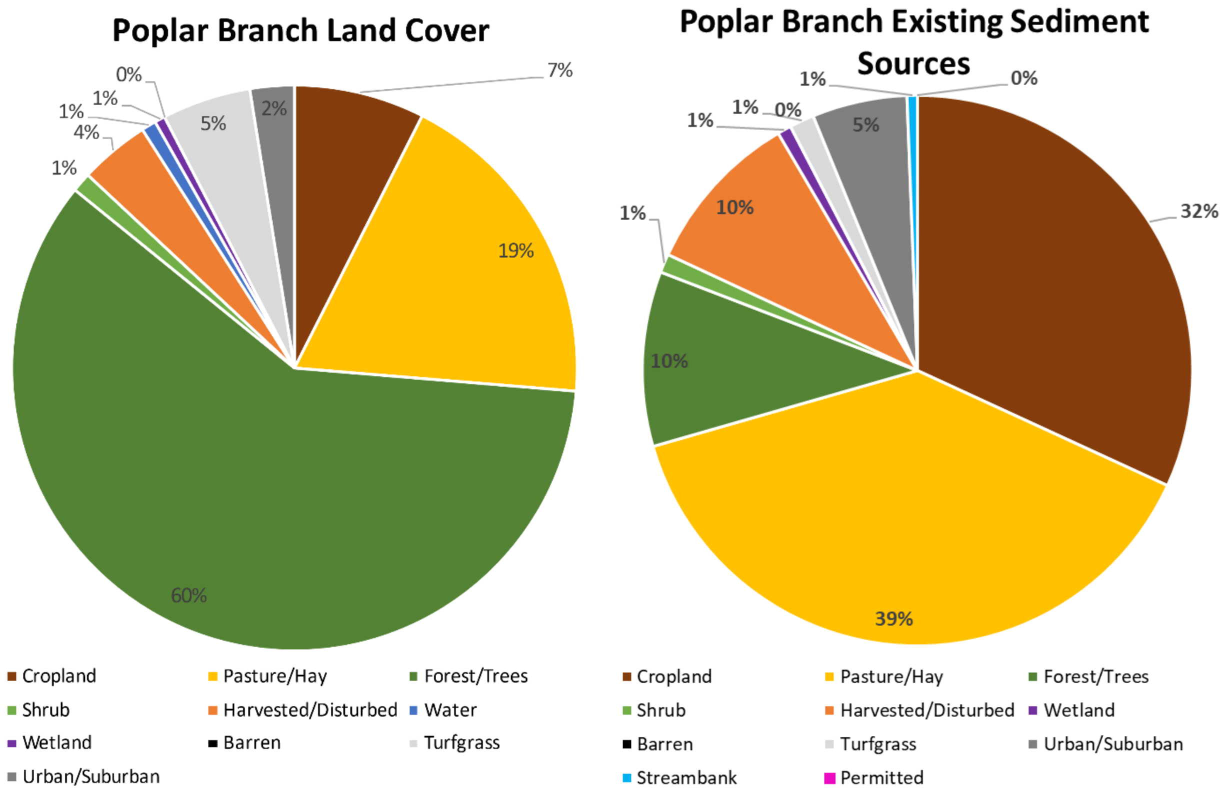

Figure 1-6. Land cover and existing source load distribution in the Poplar Branch watershed.

1.5. Future Goals (the TMDL)

After determining the source of sediment in the impaired stream, a computer model was used to determine the amount that sediment loads need to be reduced to promote healthy aquatic life in each stream. The goal for these reductions is for the impaired streams to have sediment levels that allow for diverse and abundant aquatic life. The reductions in sediment needed to meet these goals are shown in **Table 1-2**.

Table 1-2. Percent reductions in sediment needed to clean up the impaired waters.

Watershed	Crop, Pasture, Hay (%)	Forest, Trees, Shrubs, Wetland (%)	Developed Pervious and Impervious Areas, Barren, Turfgrass (%)	Streambank Erosion (%)	Permitted Sources (%)
Beaverdam Creek	30.4	0	30.4	30.4	0
Fryingpan Creek	76.1	0	76.1	76.1	0
Pigg River	31.5	0	31.5	31.5	0
Poplar Branch	56.1	0	56.1	56.1	0

To obtain healthy sediment levels in the impaired streams, significant reductions are needed from several sediment sources. Sediment loads from agricultural and urban/suburban land covers within Beaverdam Creek, Fryingpan Creek, Pigg River, and Poplar Branch need to be reduced by 30.4%, 76.1%, 31.5%, and 56.1%, respectively. The total amount of sediment per year that would be entering each of these streams after the recommended reductions are made represent the total maximum daily load of sediment for each stream (**Table 1-3** through **Table 1-6)**. This load includes permitted sources as well as future growth to account for potential future permitted sources. These annual loads are converted to daily maximum loads as well, as described in **Section 6.3**Error! Reference source not found. (**Table 1-7** and **Table 1-10**). If sediment loads are reduced to these amounts, healthy aquatic life is expected to be restored in these streams.

Table 1-3. Annual sediment loads that will meet the water quality standard in Beaverdam Creek.

Impairment	Allocated Permitted Point Sources (WLA) (lb/yr)	Allocated Nonpoint Sources (LA) (lb/yr)	Margin of Safety (MOS) (lb/yr)	Total Maximum Daily Load (TMDL) (lb/yr)	Existing Load (lb/yr)	Overall Reduction (%)
Beaverdam Creek (VAW-L07R_BDA01A00, VAW-L07R_BDA02A00)	**51,410**	**2,216,000**	**252,000**	**2,520,000**	3,300,000	23.7%
Domestic Sewage Permits	*183*					
VPDES Individual Permit	*822*					
Future Growth (2% of TMDL)	*50,410*					

Table 1-4. Annual loads that will meet the water quality standard in Fryingpan Creek.

Impairment	Allocated Permitted Point Sources (WLA) (lb/yr)	Allocated Nonpoint Sources (LA) (lb/yr)	Margin of Safety (MOS) (lb/yr)	Total Maximum Daily Load (TMDL) (lb/yr)	Existing Load (lb/yr)	Overall Reduction (%)
Fryingpan Creek (VAW-L18R_FRY01A06)	**6,593**	**289,300**	**32,960**	**329,000**	1,020,698	67.8%
Future Growth (2% of TMDL)	*6,593*					

Table 1-5. Annual loads that will meet the water quality standard in the Pigg River.

Impairment	Allocated Permitted Point Sources (WLA) (lb/yr)	Allocated Nonpoint Sources (LA) (lb/yr)	Margin of Safety (MOS) (lb/yr)	Total Maximum Daily Load (TMDL) (lb/yr)	Existing Load (lb/yr)	Overall Reduction (%)
Pigg River (VAW-L14R_PGG05B12, VAW-L14R_PGG06A02, VAW-L14R_PGG06B12)	**39,200**	**1,720,000**	**196,000**	**1,960,000**	2,610,000	24.9%
Future Growth (2% of TMDL)	*39,200*					

Table 1-6. Annual loads that will meet the water quality standard in Poplar Branch.

Impairment	Allocated Permitted Point Sources (WLA) (lb/yr)	Allocated Nonpoint Sources (LA) (lb/yr)	Margin of Safety (MOS) (lb/yr)	Total Maximum Daily Load (TMDL) (lb/yr)	Existing Load (lb/yr)	Overall Reduction (%)
Poplar Branch (VAW-L17R_PAA01A04)	**3,357**	**147,500**	**16,780**	**168,000**	311,000	46.1%
Future Growth (2% of TMDL)	*3,357*					

Table 1-7. Maximum daily sediment loads for Beaverdam Creek.

Impairment	Allocated Permitted Point Sources (WLA) (lb/day)	Allocated Nonpoint Sources (LA) (lb/day)	Margin of Safety (MOS) (lb/day)	Maximum Daily Load (MDL) (lb/day)
Beaverdam Creek (VAW-L07R_BDA01A00, VAW-L07R_BDA02A00)	**141**	**14,300**	**1,600**	**16,000**
Domestic Sewage Permits	*0.25*			
VPDES Individual Permit	*2.25*			
Future Growth (2% of TMDL)	*138*			

Table 1-8. Maximum daily sediment loads for Fryingpan Creek.

Impairment	Allocated Permitted Point Sources (WLA) (lb/day)	Allocated Nonpoint Sources (LA) (lb/day)	Margin of Safety (MOS) (lb/day)	Maximum Daily Load (MDL) (lb/day)
Fryingpan Creek (VAW-L18R_FRY01A06)	**18.1**	**1,910**	**214**	**2,140**
Future Growth	*18.1*			

Table 1-9. Maximum daily sediment loads for the Pigg River.

Impairment	Allocated Permitted Point Sources (WLA) (lb/day)	Allocated Nonpoint Sources (LA) (lb/day)	Margin of Safety (MOS) (lb/day)	Maximum Daily Load (MDL) (lb/day)
Pigg River (VAW-L14R_PGG05B12, VAW-L14R_PGG06A02, VAW-L14R_PGG06B12)	**107**	**11,300**	**1,270**	**12,700**
Future Growth	*107*			

Table 1-10. Maximum daily sediment loads for the Poplar Branch.

Impairment	Allocated Permitted Point Sources (WLA) (lb/day)	Allocated Nonpoint Sources (LA) (lb/day)	Margin of Safety (MOS) (lb/day)	Maximum Daily Load (MDL) (lb/day)
Poplar Branch (VAW-L17R_PAA01A04)	**9.19**	**981**	**110**	**1,100**
Future Growth	*9.19*			

1.6. Public Participation

Throughout this study, VADEQ asked for the help of local residents and knowledgeable stakeholders – those who have a particular interest in or may be affected by the outcome of the project. Public participation keeps stakeholders informed, and it allows for stakeholder input to ensure information in the study is accurate. While the project was progressing, VADEQ held two public meetings and three Technical Advisory Committee (TAC) meetings. The final public meeting was held on 09/27/2022 to present the draft TMDL document and begin the official public comment period.

1.7. Reasonable Assurance

Public participation in the development of the TMDL and implementation plans, follow-up monitoring, permit compliance, and current implementation progress within the watersheds all combine to provide reasonable assurance that these TMDLs will be implemented and water quality will be restored in the impaired watersheds.

1.8. What Happens Next

VADEQ will receive public comment on this report and then submit it to the U.S. Environmental Protection Agency (USEPA) for approval. This report sets the clean-up goals for Beaverdam Creek, Fryingpan Creek, Pigg River, and Poplar Branch, but the next step is a clean-up plan (or Implementation Plan) that lays out how those goals will be reached. Clean-up plans set intermediate goals and describe actions that should be taken to improve water quality in the impaired streams. Some of the potential actions that could be included in an implementation plan for the Pigg River et. al watersheds are listed below:

- Fence out cattle from streams and provide alternative water sources
- Implement conservation tillage practices on cropland
- Conduct stream bank restoration projects in areas where banks are actively eroding
- Leave a band of 35 – 100 ft along the stream natural so that it buffers or filters out sediment from farm or residential land (a riparian buffer)
- Expanded street sweeping programs in urban areas
- Reduce runoff by increasing green spaces and reducing hardened spaces (asphalt or concrete)

Frequently Asked Question:

How will the TMDL be implemented? For point sources, TMDL reductions will be implemented through discharge permits. For nonpoint sources, TMDL reductions will be implemented through best management practices (BMPs). Landowners will be asked to voluntarily participate in state and federal programs that help defer the cost of BMP installation.

These and other actions that could be included in a clean-up plan are identified in the planning process along with associated costs and the extent of each practice needed. The clean-up plan also identifies potential sources of money to help in the clean-up efforts. Most of the money utilized to implement actions in the watersheds to date has been in the form of cost-share programs, which share the cost of improvements with the landowner. Additional funds for urban stormwater practices have been made available through various grants. Please be aware that the state or federal government will not fix the problems with the impaired streams. It is primarily the responsibility of individual landowners and local governments to take the actions necessary to improve these streams. The role of state agencies is to help with developing the plan and find money to support implementation, but actually making the improvements is up to those that live in the watershed. By increasing education and awareness of the problem, and by working together to each do our part, we can make the changes necessary to improve the streams.

VADEQ will continue to sample aquatic life in these streams and monitor the progress of clean-up. This sampling will let us know when the clean-up has reached certain milestones listed in the plan. To begin moving towards these clean-up goals, VADEQ recommends that concerned citizens come together and begin working with local governments, civic groups, soil and water conservation districts, and local health districts to increase education and awareness of the problem and promote those activities and programs that improve stream health.

2.0 INTRODUCTION

2.1. Watershed Location and Description

The Beaverdam Creek watershed is approximately 17,250 acres and lies within Bedford County, Fryingpan Creek watershed is approximately 3,450 acres and lies within Pittsylvania County, the study portion of the Pigg River watershed is approximately 9,975 acres and lies within Franklin County, and Poplar Branch watershed is approximately 1,075 acres and lies within Franklin County (**Figure 1-1**). All watersheds are rural in nature, and don't include any large towns, cities, or other highly developed areas. The study watersheds include VAHU6 watersheds RD17, RD18, RD24, RD34, RD51, RD55, RD57, RU17, RU25, RU29, RU35, RU37, RU40, RU41, RU48, RU59, RU64, and RU72. Beaverdam Creek and the Pigg River are direct tributaries to the Roanoke River, and Fryingpan Creek and Poplar Branch are indirect tributaries to the Roanoke River, which flows southeast through North Carolina and into the Albemarle Sound and the Atlantic Ocean.

2.2. Designated Uses and Applicable Water Quality Standards

Virginia's Water Quality Standards (9VAC25-260) consist of designated uses established for water bodies in the Commonwealth, and water quality criteria set to protect those uses. Virginia's Water Quality Standards protect the public and environmental health of the Commonwealth and serve the purposes of the State Water Control Law (§62.1-44.2 et seq. of the Code of Virginia) and the federal Clean Water Act (33 USC §1251 et seq.).

2.2.1. Designation of Uses (9 VAC 25-260-10)

> "A. All state waters, including wetlands, are designated for the following uses: recreational uses, e.g., swimming and boating; the propagation and growth of a balanced, indigenous population of aquatic life, including game fish, which might reasonably be expected to inhabit them; wildlife; and the production of edible and marketable natural resources, e.g., fish and shellfish" (SWCB, 2011).

Beaverdam Creek, Fryingpan Creek, Pigg River, and Poplar Branch currently do not support the aquatic life designated use based on biological monitoring of the benthic macroinvertebrate community.

2.2.2. General Standard (9VAC 25-260-20)

The following general standard protects the aquatic life use:

> "A. State waters, including wetlands, 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.
>
> Specific substances to be controlled include, but are not limited to: floating debris, oil scum, and other floating materials; toxic substances (including those which bioaccumulate); substances that produce color, tastes, turbidity, odors, or settle to form sludge deposits; and substances which nourish undesirable or nuisance aquatic plant life. Effluents which tend to raise the temperature of the receiving water will also be controlled" (SWCB, 2011).

VADEQ's biological monitoring program is used to evaluate compliance with the above standard. This program monitors the assemblage of benthic (bottom-dwelling) macro (large enough to see) invertebrates (insects, mollusks, crustaceans, and annelid worms) in streams to determine the biological health of the stream. Benthic macroinvertebrates are sensitive to water quality conditions, important links in aquatic food chains, major contributors to energy and nutrient cycling in aquatic habitats, relatively immobile, and easy to collect. These characteristics make them excellent indicators of aquatic health. Changes in water quality are reflected in changes in the structure and diversity of the benthic macroinvertebrate community. Currently, VADEQ assesses the health of the benthic macroinvertebrate community using the Virginia Stream Condition Index (VSCI). This index was first developed by Tetra Tech (2003) and later validated by VADEQ (2006). The VSCI is a multimetric index based on 8 biomonitoring metrics. The index provides a score from 0-100, and scores from individual streams are compared to a statistically derived cutoff value based on the scores of regional reference sites.

2.3. 305(b)/303(d) Water Quality Assessment

Under Section 305(b) of the Federal Clean Water Act, states are required to assess the quality of their water bodies in comparison to the applicable water quality standards. States are also required, under Section 303(d) of the Act, to prepare a list of water bodies that do not meet one or more water quality standards. This list is often called the "Impaired Waters List", or the "303(d) List", or the "TMDL List", or even the "Dirty Waters List". The Commonwealth of Virginia accomplishes both of these requirements through the publishing of an Integrated 305(b)/303(d) Water Quality Assessment Report every two years. Each report assesses water quality by evaluating monitoring data from a six-year window. The assessment window for the most recent 2020 305(b)/303(d) Integrated Water Quality Assessment Report was from January 1, 2013 through December 31, 2018. According to VADEQ's current Water Quality Assessment Guidance (VADEQ, 2014), streams with a calculated VSCI score ≥60 are assessed as "fully supporting" the aquatic life designated use. Streams with VSCI scores <60 are assessed as "impaired" or "not supporting" the aquatic life designated use.

2.3.1. Impairment Listings

According to Virginia's 2020 305(b)/303(d) Integrated Report (VADEQ, 2020), portions of Beaverdam Creek, Fryingpan Creek, the Pigg River, and Poplar Branch are considered impaired (**Table 1-1**, **Figure 1-1**). Data collected to evaluate streams in the watersheds are collected by VADEQ and other government officials. All study streams are considered impaired for failure to support aquatic life use (i.e., a benthic impairment). During the 2020 assessment window (January 1, 2013 to December 31, 2018) the median VSCI score was 54.61 in Beaverdam Creek, 53.59 in Fryingpan Creek, 55.98 in the Pigg River, and 52.95 in Poplar Branch; this indicates impairment of the benthic macroinvertebrate community. A summary of each stream's listing is presented below.

> Beaverdam Creek is impaired from its headwaters to its confluence with the Roanoke River (roughly 10.3 miles) and was initially listed on Virginia's 303(d) Report in 2010 based on data collected in 2008. Beaverdam Creek was placed on this list based on data collected at VADEQ monitoring station 4ABDA006.72.
>
> Fryingpan Creek is impaired from its headwaters downstream roughly 2.5 miles and was first listed on Virginia's 303(d) Report in 2006 for an aquatic life use impairment based on biomonitoring in 2003 for DEQ's probabilistic monitoring program. Fryingpan Creek was listed due to low VSCI scores at station 4AFRY006.08.
>
> The Pigg River is impaired from a point near Five Mile Mountain Road (Rt. 748) to its confluence with Turners Creek (roughly 4.4 miles in total) and was initially listed on Virginia's 303(d) Integrated Report in 2012 for an aquatic life use impairment based on data collected for the probabilistic program in 2009. The Pigg River was listed due to low VSCI scores at stations 4APGG076.93 and 4APGG077.15.
>
> Poplar Branch is impaired from its headwaters to its confluence with Snow Creek (roughly 2.5 miles) and was initially listed on Virginia's 303(d) Report in 2008 based on data collected in 2001. Poplar Branch was listed due to low VSCI scores at stations 4APAA000.24 and 4APAA000.71.

2.4. TMDL Development

Section 303(d) of the Federal Clean Water Act and the U.S. Environmental Protection Agency's (USEPA) Water Quality Planning and Management Regulations (40 CFR Part 130) require states to develop Total Maximum Daily Loads (TMDLs) for water bodies that fail to meet designated water quality standards and are placed on the state's Impaired Waters List. A TMDL reflects the total pollutant loading that a water body can receive and still meet water quality standards. A TMDL establishes the maximum allowable pollutant loading from both point and nonpoint sources for a water body, allocates the load among the pollutant contributors, and provides a framework for taking actions to restore water quality.

2.4.1. Pollutants of Concern

TMDL target pollutants, or pollutants of concern (POC), are the physical or chemical substances that will be controlled and allocated in the TMDL to result in restored aquatic life (measured by benthic macroinvertebrate health). POCs must be pollutants that are controllable through source reductions, such as sediment, phosphorus, nitrogen, or other substances. Physical factors or environmental conditions, such as flow regimes, hydrologic modifications, or physical structures (like dams) cannot be TMDL POCs. Even though these conditions influence ecological communities and may be sources of stress, they do not represent substances that originate from point and nonpoint sources, they cannot be quantified, summed, and allocated to respective sources, and they cannot be controlled through source reductions.

In 2021, a benthic stressor identification analysis study was conducted to determine the POC(s) contributing to the benthic impairments in the study watersheds. This study is included in **Appendix D**. The stressor analysis study used a formal causal analysis approach developed by USEPA, known as CADDIS (Causal Analysis Diagnosis Decision Information System). The CADDIS approach evaluates 14 lines of evidence that support or refute each candidate stressor as the cause of impairment. In each stream, each candidate stressor was scored from -3 to +3 based on each line of evidence. Total scores across all lines of evidence were then summed to produce a stressor score that reflects the likelihood of that stressor being responsible for the impairment. The study found that sediment (measured as total suspended solids or TSS) was a probable stressor in all the impaired study watersheds. For Poplar Branch impairment, the stressor identification analysis also identified hydrologic modification (via small farm ponds) as a probable stressor, however it is infeasible to expect any alteration to existing ponds, nor can hydrologic modification be the target of a TMDL.

3.0 WATERSHED CHARACTERIZATION

The Beaverdam Creek watershed is roughly 17,250 acres and is situated in Bedford County, draining the area east of the City of Roanoke, including the town of Stewartsville. Beaverdam Creek flows into upper Smith Mountain Lake (Roanoke River). The study portion of the Fryingpan Creek watershed is roughly 3,450 acres and is situated in Pittsylvania County west of Grenta, a predominantly rural area. Fryingpan Creek flows northwest into the Pigg River just before it joins Leesville Lake. The study portion of the Pigg River watershed is roughly 9,975 acres and is situated in Franklin County between Ferrum and Callaway, draining a predominantly rural area on the eastern slope of the Blue Ridge Mountains. The Pigg River ultimately flows into Leesville Lake on the Roanoke River. The Poplar Branch watershed is roughly 1,075 acres and is situated in Franklin County near the community of Penhook, a predominantly rural area. Poplar Branch is a tributary of Snow Creek, which flows into the Pigg River. All watersheds either directly or indirectly drain to the Roanoke River (Staunton River/ Smith Mountain Lake/ Leesville Lake), which flows southeast through North Carolina and into the Albemarle Sound and the Atlantic Ocean (**Figure 1-1).**

3.1. Ecoregion

Beaverdam Creek is in the Northern Inner Piedmont and Northern Igneous Ridges ecoregions (**Figure 3-1**). Fryingpan Creek and Poplar Branch are located entirely within the Northern Inner Piedmont ecoregion. The Pigg River is in the Northern Inner Piedmont, the Southern Crystalline Ridges and Mountains, and the New River Plateau ecoregions. A description of each ecoregion is below, adapted from (Woods et al., 1999).

> The Northern Inner Piedmont ecoregion is a dissected upland with hills, irregular plains, and some isolated ridges and mountains, and is underlain by deformed and weathered gneiss, schist, and melange, with intrusions of plutons. Originally this ecoregion would have consisted of mixed oak-hickory-pine forests but is now a patchwork of pine dominated forests and agricultural fields.
>
> The Northern Igneous Ridges ecoregion consists of long ridges composed of sedimentary rock that show minimal branching, thus resulting in numerous isolated mountain peaks. This ecoregion is mostly forested, with a small number of dairies and apple orchards. Agriculture is limited due to a soil composition that is largely rocky, acidic, and nutrient poor.
>
> The Southern Crystalline Ridges and Mountains ecoregion (also known as the Southern Igneous Ridges and Mountains) consists of ridges and mountains separated by high gaps. Slopes tend to be steep with well dissected mountain flanks, representing some of the most rugged terrain in the Appalachians. Bedrock is mostly coarse-grained metamorphic rock,

typically gneiss and schist. Higher elevations tend to be forested (mix of hardwood and pine) with lower elevations showing a small amount of pastureland, apple orchards, and cropland. Forest is mostly second growth, with old growth confined to steep and hard to access slopes.

The New River Plateau (Interior Plateau) ecoregion is a high elevation plateau nestled between higher elevation ridges of the Blue Ridge Mountains. The plateau is hilly with scattered isolated knobs and ridges and low local relief (less than 200 feet). The bedrock is metamorphic and includes quartzite, graywacke, and conglomerate, additionally, there are outcroppings of gneiss and schist. Originally a mixed forest, the landscape is now a patchwork of agricultural land and large blocks of forest, with agriculture predominating flatter areas.

3.2. Soils

The soil related parameters for the watershed were derived from the Soil Survey Geographic (SSURGO) dataset. The predominant factor analyzed was the hydrologic soil group (HSG). Hydrologic soil groups are an index of the rate at which water infiltrates through the soil with group A having the greatest rate of infiltration and D having the lowest rate of infiltration. When rainfall amounts exceed the capacity of the soil to infiltrate water, the excess water runs off and contributes to erosion. All study watersheds are predominantly composed of hydrologic soil group B, with Beaverdam Creek and the Pigg River having a small but not insignificant component consisting of group C (**Figure 3-2**).

3.3. Climate

Daily rainfall and temperature data for the watershed was obtained from Oregon State's spatially distributed PRISM model (Parameter-Elevation Regressions on Independent Slopes Model), which interpolates available datasets from a range of monitoring networks and is used as the official spatial climate data sets of the USDA. PRISM was utilized to obtain a more exact estimate of historical weather within the watershed, rather than relying on a nearby gauge outside of the watershed. See Daly et al. 2008 for more information on the PRISM model. The local annual average precipitation total in Rocky Mount, VA (centroidal to the study watersheds) is 47.06 inches, and the daily average temperature is 55.0° F. The normal summer high temperature is 86.0° F, while the normal winter low temperature is 29.0° F.

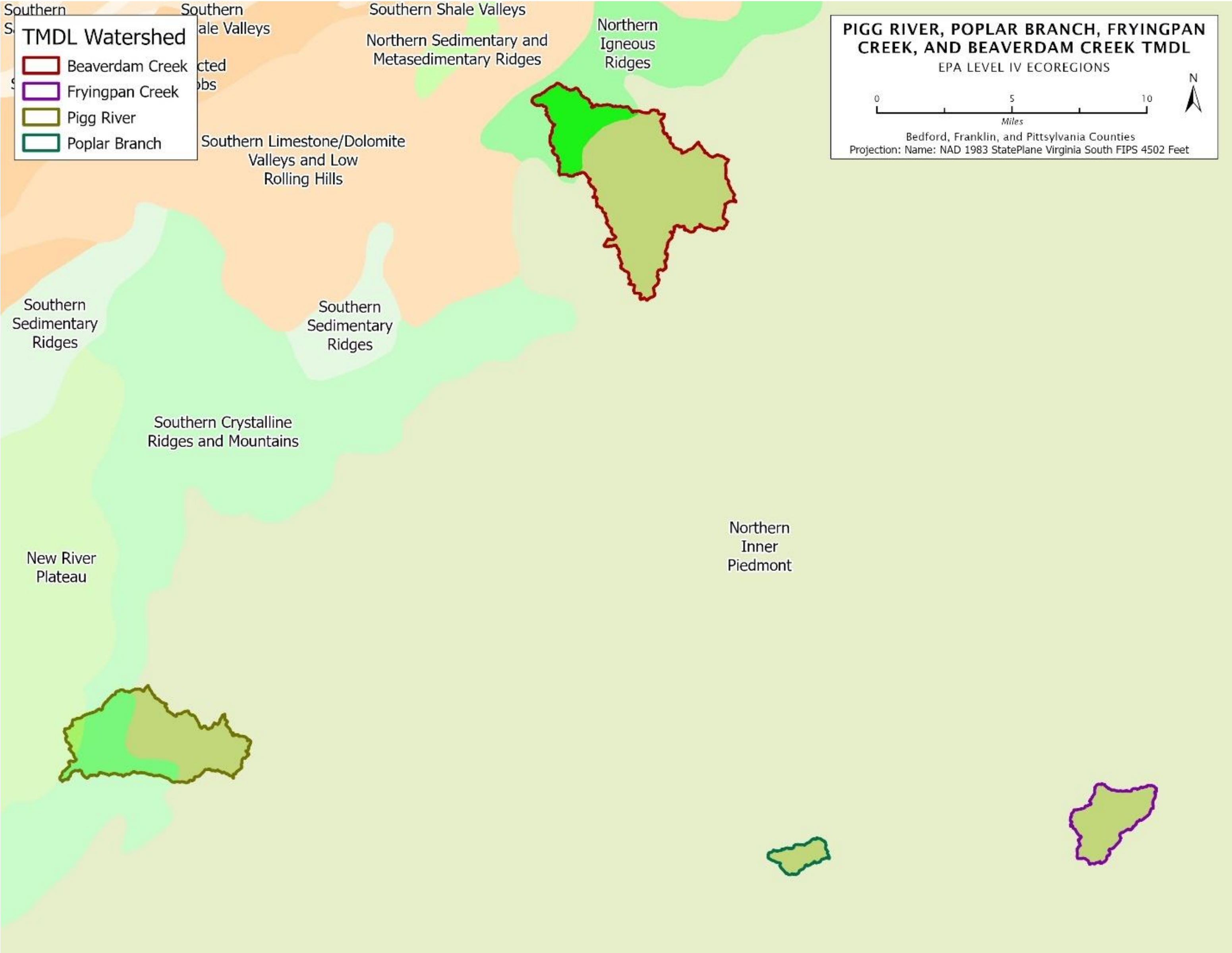

Figure 3-1. USEPA ecoregions overlapping the Beaverdam Creek, Fryingpan Creek, Pigg River, and Poplar Branch watersheds.

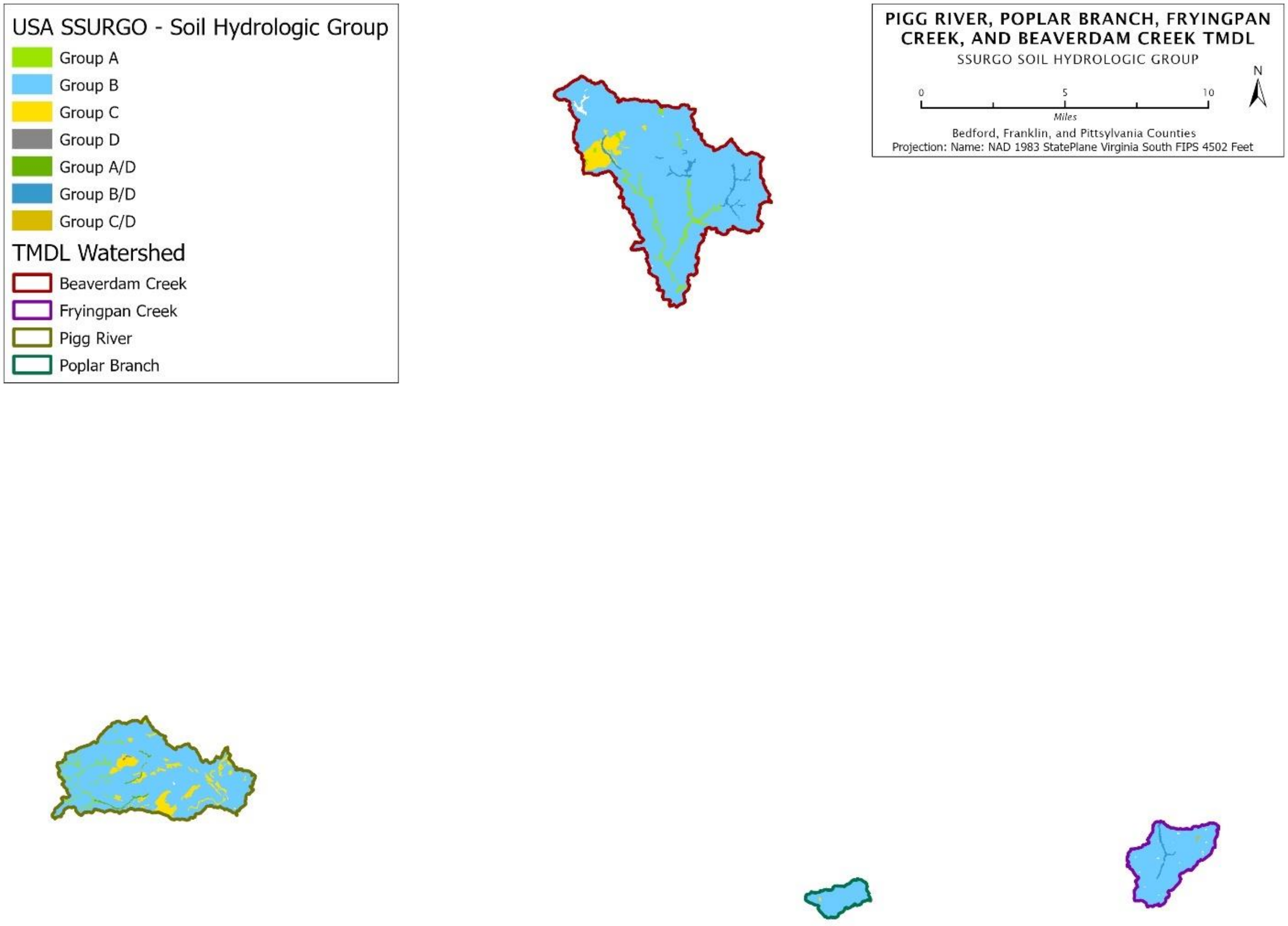

Figure 3-2. SSURGO hydrologic soil groups throughout the Beaverdam Creek, Fryingpan Creek, Pigg River, and Poplar Branch watersheds.

3.4. Land Cover/Land Use

The 2016 VGIN Virginia Land Cover Dataset (VLCD) was used to determine the land cover distribution throughout the watershed (**Figure 3-3** through **Figure 3-6**). **Table 3-1** through **Table 3-4** summarize the land cover distributions for each of the impaired watersheds.

The VGIN dataset contains two different types of impervious land cover: extracted and local datasets. The local datasets impervious land cover is based on locally-developed datasets covering specifically building footprints, roads, and other known impervious areas. This land cover type is included in the computer model as entirely impervious. VGIN's extracted impervious land cover layer was developed using computer algorithms to extract additional areas that are likely impervious, beyond those areas identified in local datasets. When compared with aerial imagery, the extracted land cover set includes some areas that are not impervious. Based on visual comparisons, the extracted impervious land cover layer from VGIN was treated in the model as 80% developed impervious and 20% developed pervious.

The 'NWI/other' land cover type in the VGIN dataset is based on the combined National Wetlands Inventory and Tidal Marsh Inventory datasets and represents all identified wetland areas in those datasets.

The VGIN dataset contains categories for cropland and pasture, which were subdivided for modeling purposes using the 2020 Nonpoint Source (NPS) Assessment Land Use/Land Cover database maintained by the Virginia Department of Conservation and Recreation (VADCR) (VADCR, 2020). The VADCR NPS land use database includes acreage estimates for acres in conventional and conservation tillage, as well as hay and three quality-based categories of pasture by county and by VAHU6 watersheds. The ratio of conventional to conservation tillage for each modelled subwatershed was used to divide the VGIN cropland acres for that subwatershed into acreages of high till and low till, which were simulated using appropriately different parameters within the model, such as curve number, cover management (C) factor, and practice (P) factor. The VGIN pasture acres for each subwatershed were divided into four categories based on the NPS database: hay, pasture-good, pasture-fair, and pasture-poor. These categories were simulated with appropriately different curve number and C-factor.

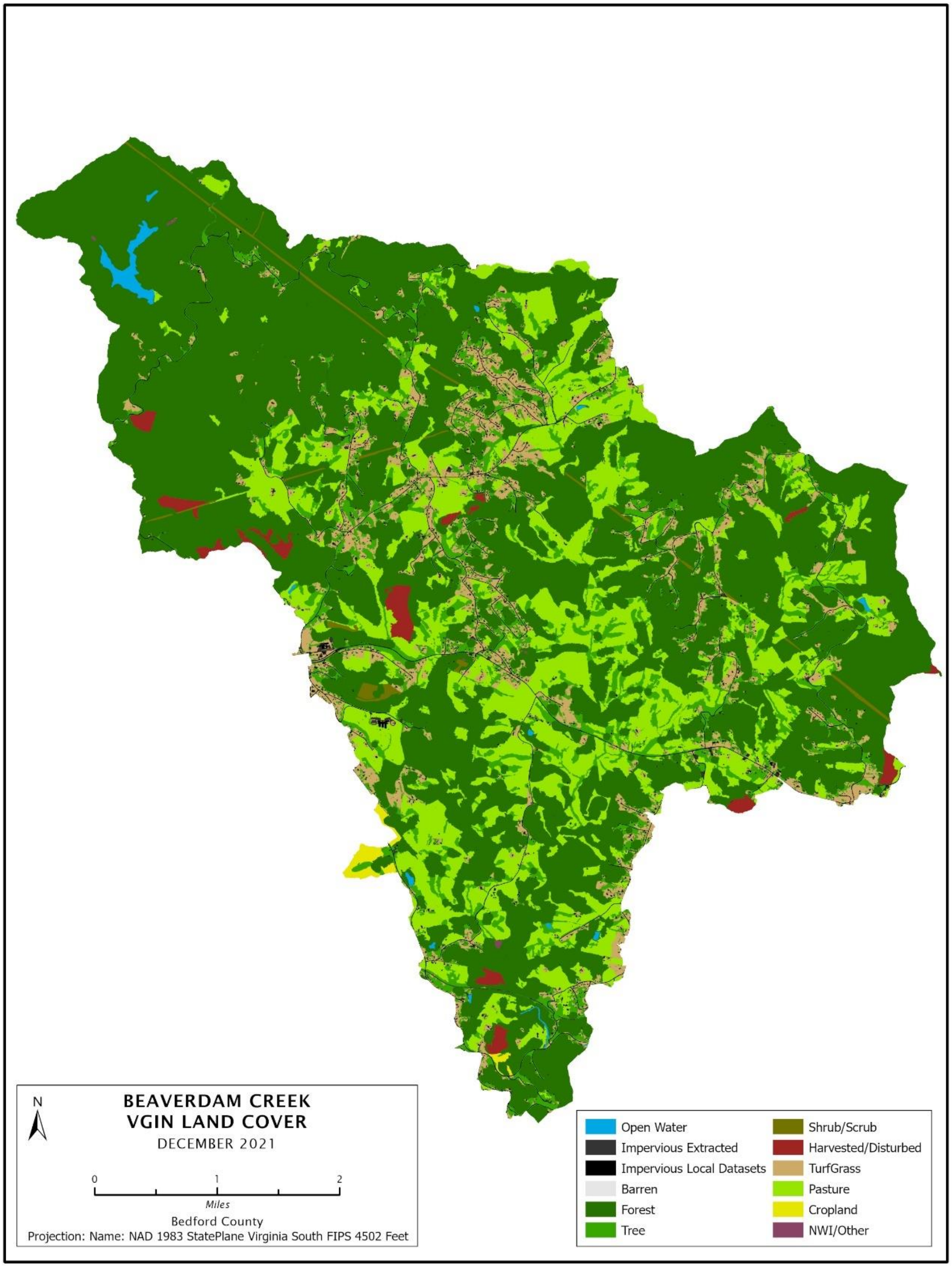

Figure 3-3. Land cover distribution used in the Beaverdam Creek watershed model.

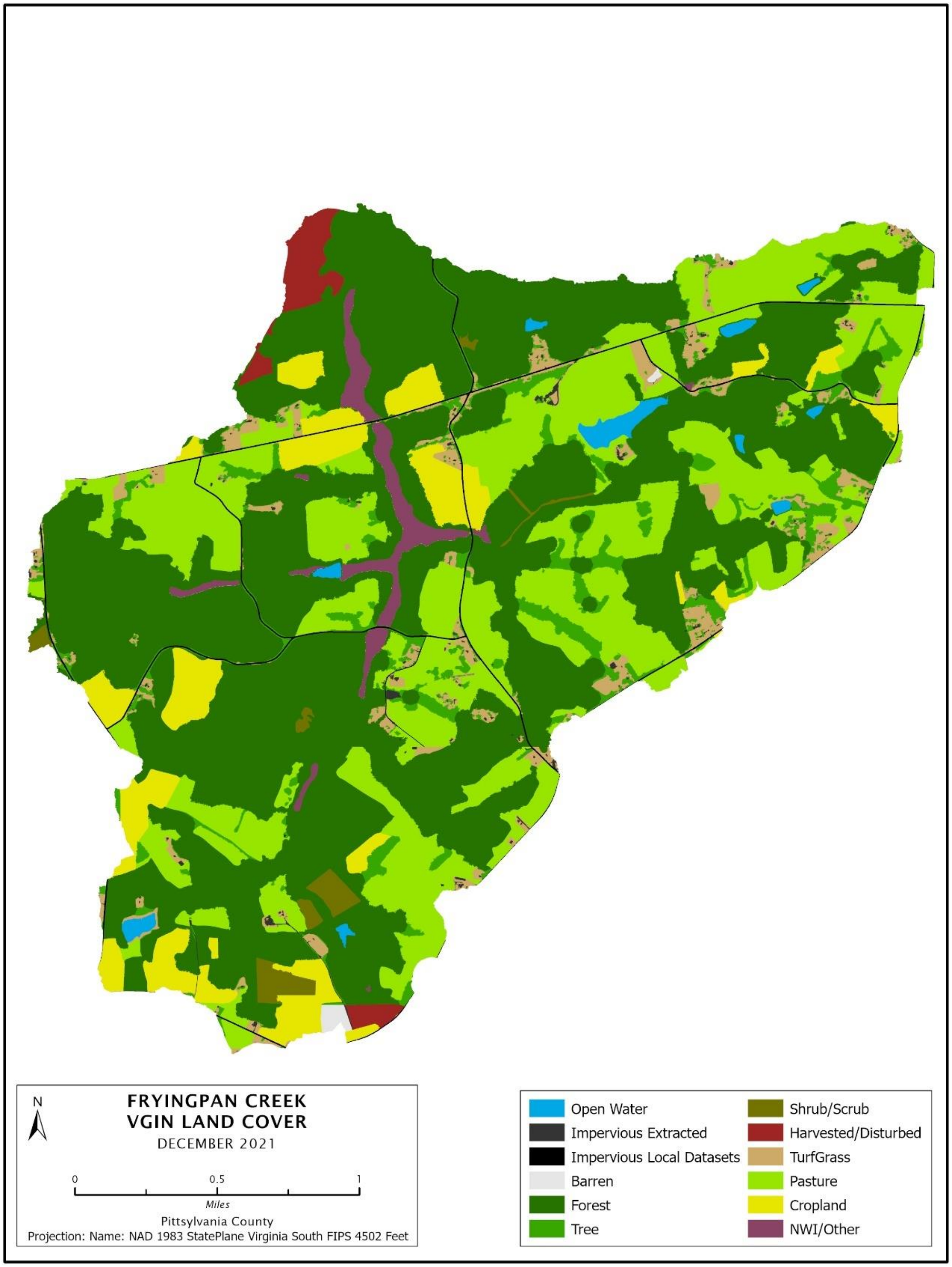

Figure 3-4. Land cover distribution used in the Fryingpan Creek watershed model.

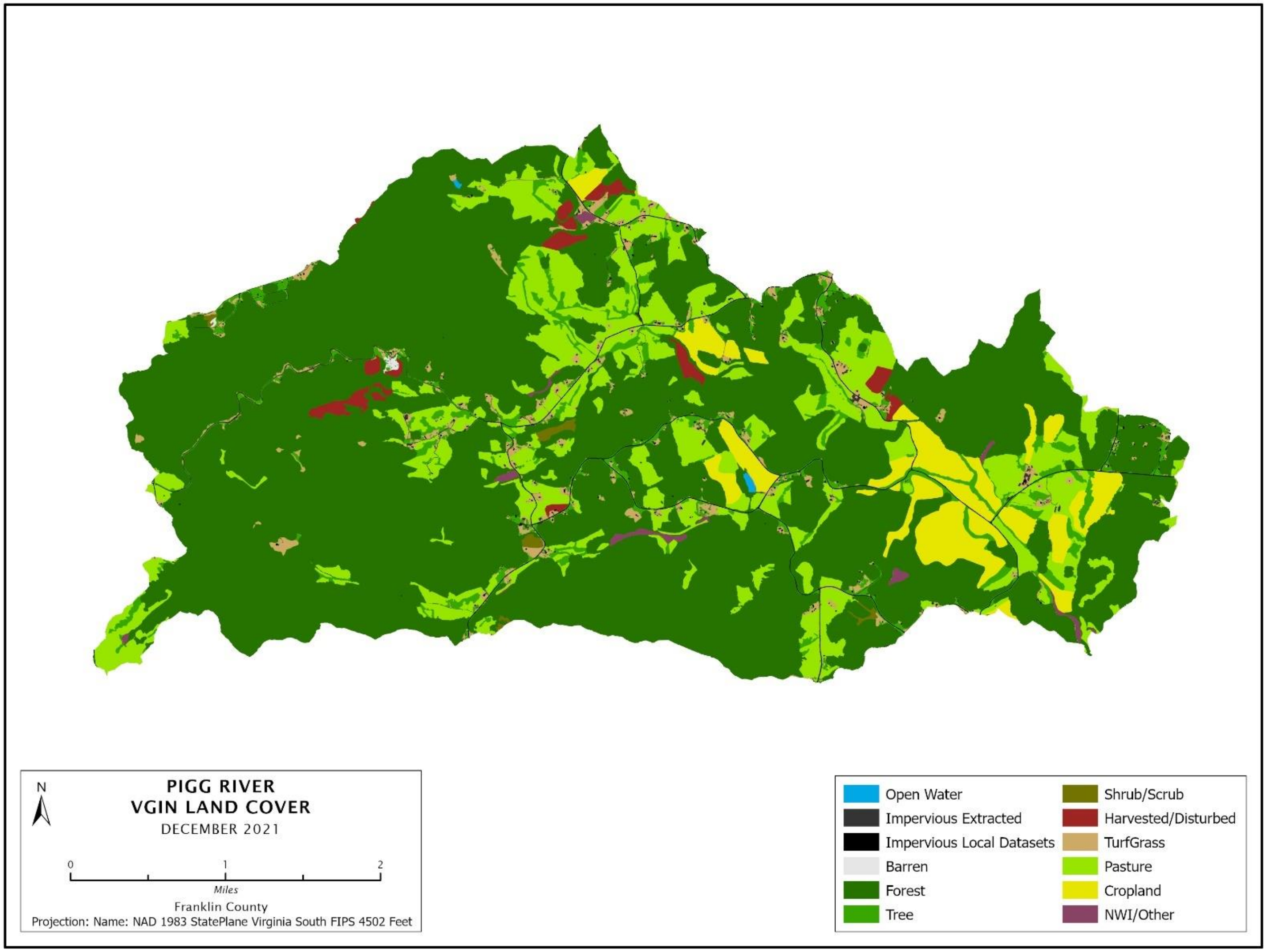

Figure 3-5. Land cover distribution used in the Pigg River watershed model.

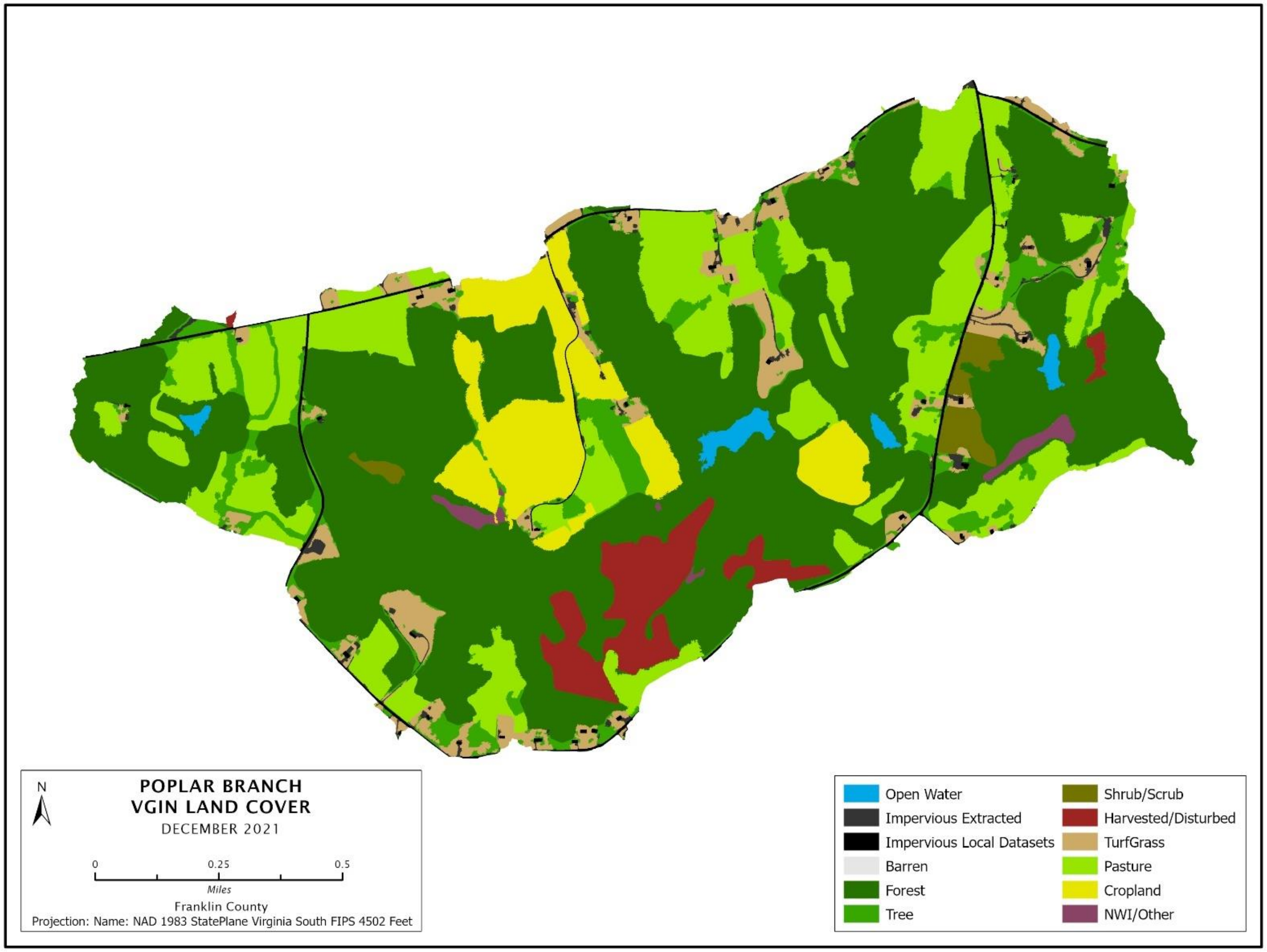

Figure 3-6. Land cover distribution used in the Poplar Branch watershed model.

Table 3-1. Land cover distribution in the Beaverdam Creek Watershed.

Land Cover Category	Acres	%
Cropland	26	0.2%
Hay	1,775	10.3%
Pasture	1,439	8.3%
Forest	10,396	60.3%
Trees	1,734	10.1%
Shrub	90	0.5%
Harvested/Disturbed	189	1.1%
Water	74	0.4%
Wetland	5	0.0%
Barren	0	0.0%
Turfgrass	1,036	6.0%
Developed, pervious	33	0.2%
Developed, impervious	441	2.6%
Total	*17,236*	*100.0%*

Table 3-2. Land cover distribution in the Fryingpan Creek watershed.

Land Cover Category	Acres	%
Cropland	232	6.7%
Hay	541	15.7%
Pasture	371	10.8%
Forest	1,785	51.8%
Trees	169	4.9%
Shrub	35	1.0%
Harvested/Disturbed	44	1.3%
Water	31	0.9%
Wetland	62	1.8%
Barren	6	0.2%
Turfgrass	120	3.5%
Developed, pervious	3	0.1%
Developed, impervious	46	1.3%
Total	*3,444*	*100.0%*

Table 3-3. Land cover distribution in the Pigg River watershed.

Land Cover Category	Acres	%
Cropland	497	5.0%
Hay	594	6.0%
Pasture	865	8.7%
Forest	7,068	70.9%
Trees	448	4.5%
Shrub	23	0.2%
Harvested/Disturbed	107	1.1%
Water	5	0.0%
Wetland	39	0.4%
Barren	4	0.0%
Turfgrass	192	1.9%
Developed, pervious	10	0.1%
Developed, impervious	117	1.2%
Total	*9,968*	*100.0%*

Table 3-4. Land cover distribution in the Poplar Branch watershed.

Land Cover Category	Acres	%
Cropland	79	7.5%
Hay	129	12.2%
Pasture	71	6.7%
Forest	568	53.4%
Trees	65	6.1%
Shrub	12	1.1%
Harvested/Disturbed	43	4.0%
Water	9	0.8%
Wetland	6	0.6%
Barren	0	0.0%
Turfgrass	54	5.1%
Developed, pervious	2	0.2%
Developed, impervious	25	2.3%
Total	*1,062*	*100.0%*

3.5. Water Quality and Biological Monitoring Data

Biological, physical, and chemical data from nine monitoring stations within the TMDL watersheds were used in developing the stressor analysis study. This includes eight benthic and nine water quality monitoring stations (eight sites are co-located benthic and water quality monitoring stations). The data from these monitoring stations are explored in the attached benthic stressor analysis report (**Appendix D**) and summarized in **Table 3-5.** The various benthic monitoring stations are shown in **Figure 3-7.**

Total habitat scores in Fryingpan Creek were within the medium to high probability for aquatic stress category and were driven by poor scores for bank stability, pool variability, instream sediment conditions, and substrate. Observations of the sediment deposition and embeddedness also indicate that sedimentation is a primary stressor to the benthic community. Total habitat scores in Beaverdam Creek and the impaired section of the Pigg River were generally within the medium probability range for aquatic stress, generally having poor riparian vegetation, unstable and poorly vegetated banks, and excess sediment. Both Beaverdam Creek and the impaired section of Pigg River had several spikes of TSS and turbidity, indicating high levels of sediment. Hydromodification was identified as a likely stressor to the Poplar Branch benthic community due to the impoundments observed upstream that appear to impact the stream flow. The total habitat scores were higher in Poplar Branch than the other impaired streams; however, the individual scores of sediment, flow regime, and bank stability were in the poor or suboptimal categories.

Based on collected data and a weight-of-evidence approach, probable stressors to the benthic community were identified. TMDL target pollutants were selected by analyzing the causal pathways of identified probable stressors and determining the primary substance responsible for controlling the pathway. TMDL target pollutants are the physical or chemical substances that will be controlled and allocated in the TMDL to result in restored aquatic life (measured by benthic macroinvertebrate health). TMDL targets must be pollutants that are controllable through source reductions, such as sediment, phosphorus, nitrogen, or other substances. Physical factors or environmental conditions, such as flow regimes, hydrologic modifications, or physical structures cannot be TMDL target pollutants. Even though these conditions influence ecological communities and may be sources of stress, they do not represent substances that originate from point and nonpoint sources, they cannot be quantified, summed, and allocated to respective sources, and they cannot be controlled through source reductions. The TMDL may not directly address these conditions, but they should be considered when implementing or evaluating the success of the TMDL.

Excess sediment was identified as the target pollutant in all study watersheds. When it rains, soil is washed off the land surface into nearby creeks and rivers. The amount of soil that is washed off depends upon how much it rains and the type of land that the rain falls on. Some land types, like a freshly plowed farm field or a construction site, can yield large volumes of eroded soil when it rains, while other land types, like forests and well-maintained pasture, yield smaller volumes. When the eroded soil is transported into nearby streams (henceforth referred to as sediment), it settles to the stream bottom and can smother aquatic insects that dwell there, limiting the diversity of aquatic life. Evidence leading to the conclusion that sediment was the primary stressor included low Total Habitat scores, biologist observations, and embeddedness measurements (**Appendix D**).

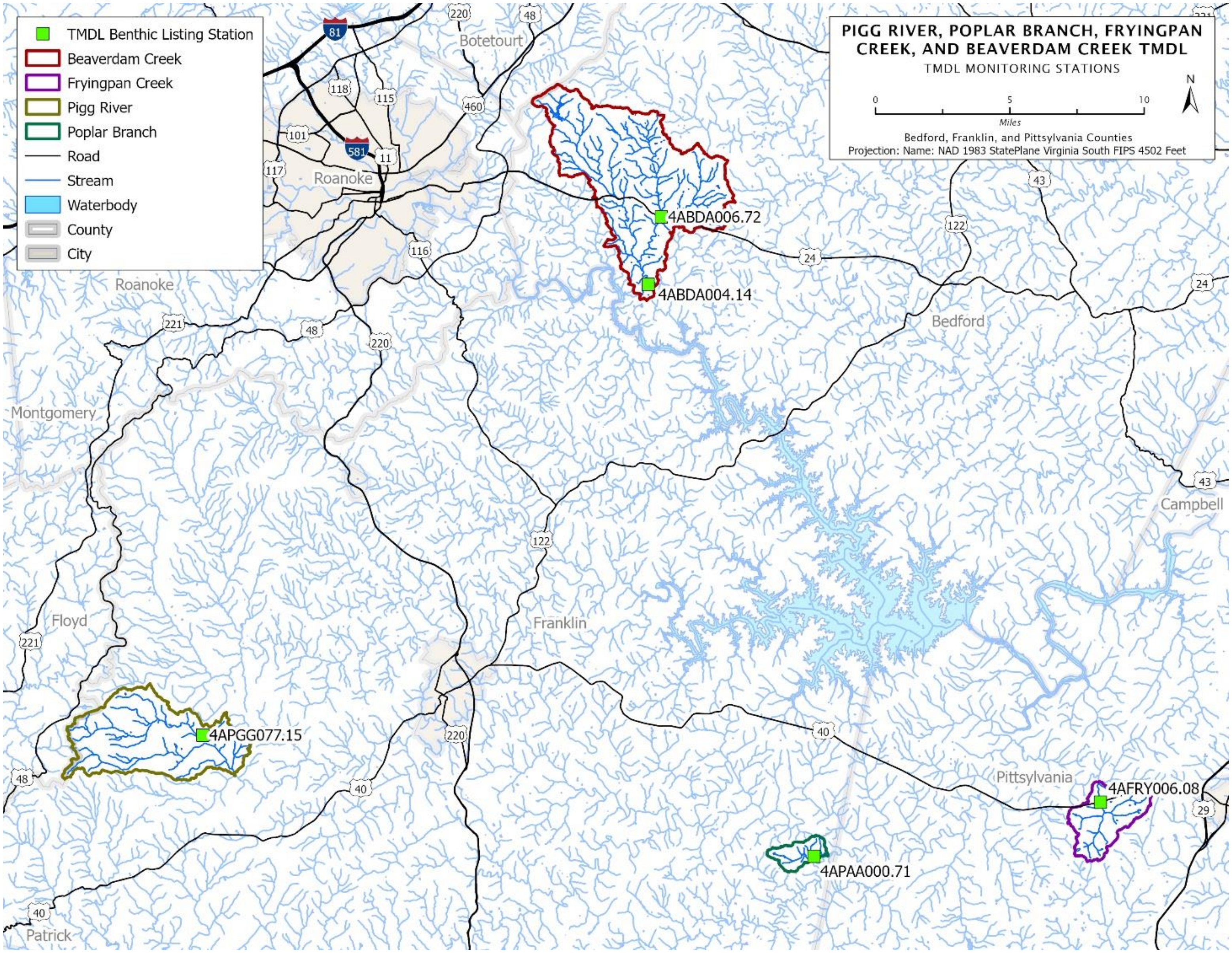

Figure 3-7. Locations of VADEQ monitoring stations in the Beaverdam Creek, Fryingpan Creek, Pigg River, and Poplar Branch watersheds.

Table 3-5. Summary data type collected at each monitoring station.

Benthic Station ID	Location	Monitoring Program Type	Years Sampled	Parameters Sampled
4AFRY006.08	At Route 40 Bridge	Ambient, Bio, TM, APROB	2003- 2018	Biology, Nutrients, Total Habitat, Chemical Data
4APGG077.15	At Route 602 Bridge	Ambient, Bio, TM	2013- 2019	Biology, Nutrients, Total Habitat, Chemical Data
4APGG076.93	Upstream of South Prong Pigg confluence	Probabilistic	2009	Biology, Nutrients, Metals, Total Habitat, Chemical Data, Fish community
4APAA000.71	Route 629 Crossing	Ambient, Bio, TM	2013-2018	Biology, Nutrients, Total Habitat, Chemical Data
4APAA000.24	LaPrade Farm below Rte. 629	Probabilistic	2001	Biology, Nutrients, Total Habitat, Chemical Data
4ABDA011.79	Lick Mountain Road off Rte. 635	Probabilistic	2001	Biology, Nutrients, Total Habitat, Chemical Data
4ABDA006.27	Below Rte. 24 Bridge	Bio	2008	Biology, Total Habitat
4ABDA004.14	Route 757 Bridge	Ambient, Bio	2017-2018	Biology, Nutrients, Total Habitat, Chemical Data
4ABDA003.63	STA #7 off Rte. 757 Bedford County	Ambient, Trend	1992-2012	Bacteria, nutrients

4.0 MODELING PROCESS

A computer model was used in this study to simulate the relationship between pollutant loadings and in-stream water quality conditions.

4.1. Model Selection and Description

The model selected for development of the sediment TMDL in the study watersheds was the Generalized Watershed Loading Functions (GWLF) model, developed by Haith et al. (1992), with modifications by Evans et al. (2001), Yagow et al. (2002), and Yagow and Hession (2007). GWLF is based on loading functions, which are a compromise between the empiricism of export coefficients and the complexity and data-intensive nature of process-based simulations (Haith et al., 1992). GWLF operates in metric units, but outputs were converted to English units for this report.

GWLF is a continuous simulation model that operates on a daily timestep for water balance calculations and outputs a monthly sediment and nutrient yield for the watershed. The model allows for multiple different land cover categories to be incorporated, but spatially it is lumped, in the fact that it does not account for the spatial distribution of sources and has no method of spatially routing sources within the watershed.

Observed daily precipitation and temperature data is input, along with land cover distribution and a range of land cover parameters, which the model uses to estimate runoff and sediment loads in addition to dissolved and attached nitrogen and phosphorus loads. Surface runoff is calculated using the Soil Conservation Service Curve Number (SCS-CN) approach. Curve numbers are a function of soils and land use type. Erosion is calculated in GWLF based on the Universal Soil Loss Equation (USLE). USLE incorporates the erosivity of rainfall in the watershed area, inherent erodibility of the soils, length and steepness of slopes, as well as factors for cover and conservation practices that affect the impact of rainfall and runoff on the landscape. Impervious or urban sediment inputs are calculated in GWLF with exponential accumulation and washoff functions. GWLF incorporates a delivery ratio into the overall sediment supply to estimate sediment deposition before runoff carries it to a stream segment. GWLF's sediment transport algorithm takes into consideration the transport capacity of the runoff based on calculated runoff volume.

Stream bank and channel erosion is calculated using an algorithm by Evans et al. (2003) as incorporated in the AVGWLF version (Evans et al., 2001) of the GWLF model and corrected for a flow accumulation coding error (VADEQ, 2005). This algorithm incorporates the stream flow, fraction of developed land (i.e. impervious cover) in the watershed, and livestock density in the watershed with the area-weighted curve number and soil erodibility factors and the mean slope of the watershed.

Groundwater discharge to the stream is calculated using a lumped parameter for unsaturated and shallow saturated water zones throughout the watershed. Infiltration to the unsaturated zone occurs when precipitation exceeds surface runoff and evapotranspiration. Percolation from the unsaturated zone to the shallow saturated zone occurs when the unsaturated zone capacity is exceeded. The shallow saturated zone contributes groundwater discharge to the stream based on a recession coefficient, and groundwater loss to a deep saturated zone can be modeled using a seepage coefficient.

4.2. Model Setup

Watershed data needed to run GWLF were generated using spatial data, water quality monitoring data, streamflow data, local weather data, literature values, stakeholder input, and best professional judgement. In general, the GWLF manual (Haith et al., 1992) served as the primary source of guidance in developing input parameters where newer published methods were not available. Values for the various GWLF input parameters for each model are detailed in **Appendix A**. A sensitivity analysis of the model to select parameters is presented in **Appendix B**.

Daily rainfall and temperature data for the watershed was obtained from Oregon State's spatially distributed PRISM model (Parameter-Elevation Regressions on Independent Slopes Model), which interpolates available datasets from a range of monitoring networks and is used as the official spatial climate data sets of the USDA. PRISM was utilized to obtain a more exact estimate of historical weather within the watershed, rather than relying on a nearby gauge outside of the watershed. See Daly et al. 2008 for more information on the PRISM model.

The model allows for multiple land cover categories to be incorporated, but spatially it is lumped, meaning that it does not account for the spatial distribution of sources and has no method of spatially routing sources within the watershed. The standard practice is to then sub-divide larger watersheds into smaller subwatersheds that can be simulated individually to get a more granular assessment of the pollutant loads. The TMDL study area was divided into eight subwatersheds to obtain a more granular assessment of the pollutant loads throughout the watershed. The Beaverdam Creek study area was divided into subwatersheds one and two, the Fryingpan Creek study area was divided into subwatersheds seven and eight, the Pigg River into subwatersheds three and four, and Poplar Branch into subwatersheds five and six (**Figure 4-1**). Locations of monitoring stations were used to guide subwatershed development to take advantage of available data. Junctions of streams were also used as breaking points to reduce subwatershed size, allowing large tributaries to be modeled independently. General differences in land cover also guided subwatershed divisions.

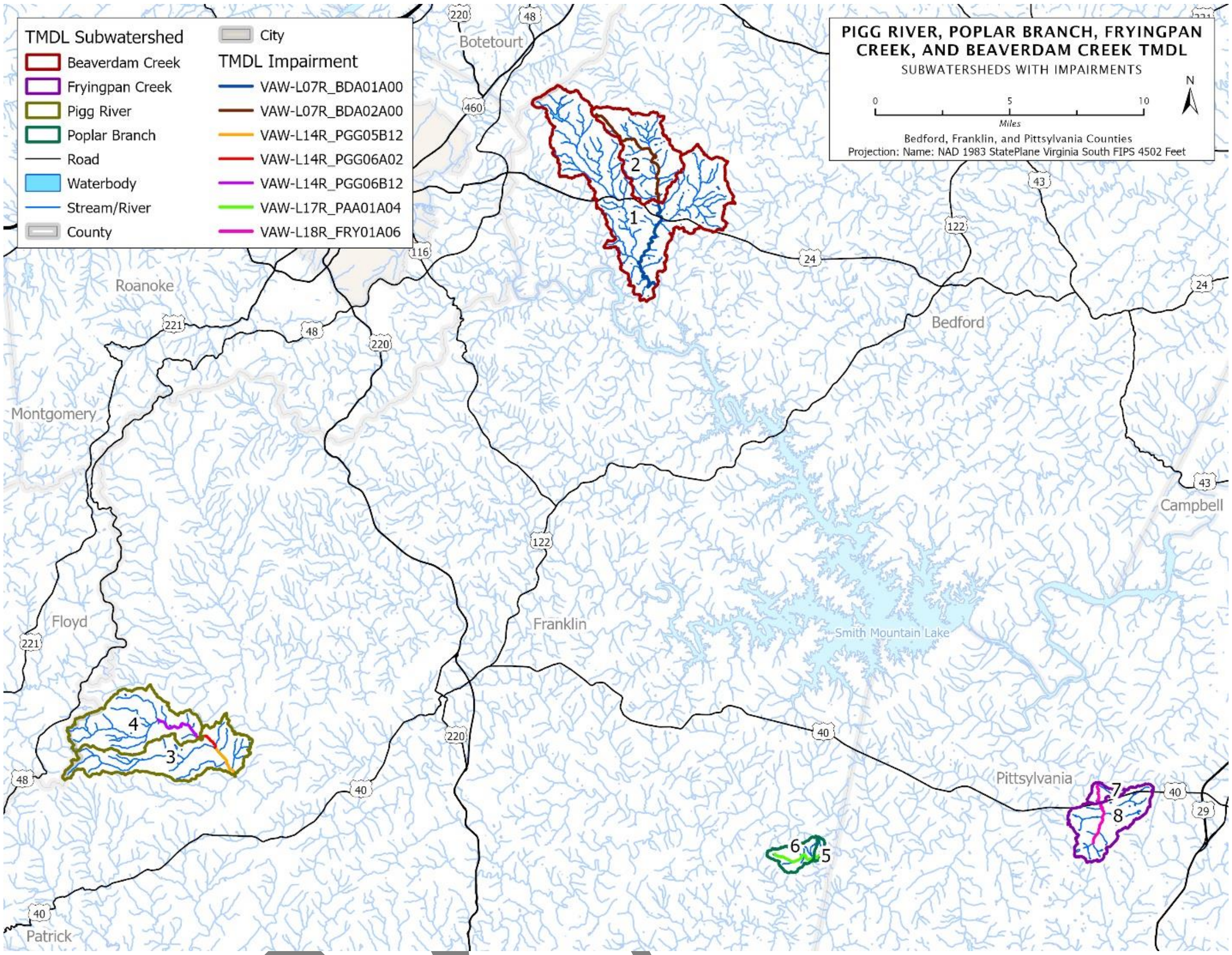

Figure 4-1. Beaverdam Creek, Fryingpan Creek, Pigg River, and Poplar Branch TMDL model subwatersheds.

4.3. Source Assessment

Sediment can be delivered to streams by either point or nonpoint sources. Point sources include permitted sources such as water treatment facilities. Nonpoint sources encompass all other sources in the watersheds. Nonpoint sediment is primarily from surface runoff (anywhere not captured and converted to point sources) and erosion happening within and on the banks of streams.

4.3.1. Nonpoint Sources

4.3.1.1. Surface Runoff

Sediment can be transported from both pervious and impervious surfaces during runoff events. Between rainfall events, sediment accumulates on impervious surfaces and can then be washed off during runoff events. On pervious surfaces, soil particles are detached by rainfall impact and shear stress from overland flow and then transported with the runoff water to nearby streams. Various factors including rainfall intensity, storm duration, surface cover, topography, tillage practices, soil erosivity, soil permeability, and other factors all impact these processes.

VGIN 2016 land cover data was used to determine the distribution of different land cover types in the watersheds (with the modifications noted in **Section 3.4**). Values for various parameters affecting sediment loading were gleaned from literature guidance (CBP, 1998; Haith et al., 1992; Hession et al., 1997).

4.3.1.2. Streambank Erosion

Sediment is transported in stream systems as part of their natural processes. However, changes to the landscape can alter these processes, in turn changing the balance of sediment mobilization and deposition within the stream system. Increases in impervious areas can increase the amount and rate of flow in streams following rainfall events, which provides more erosive power to the streams and increases the channel erosion potential. This is often the cause of the entrenchment, or downcutting, of urban streams – disconnecting higher flow events from the surrounding floodplain. The higher flows are then increasingly confined to the channel, and thus mobilize more sediment, both as total suspended sediment (TSS) in the water column and bedload (the movement of larger particles along the bottom of the channel). Erosion of entrenched streams continues as steep banks are more susceptible to erosion and eventually mass wasting occurs as chunks of undercut banks are dislodged into the stream. Sediment deposition between storm events and the highly mobile bed material during erosive storm flows negatively impact aquatic life.

Additionally, impacts to riparian (streambank) vegetation from livestock access and other management practices weaken the stability of the streambanks themselves as root system matrices break down. Weakened streambanks are more easily eroded by storm flows and can lead to excessive channel migration and eventual channel over-widening. Increasing channel width decreases stream depth which can lead to increased sediment deposition and increased water temperatures, which both negatively impact aquatic life.

Stream bank and channel erosion is calculated in GWLF using an algorithm by Evans et al. (2003) as incorporated in the AVGWLF version (Evans et al., 2001) of the GWLF model and corrected for a flow accumulation coding error (VADEQ, 2005). This algorithm estimates average annual streambank erosion as a function of cumulative stream flow, fraction of developed land (i.e. impervious cover) in the watershed, and livestock density in the watershed with the area-weighted curve number and soil erodibility factors and the mean slope of the watershed.

4.3.2. Point Sources

Several point sources of sediment exist within the Beaverdam Creek watershed (none were identified in the other TMDL watersheds). In this study, the permits included are based on data for March 2021. These point sources are permitted under the Virginia Pollutant Discharge Elimination System (VPDES) program and include domestic sewage permits and a VPDES individual permit.

The approach for determining loads from each of these permit types is described below. Typically, wasteload allocations for VPDES general permits in a TMDL are aggregated by permit type.

4.3.2.1. VPDES Individual Permit

There is one VPDES individual permit within the Beaverdam Creek watershed, associated with an elementary school. The typical sediment load from the facility was calculated from discharge monitoring report data and used to model existing conditions (**Table 4-1**). The permitted load, which is included in the wasteload allocation of the TMDL, was calculated based on the permitted discharge and concentration for the facility.

Table 4-1. Sediment loads associated with VPDES individual permit.

Permit No	Facility Name	Watershed	Permitted Discharge (MGD)	Permitted Concentration (mg/L TSS)	Typical (Existing) Load (lb/yr TSS)	Permitted Load (lb/yr TSS)
VA0020842	Bedford County Schools - Stewartsville Elementary	Beaverdam Creek	0.006	45	83	822

4.3.2.2. Domestic Sewage Permits

There are two domestic sewage general permits in the Beaverdam Creek watershed (**Table 4-2**). The domestic sewage general permit specifies a maximum flow rate of 1000 gallons per day at a sediment concentration of 30 mg/L. These permit limits were used to calculate a wasteload allocation of 91.44 lb/yr TSS for each of the domestic sewage permits in the TMDL.

Table 4-2. Domestic sewage general permit in the study area.

Receiving Stream	Permit Number	Permitted Load (lb/yr TSS)	Aggregate Permitted Load (lb/yr TSS)
Beaverdam Creek	VAG402101	91.44	182.88
	VAG402030	91.44	

4.3.2.3. Construction Stormwater Permits

There are currently no active Virginia Stormwater Management Program (VSMP) Construction General Permits within the study area. These permits are a potential source of sediment and are often assigned wasteload allocations in the TMDL based on the typical annually disturbed area associated with the permits. A database search was performed for the past five years and no active

VSMP Construction General Permits were found in that time frame in the study area. To account for future construction and associated loads, the future growth set-aside was increased to 2%.

4.4. Best Management Practices

Several entities and private citizens have installed best management practices (BMPs) throughout the Beaverdam Creek and Fryingpan Creek watersheds. Many BMPs have associated removal efficacies defined in the literature, which can be applied to the raw pollutant accumulation loads for the land areas draining to the BMP. Other BMPs can be simulated as a change in land use over the treated acreage, such as planting a riparian buffer and turning previous pasture into forested areas. The BMPs installed in the watersheds are detailed in **Table 4-3**, along with their various removal efficacies. The Chesapeake Bay Phase 5.3 Community Model Documentation Section 6 (USEPA, 2010) was used to guide the TSS removal estimates. Other BMPs exist within the watersheds, but are either maintenance practices or contribute only nutrient reductions without an associated sediment reduction. In this study, the BMPs included are based on data for March 2021.

Table 4-3. BMPs installed in the TMDL study area.

Receiving Stream	Practice	Count	Extent Installed	Efficacy method (fraction removal, other)	TSS Removed (lb/yr)
Beaverdam Creek	CREP Riparian Forest Buffer Planting (CRFR-3)	1	22.4 ac	0.40, Land cover change	5,011
	CREP Linear Foot of Streambank Protected (CRLF-1)	1	2,021 lf	0.40 , Reduce from streambank erosion	2,825
	Stream Exclusion With Grazing Land Management (SL-6)	1	130.5 ac 3,098 lf	0.40 , Land cover change.	63,528
Fryingpan Creek	Livestock Exclusion With Riparian Buffers (LE-1T)	1	25.9 ac	0.40, Land cover change	17,048
	Sod Waterway (WP-3)	1	0.69 ac	0.40, Land Cover Change	1,054

4.5. Flow Calibration

GWLF was originally developed as a planning tool for estimating nutrient and sediment loadings in ungauged watersheds and was designed to be implemented without calibration. Hydrologic calibration was still performed as a preliminary modeling step to ensure that hydrology was being simulated as accurately as feasibly possible.

Historic daily flow data was available from USGS flow gauge #02076500 – Georges Creek near Gretna from 1982 to 1996. While not located directly on any of the TMDL streams, the gauge is located on nearby Georges Creek, which was included in the development of the AllForX regression (**Section 5.0**, Georges Creek watershed correlates to station 4AGEO006.73 in **Figure C-2**). Georges Creek watershed is similar in size to the study watersheds, with similar land cover distributions, and is close geographically, all indicating that it is likely to have a hydrologic response similar to the study watersheds. Hydrologic calibration was completed on Georges Creek, and calibrated parameters were applied to the other modeled watersheds. Local weather data was obtained from Oregon State's spatially distributed PRISM model, see **Section 3.3**. Leaving a 'warm-up' period for the model (1981), the years from 1989 to 1995 were used as the calibration period, and 1982 to 1988 were used as a validation dataset. These ranges are sufficiently long that a range of both dry and wet years are encompassed in each to get a good assessment of the model's performance.

Calibration efforts focused on adjusting watershed scale parameters, such as the recession coefficient and seepage coefficient, that cannot be calculated or estimated reliably from available guidance. The typical target ranges for GWLF calibration efforts are to achieve ±5% of the observed total flow and ±20% compared to seasonal flow distribution. While calibration efforts make a best effort at meeting the target for all criteria, this is not always possible as no model is a perfect simulation of the reality it is approximating. The final GWLF calibration results are shown in **Figure 4-2** and **Figure 4-3** and summarized in **Table 4-4**. The results of the calibration were also assessed for overall correlation by calculating an R^2 value for the datasets. Generally, for GWLF, an R^2 value greater than 0.7 indicates a strong positive correlation between simulated and observed data. Following calibration, the model output was run compared to the observed 1982-1988 discharge as a validation of the model calibration. The final GWLF validation results are summarized in **Table 4-4** and shown in **Figure 4-4** and **Figure 4-5**.

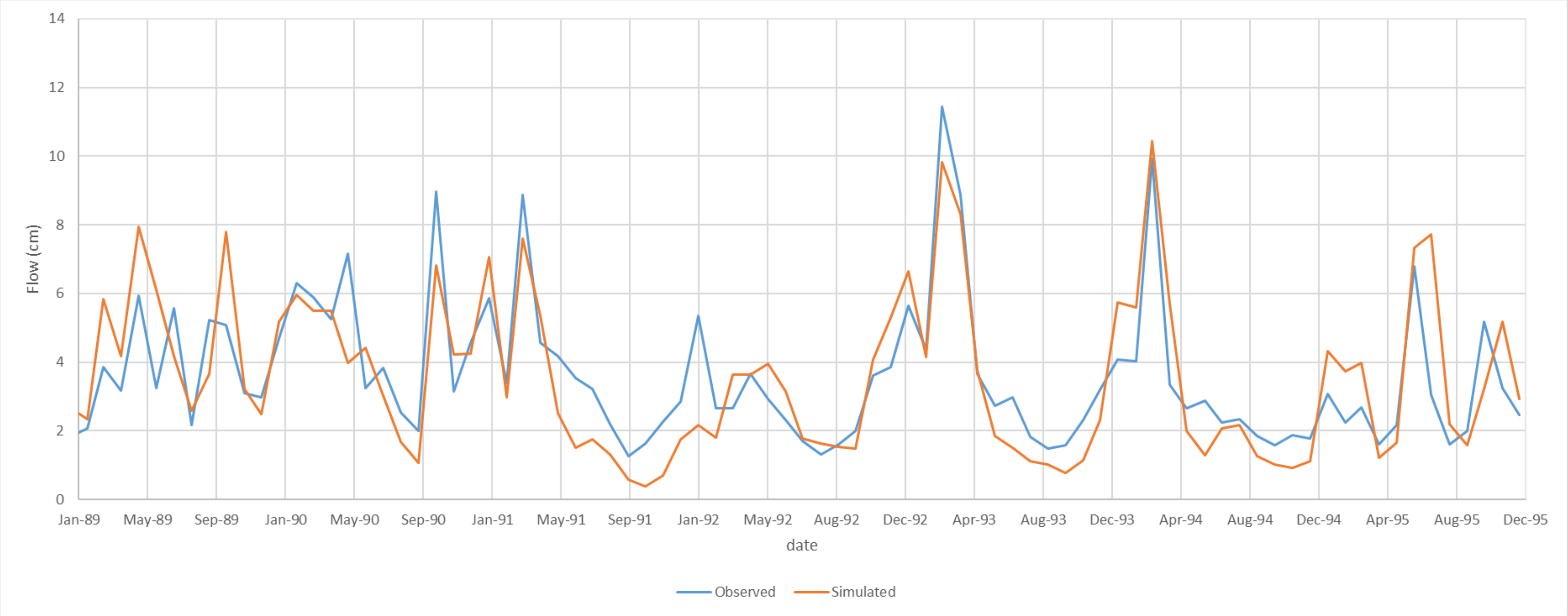

Figure 4-2. Calibration data set of simulated stream flow compared to observed flow (USGS#02076500).

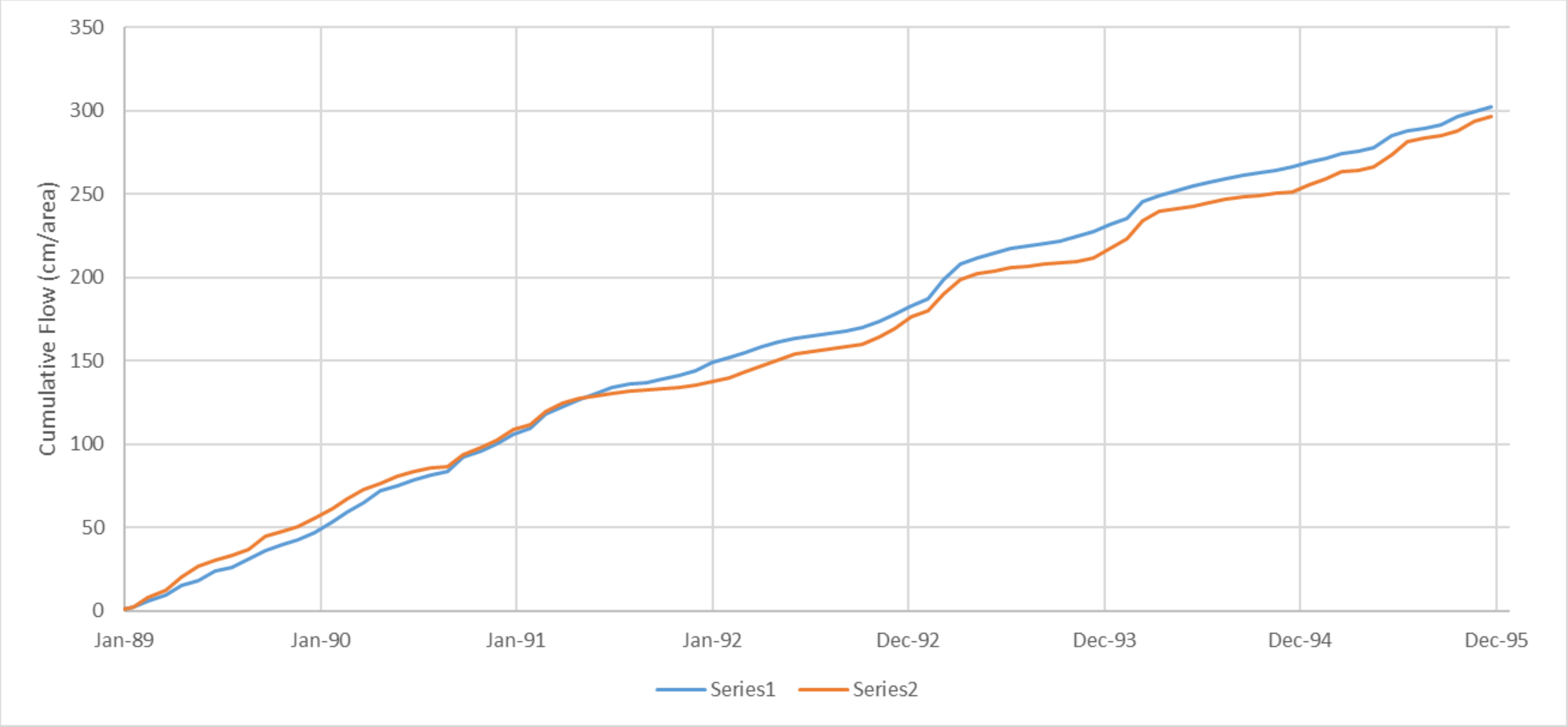

Figure 4-3. Calibration data set simulated cumulative flow from model compared to observed (USGS#02076500).

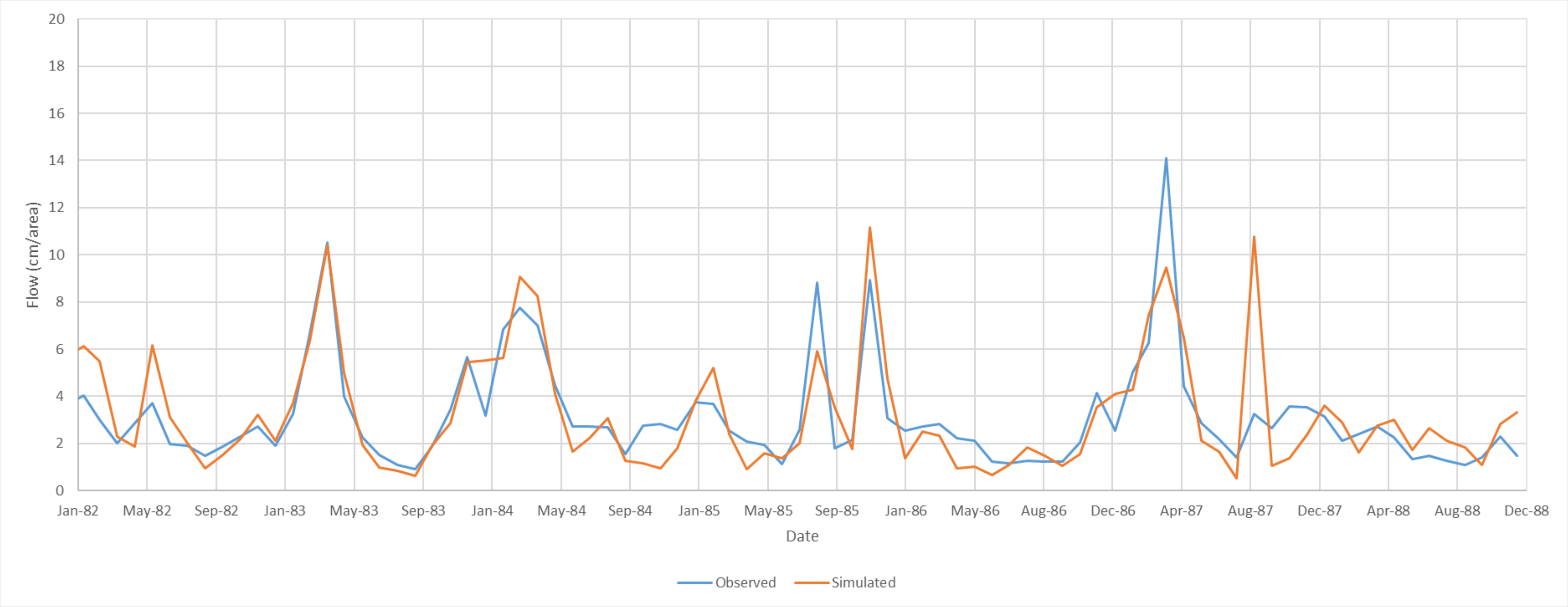

Figure 4-4. Validation data set of simulated stream flow compared to observed flow (USGS#02076500).

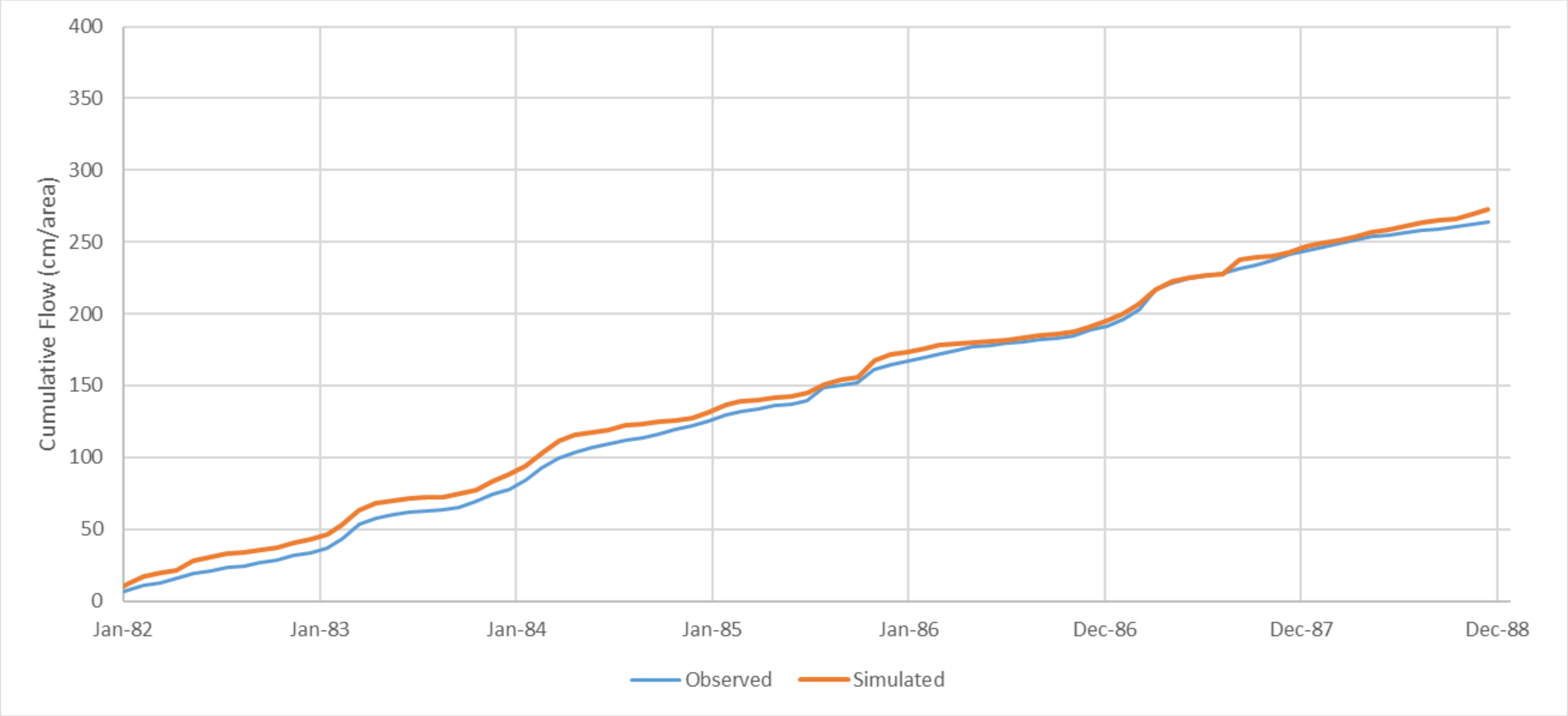

Figure 4-5. Validation data set simulated cumulative flow from model compared to observed (USGS#02076500).

Table 4-4. Results of hydrology calibration of GWLF model compared to observed data.

Criteria	Calibration Range Percent Difference (%)	Validation Range Percent Difference (%)
Total Cumulative Discharge	-1.66	3.10
Spring Discharge	1.71	-5.62
Summer Discharge	-12.62	16.27
Fall Discharge	-9.17	-9.30
Winter Discharge	6.17	14.20
R^2	0.67	0.66

4.6. Consideration of Critical Conditions and Seasonal Variations

To quantify existing conditions and develop reduction allocations, the GWLF model simulated a 20-year period (2001 through 2020) with an additional buffer period of nine months at the beginning of the run serving as a ‘warm-up’ period for the model to equilibrate and minimize the impact of uncertain initial conditions. Using this extended modeling period allows the results to account for both annual and seasonal variations in hydrology and sediment loads.

The modeled time period encompasses a range of weather conditions for the area, including ‘dry’, ‘normal’, and ‘wet’ years, which allows the model to represent critical conditions during both low and high flows. Critical conditions during low flows are generally associated with point source loads, while critical conditions during high flows are generally associated with nonpoint source loads.

GWLF considers seasonal variation through several mechanisms. Daily time steps are used for weather data inputs and water balance equation calculations. GWLF also incorporates parameters that vary by month, including evapotranspiration cover coefficients and average hours per day of daylight. Additionally, the values for the rainfall erosivity coefficient vary if a month falls within or out of the growing season.

4.7. Existing Conditions

Existing sediment loads from the impaired watersheds were simulated in GWLF as described above. **Table 4-5** through **Table 4-8** summarize the resulting loads. While the model is run using weather data from a twenty year period to capture a range of seasonal and annual variation, the land cover and sources within the model do not vary over time as the model runs. Instead, the land cover and pollutant sources simulate a snapshot in time representing available data and active permits. In this model, the land cover is from 2016, and the permits and BMPs included are reflective of conditions in March 2021. These dates reflect the collected water quality monitoring data used to determine the necessity of developing this TMDL and to gauge the existing conditions in the model results. The monitoring window for sediment data analyzed for this study ran through November 2019.

Any apparent differences in calculated values are due to rounding. Model results were rounded to 4 significant figures, and calculated totals of those results were rounded to 3 significant figures.

Table 4-5. Existing sediment loads in the Beaverdam Creek watershed, accounting for known BMPs (not including MOS or Future Growth detailed in Section 6.0).

Land Cover Category	TSS (lb/yr)
Cropland	17,810
Hay	132,100
Pasture	1,686,000
Forest	304,700
Trees	96,380
Shrub	24,450
Harvested	110,800
Wetland	405
Barren	0
Turfgrass	64,030
Developed Pervious	5,339
Developed Impervious	258,700
Streambank Erosion	297,300
Permitted	1,000
Total	*3,000,000*

Table 4-6. Existing sediment loads in the Fryingpan Creek watershed, accounting for known BMPs (not including MOS or Future Growth detailed in Section 6.0).

Land Cover Category	TSS (lb/yr)
Cropland	470,800
Hay	27,880
Pasture	318,100
Forest	42,260
Trees	6,609
Shrub	7,081
Harvested	24,080
Wetland	16,030
Barren	27,380
Turfgrass	5,384
Developed Pervious	296
Developed Impervious	25,490
Streambank Erosion	9,796
Total	*981,000*

Table 4-7. Existing sediment loads in the Pigg River watershed, accounting for known BMPs (not including MOS or Future Growth detailed in Section 6.0).

Land Cover Category	TSS (lb/yr)
Cropland	387,800
Hay	48,590
Pasture	1,211,000
Forest	270,100
Trees	30,640
Shrub	3,872
Harvested	79,560
Wetland	5,177
Barren	87,440
Turfgrass	13,990
Developed Pervious	1,929
Developed Impervious	71,400
Streambank Erosion	161,900
Total	*2,370,000*

Table 4-8. Existing sediment loads in the Poplar Branch watershed, accounting for known BMPs (not including MOS or Future Growth detailed in Section 6.0).

Land Cover Category	TSS (lb/yr)
Cropland	92,610
Hay	11,130
Pasture	101,300
Forest	25,070
Trees	4,793
Shrub	3,200
Harvested	27,970
Wetland	2,359
Barren	0
Turfgrass	4,205
Developed Pervious	595
Developed Impervious	15,630
Streambank Erosion	1,768
Total	*291,000*

5.0 SETTING TARGET SEDIMENT LOADS

TMDL development requires an endpoint or water quality goal to target for the impaired watershed(s). Many pollutants have numeric water quality criteria set in regulatory documentation, and it is assumed that compliance with these numeric criteria will lead the waterbody to achieve support of all designated uses. However, sediment does not have a numeric criterion established as the acceptable level of sediment is expected to vary from stream to stream based on a range of contributing factors. Therefore, an alternative method must be used to determine the water quality target for sediment TMDLs.

The method used to set TMDL endpoint loads for the Beaverdam Creek, Fryingpan Creek, Pigg River, and Poplar Branch watersheds is called the "all-forest load multiplier" (AllForX) approach, which has been used in developing many sediment TMDLs in Virginia since 2014. AllForX is the ratio of the simulated pollutant load under existing conditions to the pollutant load from an all-forest simulated condition for the same watershed. In other words, AllForX is an indication of how much higher current sediment loads are above an undeveloped condition. These multipliers were calculated for a total of 23 watersheds of similar size and within the same ecoregion as the TMDL watersheds (**Appendix C**). These watersheds included both unimpaired and impaired streams to represent a wide distribution of current conditions. A regression was then developed between the 33rd percentile of Virginia Stream Condition Index (VSCI) scores at monitoring stations and the corresponding AllForX ratio calculated for each contributing watershed. The 33rd percentile was used because DEQ biologists often prefer two consecutive years of benthic monitoring above the VSCI threshold of 60 before delisting the stream as unimpaired to account for seasonal and annual variation. Based on a 6-yr assessment window and typical DEQ monitoring every 2 years, no more than a third (33%) of benthic scores could be below the threshold of 60 and meet the recommendations for delisting. This approach accounts for natural variability in VSCI scores over time and considers the methodology for assessing and delisting Virginia streams. **Table 5-1** shows the regression developed for Beaverdam Creek, Fryingpan Creek, Pigg River, and Poplar Branch. Based on the regression, a 33rd percentile VSCI score of 60 corresponded to a target AllForX ratio of 4.7 (**Figure 5-1**). This means that the TMDL streams are expected to achieve consistently healthy benthic conditions if sediment loads are less than 4.7 times the simulated load of an all-forested watershed. The AllForX target of 4.7 was then used to determine the allowable pollutant TMDL loads in the study watersheds.

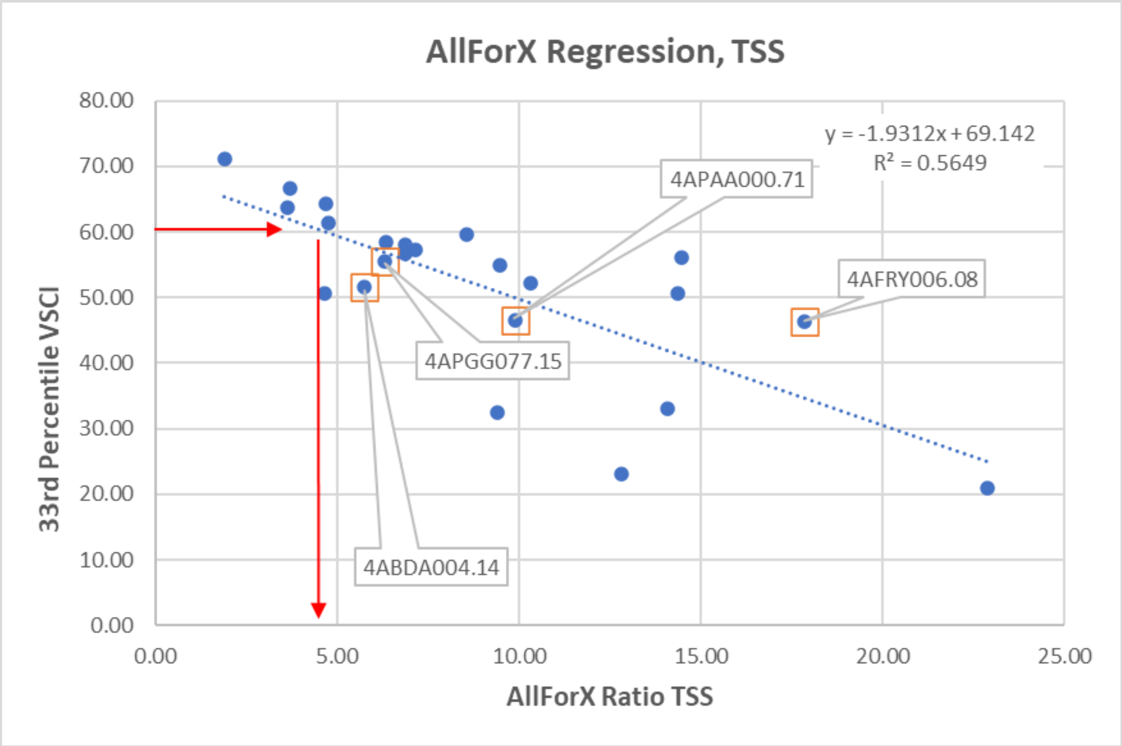

Figure 5-1. Regression between stream condition index and all-forest multiplier for sediment in the Beaverdam Creek, Fryingpan Creek, Pigg River, and Poplar Branch TMDL using the 33rd percentile of VSCI scores, resulting in an AllForX target ratio of 4.7.

Table 5-1. Target sediment loading rates and reductions as determined by AllForX regression for Beaverdam Creek, Fryingpan Creek, Pigg River, and Poplar Branch TMDL. Existing loads listed include both point and nonpoint sources, BMPs, and the margin of safety and future growth, as discussed in Section 6.0. Values have been rounded to three significant figures.

Impaired Stream	TSS Existing (lb/yr)	TSS AllForest (lb/yr)	TSS Target (lb/yr)	Estimated % Reduction
Beaverdam Creek	3,300,000	533,000	2,520,000	23.7%
Fryingpan Creek	1,020,000	69,700	329,000	67.7%
Pigg River	2,610,000	414,000	1,960,000	24.9%
Poplar Branch	311,000	35,500	168,000	46.0%

6.0 TMDL ALLOCATIONS

Total maximum daily loads are determined as the maximum allowable load of a pollutant among the various sources. Part of developing a TMDL is allocating this load among the various sources of the pollutant of concern (POC). Each TMDL is comprised of three components, as summed up in this equation:

$$TMDL = \sum WLA + \sum LA + MOS$$

where ΣWLA is the sum of the wasteload allocations (permitted sources),
ΣLA is the sum of the load allocations (nonpoint sources), and
MOS is a margin of safety.

The wasteload allocation (WLA) is calculated as the sum of all the permitted sources of the POC within the watershed as if they were discharging at their permitted allowable rate. A description of the permitted sources and their permitted loads are included in **Section 4.3.2**. A set-aside for future growth is also included in the WLA to account for potential future permitted activity in the watershed. The margin of safety (MOS) is determined based on the characteristics of the watershed and the model used to develop the TMDL loads (see **Section 6.1**). The overall load allocation (LA) is then calculated by subtracting the total WLA and MOS from the TMDL. Various allocation scenarios are typically developed to show different breakdowns of how this LA can be divided among the various nonpoint sources of the POC (**Section 6.4**).

For model runs to develop the annual existing loads and target loads using the AllForX methodology, a 20-year period was simulated (2001 through 2020) with an additional buffer period of nine months at the beginning of the run to serve as a ‘warm-up’ period for the model to equilibrate and minimize the impact of uncertain initial conditions. Using this extended modeling period allows the results to account for both annual and seasonal variations in hydrology and sediment loading.

6.1. Margin of Safety

To account for uncertainties inherent in model outputs, a margin of safety (MOS) is incorporated into the TMDL development process. The MOS can be implicit, explicit, or a combination of the two. An implicit MOS involves incorporating conservative assumptions into the modeling process to ensure that the final TMDL is protective of water quality considering the unavoidable uncertainty in the modeling process. A MOS can also be incorporated explicitly into the TMDL development by setting aside a portion of the TMDL.

This TMDL includes both implicit and explicit MOSs. An example of implicit MOS assumptions incorporated into this TMDL are the inclusion of permitted loads at their maximum permitted rates, even when data shows that they are consistently discharging well below that threshold. An explicit MOS of 10% is also included in the TMDLs. This is a typical value used in sediment TMDLs throughout the state to account for unavoidable uncertainties in the modeling process.

6.2. Future Growth

An allocation of 2% of the total load is specifically set aside for future growth within the TMDL. This leaves flexibility in the plan for future permitted loads to be added within the watersheds, as the development of a TMDL looks only at a snapshot in time within the watershed and is not meant to prevent future economic growth.

6.3. TMDL Calculations

Sediment was determined to be the primary cause of the benthic impairments in each of the impaired watersheds (**Appendix D**), hence TMDLs were developed for sediment in each impaired watershed.

The final sediment average annual load allocated in each watershed's TMDL is presented in **Table 6-1** through **Table 6-4**. GWLF output data, being in monthly increments, is most logically presented as annual aggregates. Any apparent differences in calculated values are due to rounding. Model results were rounded to 4 significant figures, and calculated totals of those results were rounded to 3 significant figures.

Table 6-1. Annual average sediment TMDL components for Beaverdam Creek, existing load incorporates the future growth and margin of safety.

Impairment	WLA (lb/yr)	LA (lb/yr)	MOS (lb/yr)	TMDL (lb/yr)	Existing Load (lb/yr)	Reduction (%)
Beaverdam Creek (VAW-L07R_BDA01A00, VAW-L07R_BDA02A00)	**51,410**	**2,216,000**	**252,000**	**2,520,000**	3,300,000	23.7%
Domestic Sewage Permits	*183*					
VPDES Individual Permit	*822*					
Future Growth (2% of TMDL)	*50,410*					

Table 6-2. Annual average sediment TMDL components for Fryingpan Creek, existing load incorporates the future growth and margin of safety.

Impairment	WLA (lb/yr)	LA (lb/yr)	MOS (lb/yr)	TMDL (lb/yr)	Existing Load (lb/yr)	Reduction (%)
Fryingpan Creek (VAW-L18R_FRY01A06)	**6,593**	**289,300**	**32,960**	**329,000**	1,020,000	67.8%
Future Growth (2% of TMDL)	*6,593*					

Table 6-3. Annual average sediment TMDL components for the Pigg River, existing load incorporates the future growth and margin of safety.

Impairment	WLA (lb/yr)	LA (lb/yr)	MOS (lb/yr)	TMDL (lb/yr)	Existing Load (lb/yr)	Reduction (%)
Pigg River (VAW-L14R_PGG05B12, VAW-L14R_PGG06A02, VAW-L14R_PGG06B12)	**39,200**	**1,724,000**	**196,000**	**1,960,000**	2,610,000	24.9%
Future Growth (2% of TMDL)	*39,200*					

Table 6-4. Annual average sediment TMDL components for Poplar Branch, existing load incorporates the future growth and margin of safety.

Impairment	WLA (lb/yr)	LA (lb/yr)	MOS (lb/yr)	TMDL (lb/yr)	Existing Load (lb/yr)	Reduction (%)
Poplar Branch (VAW-L17R_PAA01A04)	**3,357**	**147,500**	**16,780**	**168,000**	311,000	46.1%
Future Growth (2% of TMDL)	*3,357*					

In 1991, the USEPA released a support document that included guidance for developing maximum daily loads (MDLs) for TMDLs (USEPA, 1991). A methodology detailed therein was used to determine the MDLs for the watersheds. The long-term average (LTA) daily loads, derived by dividing the average annual loads in **Table 6-1** through **Table 6-4** by 365.24, are converted to MDLs using the following equation:

$$MDL = LTA * \exp(Z_p\sigma_y - 0.5\sigma_y^2)$$

where Z_p = pth percentage point of the normal standard deviation, and

σ_y = sqrt(ln(CV^2+1)), with CV = coefficient of variation of the data.

The variable Z_p was set to 1.645 for this TMDL development, representing the 95th percentile. The CV values and final calculated multipliers to convert LTA to MDL values are summarized in **Table 6-5.**

Table 6-5. "LTA to MDL multiplier" components.

Watershed	CV of Average Annual Loads	"LTA to MDL Multiplier"
Beaverdam Creek	0.70	2.32
Fryingpan Creek	0.74	2.38
Pigg River	0.73	2.37
Poplar Branch	0.74	2.39

The daily WLA was estimated as the annual WLA divided by 365.24. The daily MOS was estimated as 10% of the MDL. Finally, the daily LA was estimated as the MDL minus the daily MOS minus the daily WLA. These results are shown in **Table 6-6** through **Table 6-9**.

Table 6-6. Maximum 'daily' sediment loads and components for Beaverdam Creek.

Impairment	WLA (lb/day)	LA (lb/day)	MOS (lb/day)	MDL (lb/day)
Beaverdam Creek (VAW-L07R_BDA01A00, VAW-L07R_BDA02A00)	**141**	**14,300**	**1,600**	**16,000**
Domestic Sewage Permits	*0.25*			
IVPDES Individual Permit	*2.25*			
Future Growth	*138*			

Table 6-7. Maximum 'daily' sediment loads and components for Fryingpan Creek.

Impairment	WLA (lb/day)	LA (lb/day)	MOS (lb/day)	MDL (lb/day)
Fryingpan Creek (VAW-L18R_FRY01A06)	**18.1**	**1,910**	**214**	**2,140**
Future Growth	*18.1*			

Table 6-8. Maximum 'daily' sediment loads and components for the Pigg River.

Impairment	WLA (lb/day)	LA (lb/day)	MOS (lb/day)	MDL (lb/day)
Pigg River (VAW-L14R_PGG05B12, VAW-L14R_PGG06A02, VAW-L14R_PGG06B12))	**107**	**11,300**	**1,270**	**12,700**
Future Growth	*107*			

Table 6-9. Maximum 'daily' sediment loads and components for Poplar Branch.

Impairment	WLA (lb/day)	LA (lb/day)	MOS (lb/day)	MDL (lb/day)
Poplar Branch (VAW-L17R_PAA01A04)	**9.19**	**981**	**110**	**1,100**
Future Growth	*9.19*			

6.4. Allocation Scenarios

Various scenarios were run to determine possible options for reducing the sediment loads in the study watersheds to the recommended TMDL loads. Feedback from the TAC members was used to select preferred allocation scenarios. Feedback from stakeholders indicated that evenly spreading the required reductions among the various largely anthropogenic sources of sediment in the watersheds would be the best fit. The watersheds have a mix of agricultural and urban sources, so it seemed most equitable to share the burden evenly. This scenario allows for future implementation to target BMPs that address both agriculture and urban sources. The selected sediment allocation scenarios are presented in **Table 6-10** through **Table 6-13**.

Any apparent differences in calculated values are due to rounding. Model results were rounded to 4 significant figures, and calculated totals of those results were rounded to 3 significant figures.

Table 6-10. Allocation scenario for Beaverdam Creek sediment loads.

Source	**Existing (lb/yr)**	**Red. %**	**Allocation (lb/yr)**
Cropland	17,810	30.4	12,400
Hay	132,100	30.4	91,970
Pasture	1,686,000	30.4	1,173,000
Forest	304,700	-	304,700
Trees	96,380	-	96,380
Shrub	24,450	-	24,450
Harvested	110,800	30.4	77,130
Wetland	405	-	405
Barren	0	-	0
Turfgrass	64,030	30.4	44,560
Developed Pervious	5,339	30.4	3,716
Developed Impervious	258,700	30.4	180,000
Streambank Erosion	297,300	30.4	206,900
Permits	1,005	-	1,005
MOS (10%)	252,000	-	252,000
Future Growth (2%)	50,400	-	50,400
TOTAL	**3,300,000**		**2,520,000**
	0% red.		**23.7% red.**

Table 6-11. Allocation scenario for Fryingpan Creek sediment loads.

Source	Existing (lb/yr)	Red. %	Allocation (lb/yr)
Cropland	470,800	76.1	112,500
Hay	27,880	76.1	6,662
Pasture	318,100	76.1	76,010
Forest	42,260	-	42,260
Trees	6,609	-	6,609
Shrub	7,081	-	7,081
Harvested	24,080	76.1	5,756
Wetland	16,030	-	16,030
Barren	27,380	76.1	6,544
Turfgrass	5,384	76.1	1,287
Developed Pervious	296	76.1	71
Developed Impervious	25,490	76.1	6,092
Streambank Erosion	9,796	76.1	2,341
MOS (10%)	32,960	-	32,960
Future Growth (2%)	6,593	-	6,593
TOTAL	**1,020,000** **0% red.**		**329,000** **67.8% red.**

Table 6-12. Allocation scenario for Pigg River sediment loads.

Source	Existing (lb/yr)	Red. %	Allocation (lb/yr)
Cropland	387,800	31.5	265,700
Hay	48,590	31.5	33,290
Pasture	1,211,000	31.5	829,800
Forest	270,100	-	270,100
Trees	30,640	-	30,640
Shrub	3,872	-	3,872
Harvested	79,560	31.5	54,500
Wetland	5,177	-	5,177
Barren	87,440	31.5	59,900
Turfgrass	13,990	31.5	9,586
Developed Pervious	1,929	31.5	1,322
Developed Impervious	71,400	31.5	48,910
Streambank Erosion	161,900	31.5	110,900
MOS (10%)	196,000	-	196,000
Future Growth (2%)	39,200	-	39,200
TOTAL	**2,610,000** **0% red.**		**1,960,000** **24.9% red.**

Table 6-13. Allocation scenario for Poplar Branch sediment loads.

Source	Existing (lb/yr)	Red. %	Allocation (lb/yr)
Cropland	92,610	56.1	40,660
Hay	11,130	56.1	4,888
Pasture	101,300	56.1	44,490
Forest	25,070	-	25,070
Trees	4,793	-	4,793
Shrub	3,200	-	3,200
Harvested	27,970	56.1	12,280
Wetland	2,359	-	2,359
Barren	0	-	0
Turfgrass	4,205	56.1	1,846
Developed Pervious	595	56.1	261
Developed Impervious	15,630	56.1	6,861
Streambank Erosion	1,768	56.1	776
MOS (10%)	16,780	-	16,780
Future Growth (2%)	3,357	-	3,357
TOTAL	**311,000** **0% red.**		**168,000** **46.1% red.**

7.0 TMDL IMPLEMENTATION AND REASONABLE ASSURANCE

7.1. Regulatory Framework

There is a regulatory framework in place to help enforce the development and attainment of TMDLs and their stated goals on both the federal and the state level in Virginia. On the federal level, Section 303(d) of the Clean Water Act and current USEPA regulations, while not explicitly requiring the development of TMDL implementation plans as part of the TMDL process, do require reasonable assurance that the load and waste load allocations can and will be implemented. Federal regulations also require that all new or revised National Pollutant Discharge Elimination System (NPDES) permits must be consistent with the assumptions and requirements of any applicable TMDL WLA (40 CFR §122.44 (d)(1)(vii)(B)).

At the state level, Virginia's 1997 Water Quality Monitoring, Information and Restoration Act (WQMIRA) directs the State Water Control Board to "develop and implement a plan to achieve fully supporting status for impaired waters" (Section 62.1-44.19.7). WQMIRA also establishes that the implementation plan shall include the date of expected achievement of water quality objectives, measurable goals, corrective actions necessary and the associated costs, benefits and environmental impacts of addressing the impairments. As part of the Continuing Planning Process, DEQ staff will present the TMDLs to the State Water Control Board (SWCB) for inclusion in the appropriate Water Quality Management Plan (WQMP), in accordance with the Clean Water Act's Section 303(e) and Virginia's Public Participation Guidelines for Water Quality Management Planning.

VADEQ regulates stormwater discharges associated with permitted activities through its VPDES program and stormwater discharges from construction sites and MS4s through its VSMP program. All new or revised permits must be consistent with the assumptions and requirements of any applicable TMDL WLA.

7.2. Implementation Plans

Implementation plans set intermediate goals and describe actions (with associated costs) that can be taken to clean up impaired streams. Some of the actions that may be included in an implementation plan to address excess sediment include:

- Fence out cattle from streams and provide alternative water sources
- Implement conservation tillage practices on cropland
- Conduct stream bank restoration projects in areas where banks are actively eroding
- Leave a band of 35 – 100 ft along the stream natural so that it buffers or filters out sediment from farm or residential land (a riparian buffer)
- Expand street sweeping programs in urban areas

- Reduce runoff by increasing green spaces and reducing hardened spaces (asphalt or concrete)

Overall, implementation of TMDLs works best with a targeted, staged approach, directing initial efforts where the biggest impacts can be made with the least effort so that money, time, and other resources are spent efficiently to maximize the benefit to water quality. Progress towards meeting water quality goals defined in the implementation plan will be assessed during implementation by the tracking of new BMP installations and continued water quality monitoring by VADEQ. Several BMPs have already been implemented in the watershed and were accounted for in the development of this TMDL (**Section 4.4**).

Implementation plans also identify potential sources of funding to help in the clean-up efforts. Funds are often available in the form of cost-share programs, which share the cost of improvements with the landowner. Potential sources of funding include USEPA Section 319 funding for Virginia's Nonpoint Source Management Program, the USDA's Conservation Reserve Enhancement Program (CREP) and its Environmental Quality Incentive Program (EQIP), the Virginia State Revolving Loan Program, and the Virginia Water Quality Improvement Fund. The Virginia Guidance Manual for Total Maximum Daily Load Implementation Plans (VADEQ, 2017) contains information on a variety of funding sources, as well as government agencies that might support implementation efforts and suggestions for integrating TMDL implementation with other watershed planning efforts. Additional sources are also often available for specific projects and regions of the state. State agencies and other stakeholders may help identify funding sources to support the plan, but actually making the improvements is up to those that live in the watershed. Part of the purpose of developing a TMDL and implementation plan is to increase education and awareness of the water quality issues in the watershed and encourage residents and stakeholders to work together to improve the watershed.

7.3. Reasonable Assurance

The following activities provide reasonable assurance that these TMDLs will be implemented and water quality will be restored in the Beaverdam Creek, Fryingpan Creek, Pigg River, and Poplar Branch watersheds.

- Regulatory frameworks – Existing federal and state regulations require that new and existing permits comply with the developed TMDLs. State law also requires that implementation plans be developed to meet TMDL goals.
- Funding sources – Numerous funding sources (listed above) are available to defray the cost of TMDL implementation.
- Public participation – Public participation in the TMDL process informs and mobilizes watershed residents and stakeholders to take the necessary actions to implement the TMDL.

- Continued monitoring – Water quality and aquatic life monitoring will continue in the TMDL watersheds and track progress towards the TMDL goals. VADEQ will continue monitoring benthic macroinvertebrates and habitat in accordance with its biological monitoring program stations throughout the watershed.
- Current implementation actions – Several voluntary and subsidized best management practices have already been installed in these watersheds. The Soil and Water Conservation Districts and NRCS are actively working in these areas to promote and implement additional practices that can reduce sediment loads.

8.0 PUBLIC PARTICIPATION

Public participation was elicited at every stage of the TMDL study in order to receive input from stakeholders and to apprise the stakeholders of progress made. A series of three Technical Advisory Committee (TAC) meetings and two public meetings took place during the TMDL development process. Watershed tours were organized for each watershed for TAC members to become familiar with land uses in the watersheds and stream characteristics. The TAC included representatives from Blue Ridge Soil and Water Conservation District, Peaks of Otter Soil and Water Conservation District, Pittsylvania Soil and Water Conservation District, Roanoke Valley Alleghany Regional Commission, Franklin County, Friends of the Rivers of Virginia, Leesville Lake Association, Virginia Department of Forestry, and Appalachian Electric Power.

A preliminary TAC meeting (17 attendees, October 7th, 2021) was held in Waid Park in Rocky Mount, VA to discuss the TMDL process, the existing bacteria TMDL for the Pigg River, review the impairments and collected water quality data, provided preliminary results of the benthic stressor analysis study, and plan for the first public meeting to kick off the project.

The first public meeting (17 attendees, November 18th, 2021) was held at the Essig Recreational Center in Rocky Mount, VA. This meeting introduced attendees to DEQ's water quality planning process, the TMDL purpose and process, review benthic monitoring data collected from the four study watersheds, discuss the impairments, review the preliminary results of the stressor analysis, and solicit input on the land cover data being used in model development

The second TAC meeting (10 attendees, April 5th, 2022) was held at the Franklin County Public Library in Rocky Mount, VA. This meeting discussed the completed stressor analysis report results and the modeling process, permitted sources and existing BMPs in the watershed, and the initial results of the watershed model and estimated pollutant reductions needed for each watershed. A third TAC meeting (19 attendees, May 10th, 2022), also in the Franklin County Public Library, was held to gather input on the preferred allocation scenarios for the final TMDL.

A final public meeting was held on 09/27/2022 at The Franklin Center in Rocky Mount, VA to present the draft TMDL document. The public meeting marked the beginning of the official public comment period and was attended by ## watershed residents and other stakeholders. The public comment period ended on 10/27/2022.

.

References

Chesapeake Bay Program (CBP). 1998. Chesapeake Bay Watershed Model application and calculation of nutrient and sediment loadings. Appendix I: Model Operations Manual. A Report of the Chesapeake Bay Program Modeling Subcommittee. August 1998. Annapolis, MD.

Daly, C., Halbleib, M., Smith, J. I., Gibson, W. P., Doggett, M. K., Taylor, G. H., . . . Pasteris, P. P. (2008). Physiographically sensitive mapping of climatological temperature and precipitation across the conterminous United States. *International Journal of Climatology*. doi:10.1002/joc.1688 https://prism.oregonstate.edu/documents/pubs/2008intjclim_physiographicMapping_daly.pdf

Evans, B. M., S. A. Sheeder, K. J. Corradini, and W. S. Brown. 2001. AVGWLF version 3.2. Users Guide. Environmental Resources Research Institute, Pennsylvania State University and Pennsylvania Department of Environmental Protection, Bureau of Watershed Conservation.

Evans, B.M., S. A. Sheeder, and D.W. Lehning. 2003. A spatial technique for estimating streambank erosion based on watershed characteristics. J. Spatial Hydrology, Vol. 3, No. 1.

Haith, D. A., R. Mandel, and R. S. Wu. 1992. GWLF. Generalized Watershed Loading

Functions, version 2.0. User’s Manual. Department of Agricultural and Biological Engineering, Cornell University. Ithaca, New York.

Hession, W. C., M. McBride, and L. Misiura. 1997. Revised Virginia nonpoint source pollution assessment methodology. A report submitted to the Virginia Department of Conservation and Recreation, Richmond, Virginia. The Academy of Natural Sciences of Philadelphia, Patrick Center for Environmental Research. Philadelphia, Pennsylvania.

State Water Control Board (SWCB). 2011. 9VAC 25-260 Virginia Water Quality Standards. https://www.epa.gov/sites/production/files/2014-12/documents/vawqs.pdf. Accessed 9 April 2020.

Street and Storm Drain Cleaning Expert BMP Review Panel (SSDCEP). 2015. Recommendations of the Expert Panel to Define Removal Rates for Street and Storm Drain Cleaning Practices. 18 September 2015.

Tetra Tech. 2003. A stream condition index for Virginia non-coastal streams. Prepared for USEPA Office of Science and Technology, USEPA Region 3 Environmental Services Division, and Virginia Department of Environmental Quality. Available at: https://www.deq.virginia.gov/Portals/0/DEQ/Water/WaterQualityMonitoring/BiologicalMonitoring/vsci.pdf. Accessed 9 April 2020.

US Census Bureau. 2018. Census QuickFacts. Available at: https://www.census.gov/quickfacts/fact/table/US/PST045216. Accessed 8 January 2019.

USEPA. 1991. Technical Support Document for Water Quality-based Toxics Control. EPA/505/2-90-001 PB91-127415. U.S. Environmental Protection Agency, Office of Water, Washington DC. March 1991.

USEPA. 2010. *Chesapeake Bay Phase 5.3 Community Watershed Model*. EPA 903S10002 - CBP/TRS-303-10. U.S. Environmental Protection Agency, Chesapeake Bay Program Office, Annapolis MD. December 2010.

VADCR. 2020. 2020 NPS Assessmenet Land Use/Land Cover Database. http://www.dcr.virginia.gov/soil-and-water/npsassmt. Accessed 16 September 2021.

VADEQ. 2005. Memorandum from Jutta Schneider, entitled “Error in Channel Erosion Calculation using GWLF”. December 16, 2005. Virginia Department of Environmental Quality. Richmond, Virginia.

VADEQ. 2006. Using probabilistic monitoring data to validate the non-coastal Virginia Stream Condition Index. VADEQ Technical Bulletin WQA/2006-001. Richmond, Va.: Virginia Department of Environmental Quality; Water Quality Monitoring, Biological Monitoring and Water Quality Assessment Programs. Available at: http://www.deq.virginia.gov/Portals/0/DEQ/Water/WaterQualityMonitoring/ProbabilisticMonitoring/scival.pdf. Accessed 9 April 2020.

VADEQ. 2014. Water Quality Assessment Guidance Manual for 2014 305(b)/303(d) Integrated Water Quality Report. Available at: http://www.deq.virginia.gov/Portals/0/DEQ/Water/Guidance/142005.pdf. Accessed 9 April 2017.

VADEQ. 2020. Final 2020 305(b)/303(d) Water Quality Assessment Integrated Report. Available at: https://www.deq.virginia.gov/water/water-quality/assessments/integrated-report. Accessed 16 September 2021.

VADEQ. 2017. Guidance Manual for Total Maximum Daily Load Implementation Plans.

Woods, A. J., J. M. Omernik, and D. D. Brown. 1999. Level III and IV Ecoregions of Delaware, Maryland, Pennsylvania, Virginia, and West Virginia. U. S. Environmental Protections Agency.

Yagow, G., S. Mostaghimi, and T. Dillaha. 2002. GWLF model calibration for statewide NPS assessment. Virginia NPS pollutant load assessment methodology for 2002 and 2004 statewide NPS pollutant assessments. January 1 – March 31, 2002 Quarterly Report. Submitted to Virginia Department of Conservation and Recreation, Division of Soil and Water Conservation. Richmond, Virginia.

Yagow, G. and W.C. Hession. 2007. Statewide NPS Pollutant Load Assessment in Virginia at the Sixth Order NWBD Level: Final Project Report. VT-BSE Document No. 2007-0003. Submitted to the Virginia Department of Conservation and Recreation, Richmond, Virginia.

Appendix A - GWLF Model Parameters

Various GWLF parameters used for the Beaverdam Creek, Fryingpan Creek, Pigg River, and Poplar Branch watersheds are detailed below. **Table A-1** and **Table A-2** list the various watershed-wide parameters. The land use parameters for the watersheds are listed in **Table A-3** through **Table A-6**.

Table A-1. Watershed-wide GWLF parameters.

GWLF Parameter	Units	Value
Recession Coefficient	day^{-1}	0.03
Seepage Coefficient	day^{-1}	0.02
Leakage Coefficient	day^{-1}	0.25
Erosivity Coefficient (Nov-Mar)		0.12
Erosivity Coefficient (Apr-Oct)		0.33

Table A-2. Additional GWLF watershed parameters.

GWLF Parameter	Beaverdam Creek	Fryingpan Creek	Pigg River	Poplar Branch
Sediment Delivery Ratio	0.1275	0.2060	0.1501	0.2925
Unsaturated Water Capacity (cm)	21.68	20.11	17.94	18.89
aFactor	0.0001016	0.0000546	0.0000809	0.0000773
Total Stream Length (m)	26,125	7,585	30,198	3,004
Mean Channel Depth (m)	3.26	1.79	2.66	1.16
ET Cover Coefficient, Apr-Oct	0.9702	0.9764	0.9875	0.9686
ET Cover Coefficient, Nov-Mar	0.8254	0.8186	0.8102	0.8028

Table A-3. Pervious land cover parameters for Beaverdam Creek.

Land Cover	Area (ha)	CN	KLSCP	Sediment Build-up (kg/ha-d)
High_till	2.46	78.00	0.05040	n/a
Low_till	8.10	74.00	0.00612	n/a
Hay	718.30	57.95	0.00280	n/a
Pasture_Good	0.00	0.00	0.00000	n/a
Pasture_Fair	513.81	68.97	0.02802	n/a
Pasture_Poor	68.61	78.99	0.04974	n/a
Forest	4207.22	55.56	0.00122	n/a
Trees	701.56	57.69	0.00206	n/a
Shrub	36.28	48.84	0.01450	n/a
Harvested Forest	76.57	67.15	0.01590	n/a
Water	29.82	98.00	0.00000	n/a
Wetland	1.90	48.05	0.00455	n/a
Barren	0.00	0.00	0.00000	n/a
Turfgrass	419.06	61.04	0.00202	n/a
Developed pervious	13.15	60.81	0.00548	n/a
Developed impervious	52.62	98.00	0.00000	6.2
Impervious local dataset	125.67	98.00	0.00000	2.8

Table A-4. Pervious land cover parameters for Fryingpan Creek.

Land Cover	Area (ha)	CN	KLSCP	Sediment Build-up (kg/ha-d)
High_till	52.43	78.09	0.04367	n/a
Low_till	41.63	74.09	0.00530	n/a
Hay	218.87	58.01	0.00122	n/a
Pasture_Good	0.00	0.00	0.00000	n/a
Pasture_Fair	124.70	69.01	0.01225	n/a
Pasture_Poor	25.25	79.01	0.02174	n/a
Forest	722.41	55.48	0.00058	n/a
Trees	68.49	58.05	0.00091	n/a
Shrub	14.12	48.00	0.00672	n/a
Harvested Forest	17.70	66.00	0.00940	n/a
Water	12.39	98.00	0.00000	n/a
Wetland	25.17	65.49	0.00444	n/a
Barren	2.43	71.00	0.06903	n/a
Turfgrass	48.49	61.18	0.00091	n/a
Developed pervious	1.05	61.00	0.00231	n/a
Developed impervious	4.19	98.00	0.00000	6.2
Impervious local dataset	14.58	98.00	0.00000	2.8

Table A-5. Land cover parameters for the Pigg River.

Land Cover	Area (ha)	CN	KLSCP	Sediment Build-up (kg/ha-d)
High_till	23.40	79.06	0.06407	n/a
Low_till	177.83	75.06	0.00778	n/a
Hay	240.43	58.69	0.00246	n/a
Pasture_Good	0.00	0.00	0.00000	n/a
Pasture_Fair	278.17	69.53	0.02463	n/a
Pasture_Poor	71.69	79.37	0.04371	n/a
Forest	2860.20	56.24	0.00132	n/a
Trees	181.19	58.60	0.00208	n/a
Shrub	9.46	54.89	0.00614	n/a
Harvested Forest	43.14	65.64	0.01754	n/a
Water	1.88	98.00	0.00000	n/a
Wetland	15.80	57.15	0.00451	n/a
Barren	1.81	71.00	0.40686	n/a
Turfgrass	77.88	61.30	0.00200	n/a
Developed pervious	4.05	61.13	0.00526	n/a
Developed impervious	16.21	98.00	0.00000	6.2
Impervious local dataset	30.96	98.00	0.00000	2.8

Table A-6. Land cover parameters for the Poplar Branch.

Land Cover	Area (ha)	CN	KLSCP	Sediment Build-up (kg/ha-d)
High_till	4.88	78.00	0.04347	n/a
Low_till	27.23	74.00	0.00528	n/a
Hay	52.36	58.00	0.00138	n/a
Pasture_Good	0.00	0.00	0.00000	n/a
Pasture_Fair	24.18	69.00	0.01377	n/a
Pasture_Poor	4.44	79.00	0.02444	n/a
Forest	229.74	55.11	0.00076	n/a
Trees	26.23	58.16	0.00121	n/a
Shrub	4.77	48.00	0.00630	n/a
Harvested Forest	17.22	66.00	0.00790	n/a
Water	3.59	98.00	0.00000	n/a
Wetland	2.57	55.00	0.00705	n/a
Barren	0.00	0.00	0.00000	n/a
Turfgrass	21.81	61.03	0.00108	n/a
Developed pervious	0.97	61.13	0.00346	n/a
Developed impervious	3.88	98.00	0.00000	6.2
Impervious local dataset	6.04	98.00	0.00000	2.8

Appendix B - Sensitivity Analysis

Analyses were conducted to assess the sensitivity of the model to changes in hydrologic and water quality parameters, as well as to assess the potential impact of uncertainty in parameter determination. Sensitivity analyses were run on the parameters listed in **Table A-1** through **Table A-6**. The outputs from model runs using the listed base parameter values were compared to model runs changing each of the parameters by +10% and -10% of the base value. The results are shown in **Table B-1** through **Table B-4**.

The relationships exhibit largely nonlinear responses, such as decreasing AWC by 10% increasing runoff volume more than a 10% lower AWC served to increase the volume. Changes in variables specific to sediment such as KLSCP had no impact on hydrology, which was to be expected. Changes in curve numbers had the most influence on the pollutant load, followed by KLSCP. Changes in other hydrologic parameters had more impact on runoff volume than on sediment load, with curve number and the seepage and recession coefficients having the second largest impacts on hydrology after ET-CV.

Table B-1. Results of the GWLF sensitivity for Beaverdam Creek.

Model Parameter	Parameter Change (%)	Total Runoff Volume Change (%)	Total Sediment Load Change (%)
CN	+10	2.94%	19.66%
	-10	-2.80%	-17.19%
KLSCP	+10	0.00%	8.56%
	-10	0.00%	-8.54%
Recession Coefficient	+10	3.21%	0.17%
	-10	-3.63%	-0.20%
Seepage Coefficient	+10	-3.27%	-0.19%
	-10	3.54%	0.20%
Leakage Coefficient	+10	2.78%	0.18%
	-10	-2.64%	-0.18%
AWC	+10	-0.35%	-0.02%
	-10	0.59%	0.04%
ET-CV	+10	-6.00%	-0.34%
	-10	6.91%	0.39%

Table B-2. Results of the GWLF sensitivity for Fryingpan Creek.

Model Parameter	Parameter Change (%)	Total Runoff Volume Change (%)	Total Sediment Load Change (%)
CN	+10	3.04%	17.77%
	-10	-2.60%	-16.18%
KLSCP	+10	0.00%	9.39%
	-10	0.00%	-9.99%
Recession Coefficient	+10	3.20%	0.02%
	-10	-3.61%	-0.02%
Seepage Coefficient	+10	-3.26%	-0.02%
	-10	3.53%	0.02%
Leakage Coefficient	+10	2.68%	0.02%
	-10	-2.62%	-0.02%
AWC	+10	-0.46%	0.00%
	-10	0.96%	0.01%
ET-CV	+10	-5.29%	-0.03%
	-10	6.64%	0.04%

Table B-3. Results of the GWLF sensitivity for the Pigg River.

Model Parameter	Parameter Change (%)	Total Runoff Volume Change (%)	Total Sediment Load Change (%)
CN	+10	2.53%	17.87%
	-10	-1.94%	-16.06%
KLSCP	+10	0.00%	9.81%
	-10	0.00%	-8.89%
Recession Coefficient	+10	3.30%	0.13%
	-10	-3.72%	-0.15%
Seepage Coefficient	+10	-3.36%	-0.14%
	-10	3.63%	0.15%
Leakage Coefficient	+10	2.64%	0.13%
	-10	-2.67%	-0.13%
AWC	+10	-0.97%	-0.04%
	-10	1.34%	0.06%
ET-CV	+10	-4.48%	-0.18%
	-10	6.08%	0.25%

Table B-4. Results of the GWLF sensitivity for Poplar Branch.

Model Parameter	Parameter Change (%)	Total Runoff Volume Change (%)	Total Sediment Load Change (%)
CN	+10	3.31%	18.90%
	-10	-2.84%	-18.01%
KLSCP	+10	0.00%	8.51%
	-10	0.00%	-9.97%
Recession Coefficient	+10	3.17%	0.01%
	-10	-3.58%	-0.01%
Seepage Coefficient	+10	-3.23%	-0.01%
	-10	3.49%	0.01%
Leakage Coefficient	+10	2.67%	0.01%
	-10	-2.51%	-0.01%
AWC	+10	-0.55%	0.00%
	-10	1.08%	0.00%
ET-CV	+10	-4.55%	-0.02%
	-10	6.30%	0.02%

Appendix C - AllForX Development

The method used to set TMDL endpoint loads for the Beaverdam Creek, Fryingpan Creek, Pigg River, and Poplar Branch watersheds is called the "all-forest load multiplier" (AllForX) approach, introduced in **Section 5.0**. AllForX is the ratio calculated by dividing the simulated pollutant load under existing conditions by the pollutant load from an all-forest simulated condition for the same watershed. In other words, AllForX is an indication of how much higher current sediment loads are above an undeveloped condition. After calculating AllForX values for a range of comparison monitoring stations, a regression is developed between the AllForX values and corresponding VSCI scores at those stations (**Figure C-1**). This relationship between AllForX values and VSCI scores can be used to quantify the AllForX value that corresponds to the VSCI threshold score of 60.

These multipliers were calculated for a total of 23 comparison watersheds (**Figure C-2**). These watersheds included both unimpaired and impaired streams to represent a wide distribution of current conditions. Watersheds used in developing the VSCI and AllForX regression were selected to be similar in size and located near the study watersheds, ideally within the same ecoregion, to minimize differences in flow regime, soils, and other physiographic properties. Additionally, the watersheds must have adequate and recent VSCI data for a watershed to be a useful data point. The VSCI scores at each station since 2011 were included in the analysis.

For the purposes of building the AllForX regression, permitted sources were not included. This was to allow for flexibility to incorporate other watersheds into the regression that may have less available data. The same set of models were run a second time, changing all of the land use parameters to reflect forested land cover while preserving the unique soil and slope characteristics of each watershed. The AllForX multiplier was calculated for each modeled watershed by dividing the original model loads by the All-Forested model loads. This data is presented in **Table C-1**.

A regression was then developed between the 33rd percentile of Virginia Stream Condition Index (VSCI) scores at monitoring stations and the corresponding AllForX ratio calculated for the watershed draining to each station. The 33rd percentile was used because DEQ recommends two consecutive years of benthic monitoring above the VSCI threshold of 60 before delisting the stream as unimpaired. Based on a 6-yr assessment window and typical DEQ monitoring every 2 years, no more than a third (33%) of benthic scores could be below the threshold of 60 and meet the qualifications for delisting. This approach accounts for natural variability in VSCI scores over time and considers the methodology for assessing and delisting Virginia streams.

The AllForX values were plotted against their associated 33rd percentile VSCI scores and a linear regression was plotted through the values (**Figure C-1**). The regression for sediment (TSS) resulted in an R^2 value of 0.5649. The regression was used to quantify the value of AllForX that corresponds to the benthic health threshold (VSCI = 60) for sediment. Based on the regression, a 33rd percentile VSCI score of 60 corresponded to a target AllForX ratio of 4.7. This means that the

TMDL streams are expected to achieve consistently healthy benthic conditions if sediment loads are less than 4.7 times the simulated load of an all-forested watershed. The allowable sediment TMDL load was then calculated by applying the AllForX threshold ratio where VSCI = 60 (4.7) to the All-Forest simulated pollutant load of the target watershed to determine the final target TMDL loading. An explicit margin of safety was implemented based on this target loading rate, setting aside 10% of the allowable load specifically for the margin of safety.

Table C-1. Model run results for AllForX value development.

Station ID	VASCI avg	TSS (lb/yr)	TSS All-Forested (lb/yr)	TSS AllForX
4ABAU011.17	33.0	532.32	37.79	14.09
4ABDA004.14	51.7	1,392.24	241.68	5.76
4ABOE004.86	64.3	757.44	162.01	4.68
4ACRE008.75	59.6	514.03	59.95	8.57
4ACRR011.77	56.1	226.63	15.65	14.48
4AFRY006.08	46.4	406.63	22.80	17.84
4AGEO006.73	52.2	497.23	48.21	10.31
4AGNF002.84	56.7	230.60	33.63	6.86
4ALYH000.50	32.4	220.38	23.41	9.41
4APAA000.71	46.6	115.86	11.72	9.89
4APDA000.35	23.1	348.68	27.24	12.80
4APGG077.15	55.4	654.92	103.85	6.31
4ARAB000.52	57.2	546.38	76.36	7.16
4ARAB003.64	58.0	336.44	48.97	6.87
4ARAB006.49	63.7	61.67	16.98	3.63
4ARAC000.92	20.9	400.76	17.51	22.89
4ARBC005.93	66.6	627.74	169.26	3.71
4ASOT002.90	71.1	142.71	74.90	1.91
4ATRB001.36	61.3	341.71	71.73	4.76
4ATRD000.04	50.7	1,012.80	70.48	14.37
4AWLF000.09	54.9	1,672.84	176.67	9.47
4AWPP002.53	50.6	526.23	112.68	4.67
4AXCN000.31	58.5	174.84	27.57	6.34
4ABAU011.17	33.0	532.32	37.79	14.09

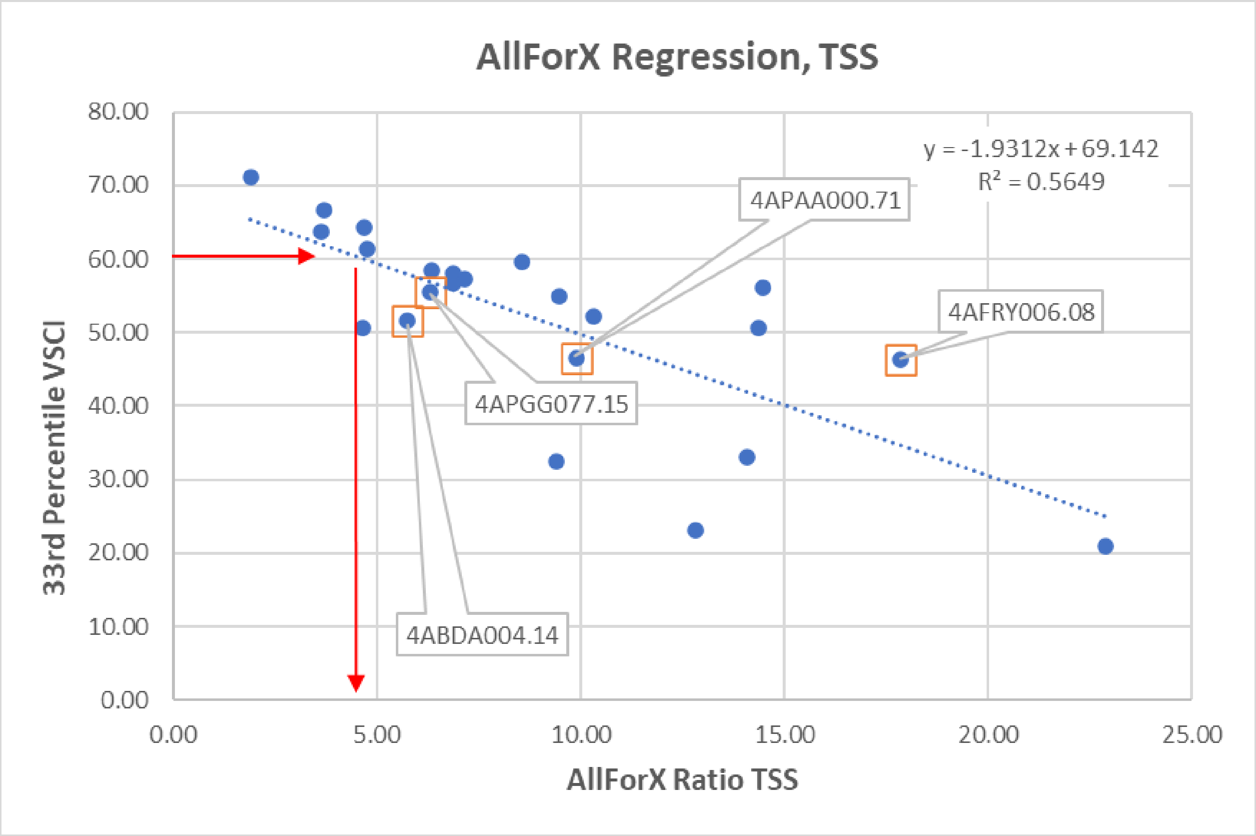

Figure C-1. Regression for sediment in the study watersheds, resulting AllForX target value of 4.7. TMDL watersheds are specifically highlighted in orange boxes.

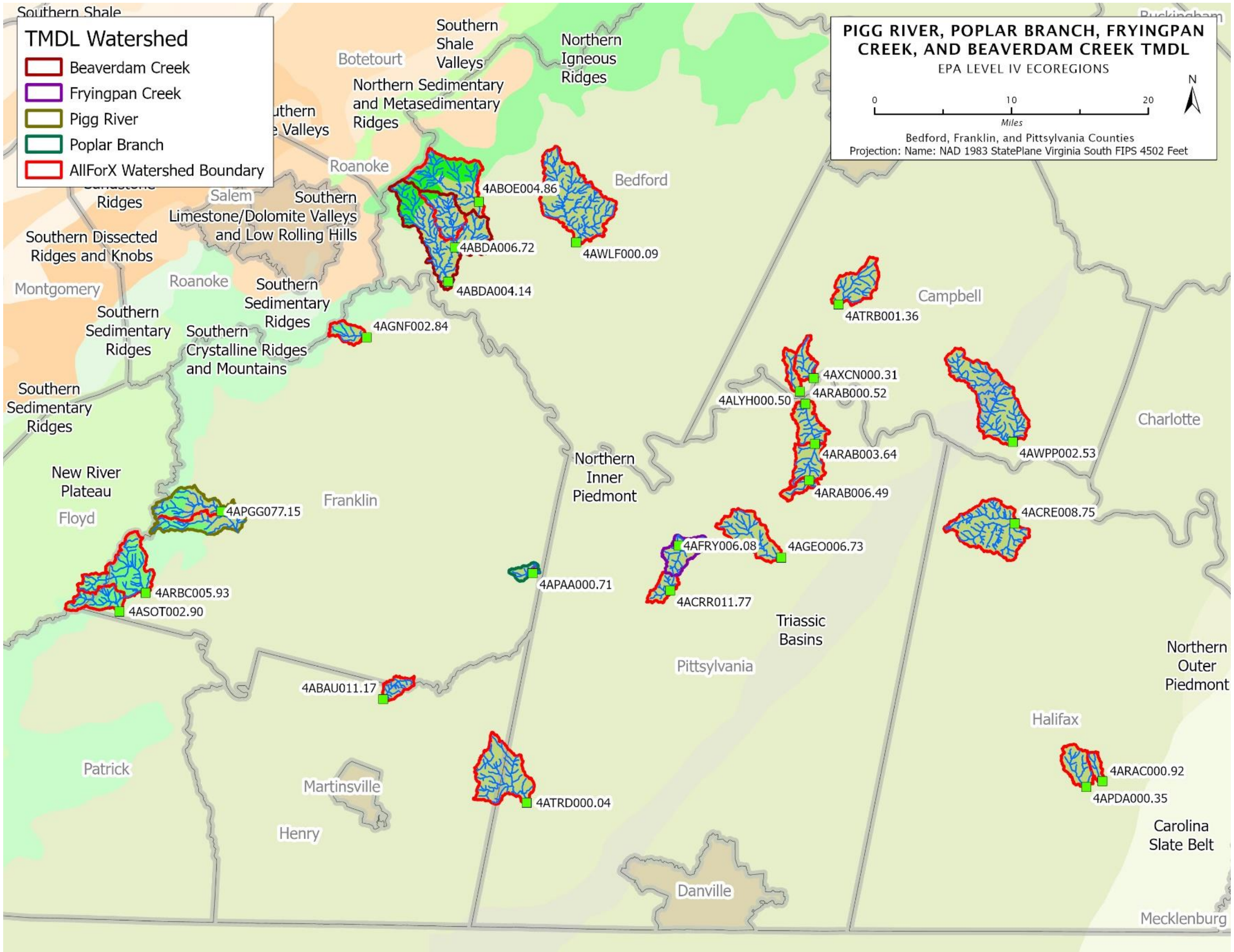

Figure C-2. Watersheds used in developing the AllForX regression.

Appendix D - Stressor Identification Analysis Report