Benthic TMDL Development for Crooked Run, Stony Creek and Pughs Run
Located in Shenandoah County, Virginia

Prepared by:

Virginia Department of Environmental Quality

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VIRGINIA DEPARTMENT OF ENVIRONMENTAL QUALITY

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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
ISW	Industrial Stormwater
LA	Load Allocation
LTA	Long-Term Average
MDL	Maximum Daily Load
MOS	Margin of Safety
MS4	Municipal Separate Storm Sewer Systems
NCDC	National Climate Data Center
NPDES	National Pollutant Discharge Elimination System
NRCS	Natural Resource Conservation Service
PWTP	Potable Water Treatment Plant
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
TMDL	Total Maximum Daily Load
TSS	Total Suspended Sediment
USEPA	United States Environmental Protection Agency
USLE	Universal Soil Loss Equation
VADEQ	Virginia Department of Environmental Quality
VDOT	Virginia Department of Transportation
VGIN	Virginia Geographic Information Network
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 Crooked Run, Stony Creek and Pughs Run watersheds are located in Shenandoah County, Virginia, and drain a predominantly rural watershed with some isolated developed areas. Stony Creek and Pughs Run drain directly to the North Fork Shenandoah River, while Crooked Run drains to Mill Creek, a tributary of the North Fork Shenandoah River. The North Fork Shenandoah River flows north into the Shenandoah River, which is part of the Potomac/Shenandoah River basin that ultimately flows into the Chesapeake Bay.

Crooked Run, Stony Creek and Pughs Run are listed as impaired on Virginia's 2022 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.

Waterbody Name	Assessment Unit	Impairment description	Length (miles)	Listing Date
Crooked Run	VAV-B48R_CKD01A00	Crooked Run from its headwaters downstream to its confluence with Mill Creek.	4.08	2008
Stony Creek	VAV-B49R_STY01A00	Stony Creek from the Route 682 (Wakemans Grove Road) bridge crossing downstream to its confluence with the North Fork Shenandoah River.	4.59	2008
Stony Creek	VAV-B49R_STY02A00	Stony Creek from the Georges Chicken discharge downstream to the Route 682 (Wakemans Grove Road) bridge crossing.	1.27	2008
Stony Creek	VAV-B49R_STY03A00	Stony Creek from its confluence with Yellow Spring Run downstream to the Georges Chicken discharge.	3.44	2016
Pughs Run	VAV-B50R_PGH01A00	Pugh's Run from the headwaters downstream to its confluence with the North Fork Shenandoah River.	7.00	2012

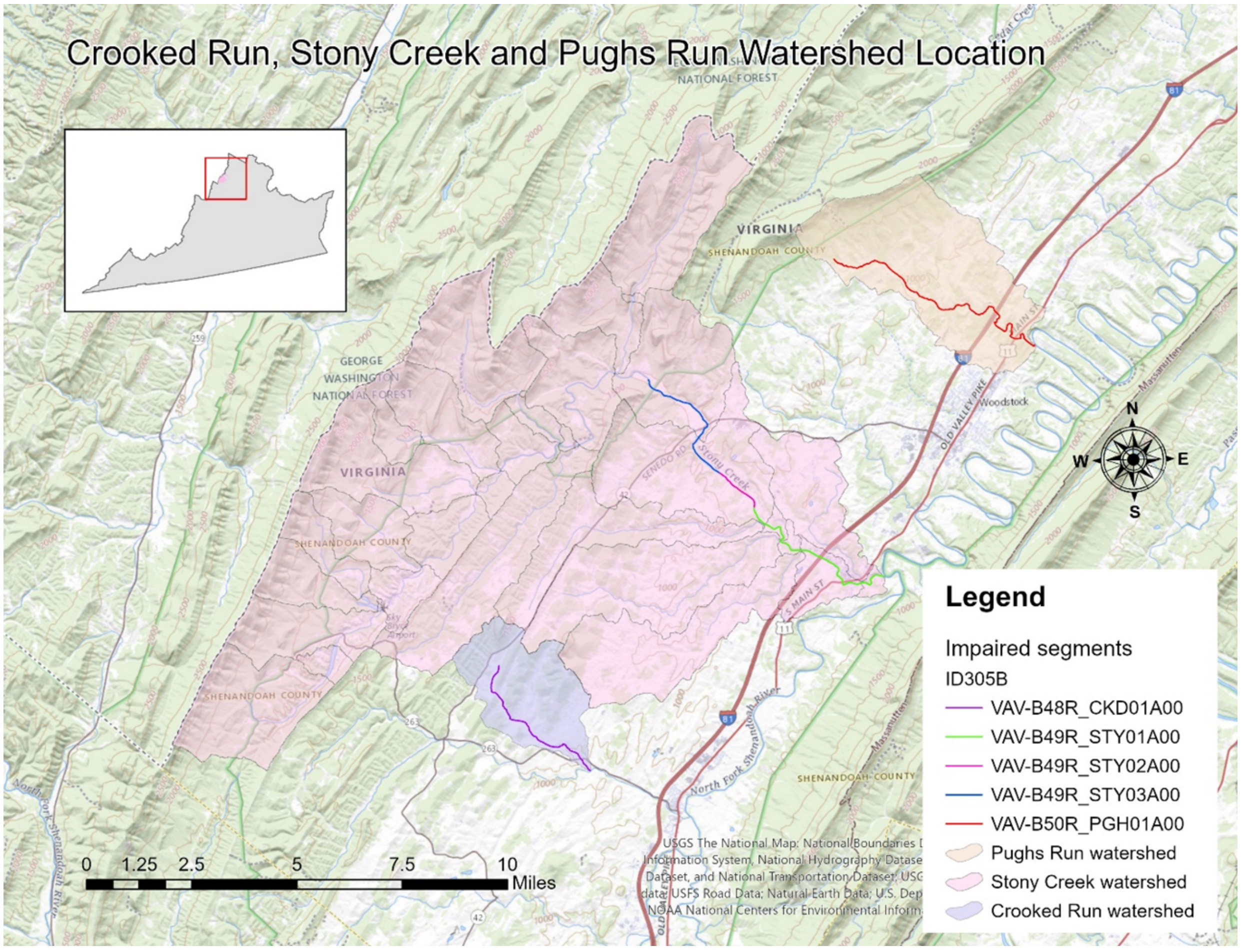


Figure 1-1. Location of the Crooked Run, Stony Creek and Pughs Run watersheds and impaired segments.

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 of benthic macroinvertebrates (bugs that live on the bottom of the stream). The health and diversity of these bugs are assessed on a scale from 0 to 100, with scores greater than 60 being acceptable. **Figure 1-2** shows the various monitoring stations throughout the watersheds, 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 aquatic life. This shows that the various impaired streams in this study fail the aquatic life standard, and pollutants within the watershed need to be reduced.

A stressor identification analysis study was completed in August 2023 to figure out the reason for the benthic impairments in the watersheds. The study found that the main cause of the impairments was too much sediment.

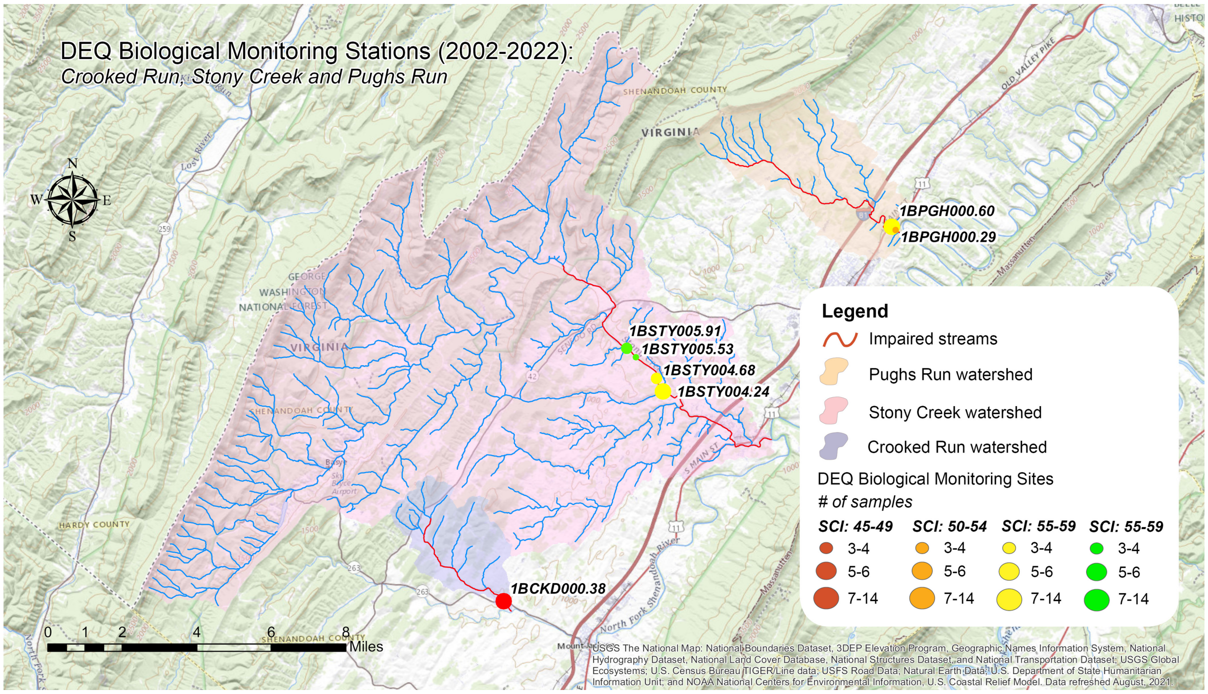


Figure 1-2. Stream health score summaries in the Crooked Run, Stony Creek and Pughs Run watersheds.

1.2.2. Too Much Sediment

Excess sediment was identified as the primary stressor in Crooked Run, Stony Creek and Pughs Run. When it rains, sediment is washed off of the land surface into nearby creeks and rivers. The amount of dirt 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 lacking sufficient controls, can yield a lot of sediment when it rains, while other land types, like forests and well-maintained pasture, yield only a little. When that dirt gets into nearby streams, it falls to the bottom as sediment and can smother certain bugs 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 Crooked Run, Stony Creek and Pughs Run watersheds, a combination of monitoring data and computer modeling was utilized. Monitoring was used to tell 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.

For this purpose, a computer model called the Generalized Watershed Loading Function model (or GWLF) was used. This model incorporates monitoring data and considers the slope, soils, land cover, erodibility, and runoff to estimate the amount of soil eroded in the watershed and deposited in the stream. Although one study recommends hydrologic calibration to improve runoff simulation estimates (Dai et al., 2000), absence of flow data in Crooked Run, Stony Creek and Pughs Run, as well as in the many comparison watersheds in this study led to the decision to simulate loads in a non-calibrated model. 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.

This report summarizes the study and sets goals for a clean-up plan. The study is called a Total Maximum Daily Load (TMDL) Study because it determines the maximum amount of sediment that can get into a certain stream without harming the stream or the creatures living in it. A TMDL allocates allowable contributions of a specific pollutant from point sources, called the wasteload allocation, and nonpoint sources, called the load allocation. It also provides a margin of safety to account for potential differences between the stream environment and the computer model.

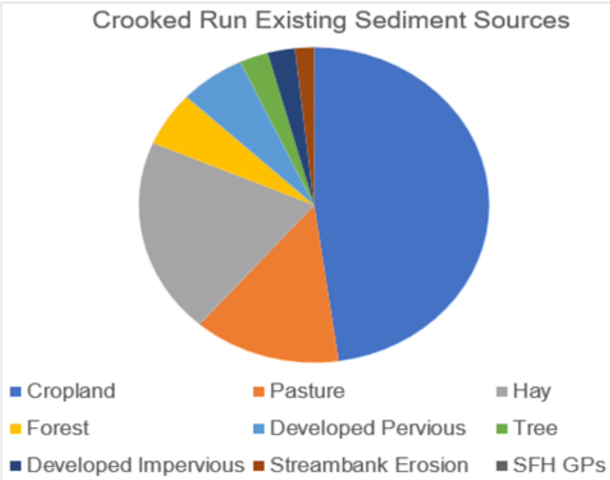
1.4. Current Conditions

For this report, the 2016 Virginia Geographic Information Network (VGIN) dataset was used to represent the current land use with minor modifications. The land cover distribution for each impaired watershed is shown in **Figure 1-3** through **Figure 1-5**. All three of the watersheds are largely forested with the majority of agricultural lands being in pasture or hay rather than cropland. Urban/suburban land uses comprise less than 10% of land cover in Crooked Run, Stony Creek and Pughs Run.

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 where the sediment in the impaired watersheds was currently coming from. **Figure 1-3** through **Figure 1-5** show the distribution of sediment contributions from various sources in the watersheds. The permitted sources include construction permits, water treatment plants, industrial stormwater permits, and other permitted point sources. Cropland, hay and pasture covers a greater extent of the three watersheds than urban areas, and as such most of the sediment loads are derived from agricultural land uses. In addition, Stony Creek has a larger network of streams, making stream bank and bed erosion a significant portion of the overall sediment load.

Definition:

Point Source – pollution that comes out of a pipe (like at a sewage treatment plant).
Non-point Source – pollution that does not come out of a pipe but comes generally from the landscape (usually as runoff).



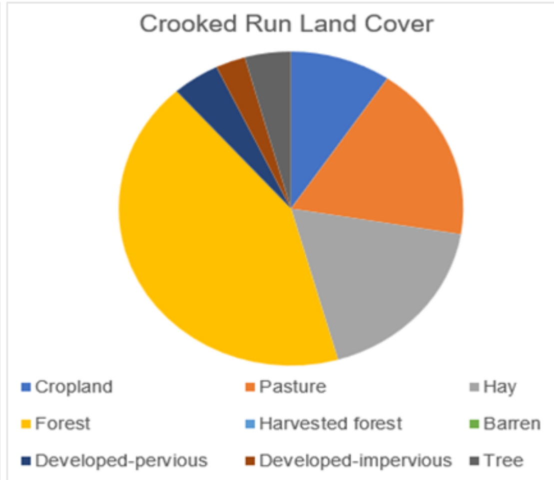
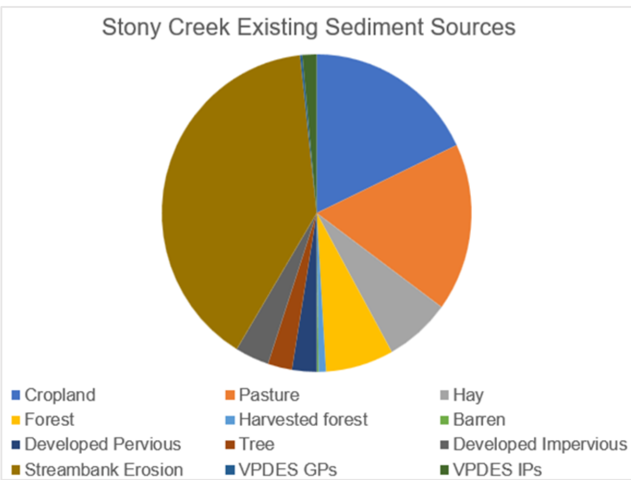


Figure 1-3. Land cover and existing source load distributions in the Crooked Run watershed.



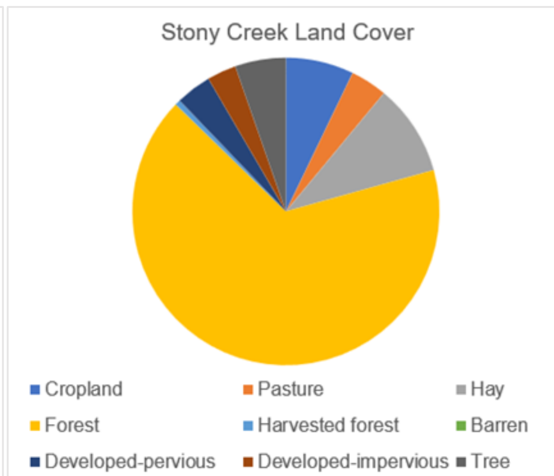
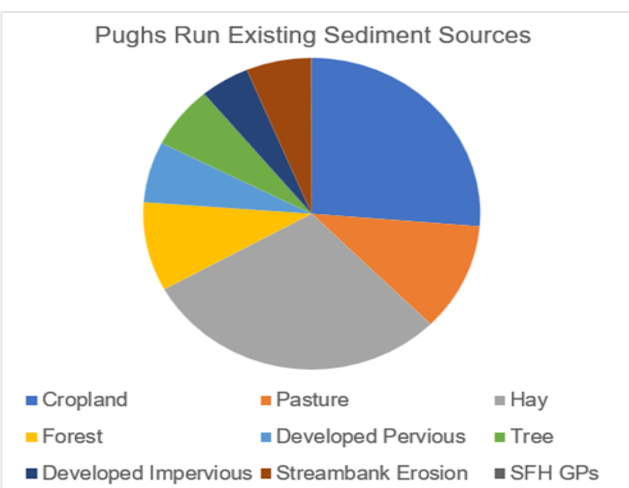


Figure 1-4. Land cover and existing source load distributions in the Stony Creek watershed.



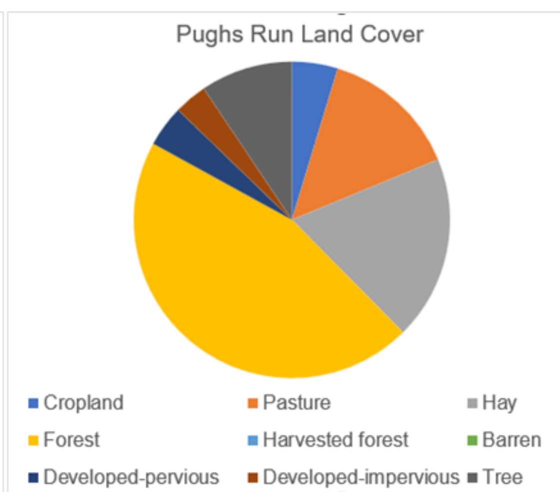


Figure 1-5. Land cover and existing source load distributions in the Pughs Run watershed.

1.5. Future Goals (the TMDL)

After figuring out where the sediment in the impaired streams is currently coming from, a computer model was used to figure out how much sediment loads need to be reduced to clean up each stream. The ultimate goal for these streams is to have sediment levels that allow for diverse and abundant aquatic life. A series of potential sediment reduction scenarios were developed for the impaired watersheds and evaluated by participants at a community engagement meeting (Section 6.4). The preferred reduction scenarios for each watershed are shown in **Table 1-2**.

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

Category	Percent Reduction in Sediment Loads Needed		
	Crooked Run	Pughs Run	Stony Creek
Cropland	56%	32%	24%
Pasture	54%	32%	24%
Hay	36%	20%	10%
Forest/Tree	0%	0%	0%
Harvested forest	0%	0%	5%
Barren	0%	0%	0%
Developed Pervious	40%	15%	18%
Developed Impervious	40%	20%	25%
Streambank	30%	20%	25%
Permitted sources	0%	0%	0%

In order to obtain healthy sediment levels in the impaired streams, reductions are needed from several sediment sources. Sediment loads from agricultural sources such as cropland, pasture, and hay need to be reduced between 10 to 56% in Crooked Run, Stony Creek and Pughs Run. Sediment reductions from urban and suburban land uses of 15 to 40% are called for in the impaired watersheds. 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**). If sediment loads are reduced to these amounts, healthy aquatic life should be restored in these streams.

Table 1-3. Annual Total Maximum Daily Load of sediment that will meet the water quality standard.

Stream *(Assessment Unit ID)*	**Existing Load (metric tons/yr)**	**Allocated Permitted Point Sources (WLA) (metric tons/yr)**	**Allocated Nonpoint Sources (LA) (metric tons/yr)**	**Margin of Safety (MOS) (metric tons/yr)**	**Total Maximum Daily Load (metric tons/yr)**	**Overall % Reduction (%)**
Crooked Run (*VAV-B48R_CKD01A00*)	418	5.6	228.4	26.0	260	37.7%
Stony Creek (*VAV-B49R_STY01A00, VAV-B49R_STY02A00, VAV-B49R_STY03A00*)	5,427	195.5	4,224.4	491.1	4,911	9.5%
Pughs Run *(VAV-B50R_PGH01A00)*	543	10.4	428.8	48.8	488	10.2%

The final average annual sediment loads allocated in the TMDL are presented in **Table 1-4** through **Table 1-6**. 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 in an effort to reflect the potential decrease in model accuracy that can occur as estimates are summed.

Table 1-4. Annual average sediment TMDL components for Crooked Run.

Impairment	**WLA**	**LA**	**MOS**	**TMDL**	**Existing Load**	**Percent Reduction**
	Sediment Load (metric tons/yr)					
Crooked Run - TSS (VAV-B48R_CKD01A00)	**5.6**	**228.4**	**26.0**	**260**	418	37.7%
Construction Permits	0.08					
Domestic Sewage Permits	0.29					
Future Growth (2% of TMDL)	5.21					

Table 1-5. Annual average sediment TMDL components for Stony Creek.

Impairment	WLA	LA	MOS	TMDL	Existing Load	Percent Reduction
	Sediment Load (metric tons/yr)					
Stony Creek - TSS (VAV-B49R_STY01A00) (VAV-B49R_STY02A00) (VAV-B49R_STY03A00)	**195.5**	**4,224.4**	**491.1**	**4,911**	5,427	9.5%
Construction Permits	11.88					
Industrial Stormwater Permits	4.10					
Domestic Sewage Permits	1.54					
Potable Water Treatment Plant Permits	0.66					
Individual VPDES Permits *VA0020508* *VA0028380* *VA0077402*	 7.25 24.87 46.98					
Future Growth (2% of TMDL)	98.22					

Table 1-6. Annual average sediment TMDL components for Pughs Run.

Impairment	WLA	LA	MOS	TMDL	Existing Load	Percent Reduction
	Sediment Load (metric tons/yr)					
Pughs Run - TSS (VAV-B50R_PGH01A00)	**10.4**	**428.8**	**48.8**	**488**	**543**	10.2%
Construction Permits	0.41					
Domestic Sewage Permits	0.25					
Future Growth (2% of TMDL)	9.76					

In 2007, the USEPA released a guidance document for developing maximum daily loads (MDLs) for TMDLs (USEPA, 2007). 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 1-4** through **Table 1-4** 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 1-7.**

Table 1-7. "LTA to MDL multiplier" components for TMDLs.

Watershed	CV of Average Annual Loads	"LTA to MDL Multiplier"
Crooked Run	0.566	2.071
Stony Creek	0.397	1.744
Pughs Run	0.560	2.060

The daily WLA for stormwater permits and future growth allocations were estimated by dividing the annual WLA by 365.24 and using the LTA multiplier. Daily WLA's for all other permits were 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 1-8Table 6-5** through **Table 1-10**.

Table 1-8. Maximum 'daily' sediment loads and components for Crooked Run.

Impairment	WLA	LA	MOS	MDL
	Sediment Load (metric tons/day)			
Crooked Run - TSS (VAV-B48R_CKD01A00)	**0.031**	**1.297**	**0.148**	**1.48**
Construction Permits	*0.0016*			
Domestic Sewage Permits	*0.0002*			
Future Growth (2% of TMDL)	*0.0295*			

Table 1-9. Maximum 'daily' sediment loads and components for Stony Creek.

Impairment	WLA	LA	MOS	MDL
	Sediment Load (metric tons/day)			
Stony Creek - TSS (VAV-B49R_STY01A00) (VAV-B49R_STY02A00) (VAV-B49R_STY03A00)	**0.768**	**20.335**	**2.345**	**23.45**
Construction Permits	*0.0567*			
Industrial Stormwater Permits	*0.0196*			
Domestic Sewage Permits	*0.0042*			
Potable Water Treatment Plant Permits	*0.0018*			
Individual VPDES Permits	*0.2166*			
Future Growth (2% of MDL)	*0.4690*			

Table 1-10. Maximum 'daily' sediment loads and components for Pughs Run.

Impairment	WLA	LA	MOS	MDL
	Sediment Load (metric tons/day)			
Pughs Run - TSS (VAV-B50R_PGH01A00)	**0.058**	**2.420**	**0.275**	**2.75**
Construction Permits	*0.0023*			
Domestic Sewage Permits	*0.0007*			
Future Growth (2% of TMDL)	*0.0550*			

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. This public participation keeps people informed about the project, and it provides local input from stakeholders to make sure that information in the study is accurate. While the computer model was being developed, VADEQ held a series of three Community Engagement Meetings (CEM) to get stakeholder input. Participants in these meetings included representatives from Shenandoah County, Lord Fairfax Soil and Water Conservation District (SWCD), Natural Resource Conservation Service (NRCS), and several local landowners. The first CEM was held on August 19, 2024 (17 attending) to discuss land cover estimates for the watersheds, and point and non point sediment sources. Participants provided feedback on areas of growth in the watersheds and projected development patterns in the future. The second CEM (13 attendees, December 16, 2024) discussed updates to sediment load estimates, particularly loads coming from streambank erosion. Participants also discussed the methodology used to establish sediment endpoints for the impaired streams (AllForX) and reviewed a series of sediment allocation scenarios for the watersheds. The third and final CEM (18 attendees) was held on February 4, 2025. During this meeting, participants reviewed the updated allocation scenarios for the impaired watersheds and discussed plans for the final public meeting.

A public meeting was held on June 18, 2024 to share information about the health of the streams and discuss the TMDL process, including opportunities for public participation (40 attending). The meeting was held at the Shenandoah County Library in Edinburg VA at 5:30 pm. A second and final public meeting was held on April 9, 2025 to present the draft TMDL document. The public meeting marked the beginning of the official public comment period and was attended by XX watershed residents and other stakeholders. The public comment period ended on May 9, 2025.

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 Crooked Run, Stony Creek and Pughs Run watersheds.

> Frequently Asked Question:
>
> ***<u>How will the TMDL be implemented?</u>*** TMDL reductions are not proposed for point sources and the TMDL will be implemented through discharge permits and future growth. 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.

1.8. What Happens Next

This report sets the clean-up goals for the Crooked Run, Stony Creek and Pughs Run, 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 Crooked Run, Stony Creek and Pughs Run 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)
- Reduce runoff by increasing green spaces and reducing hardened spaces (asphalt or concrete)

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, including a grant from the National Fish and Wildlife Foundation. Please be aware that the state or federal government will not fix the problems with Crooked Run, Stony Creek and Pughs Run. 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.

DEQ 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, DEQ 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 Stony Creek watershed is approximately 72,619 acres and includes portions of the Town of Edinburg and Shenandoah County (**Figure 1-1**). The study watershed includes VAHU6 watersheds PS65, PS66, and PS67. The VAHU6 watershed system was delineated in Virginia in 1990 and again in 1995 following issuance of new delineation standards in 1992. This hydrologic unit system includes 494 units, which are identified with 4-character codes. The first two characters are based on the major stream name in the basin, or portion of the basin, where the unit is located (PS: Potomac-Shenandoah). The two digits that follow these codes are a sequential numbering scheme based on the drainage flow (headwaters to mouth). The Pughs Run watershed is located in Shenandoah County and is approximately 8,637 acres. The watershed comprises a portion of VAHU6 watershed PS68. The Crooked Run watershed is approximately 4,289 acres, located in southern Shenandoah County, comprising a portion of VAHU6 watershed PS63.

2.2. Designated Uses and Applicable Water Quality Standards

Virginia's Water Quality Standards (9 VAC 25-260) 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).

Stony Creek, Crooked Run and Pughs Run 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 2022 305(b)/303(d) Integrated Water Quality Assessment Report was from January 1, 2015 through December 31, 2020. According to VADEQ's current Water Quality Assessment Guidance (VADEQ, 2022), 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 2022 305(b)/303(d) Integrated Report (VADEQ, 2022), Crooked Run, Stony Creek and Pughs Run are listed as impaired (**Table 1-1**, **Figure 1-1**) based on data collected by DEQ in the watersheds.

2.3.1.1. Crooked Run Impairment

The entire length of Crooked Run, from the headwaters downstream to its confluence with Mill Creek, is impaired for failure to meet the general standard for aquatic life (i.e., a benthic impairment). Crooked Run was initially listed as impaired on Virginia's 2008 303(d) Impaired Waters List. Crooked Run was placed on this list based on data collected at DEQ monitoring station 1BCKD000.38. During the 2022 assessment window (January 1, 2015 to December 31, 2022), Crooked Run had a mean VSCI score of 47.9, indicating impairment of the benthic macroinvertebrate community.

2.3.1.2. Stony Creek Impairment

Stony Creek is impaired for failing to support aquatic life use (i.e., a benthic impairment) from its confluence with Yellow Spring Run downstream to its confluence with the North Fork Shenandoah River. The two lower segments of Stony Creek were initially listed as impaired on Virginia's 2008 303(d) Impaired Waters List based on data collected at DEQ monitoring stations 1BSTY004.24 and 1BSTY004.68. The uppermost segment was listed as impaired on Virginia's 2016 303(d) Impaired Waters List based on data collected at DEQ monitoring station 1BSTY005.91. During the 2022 assessment window (January 1, 2015 to December 31, 2022), mean VSCI scores ranged from 55.3 at 1BSTY0004.68 to 65.1 at 1BSTY005.91.

2.3.1.3. Pughs Run Impairment

Pughs Run is impaired for failing to support aquatic life use (i.e., a benthic impairment) for its entire length, from the headwaters downstream to its confluence with the North Fork Shenandoah River. Pughs Run was initially listed as impaired on Virginia's 2012 303(d) Impaired Waters List based on data collected at DEQ monitoring stations 1BPGH000.29 and 1BPGH000.60. . During the 2022 assessment window (January 1, 2015 to December 31, 2022), the mean VSCI score at 1BPGH000.60 was 57.3. Only one sample was collected from 1BPGH000.29 during this period, with a VSCI score of 54.0.

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.

In 2023, a stressor identification analysis study was conducted to determine the POC(s) contributing to the benthic impairments in the Crooked Run, Stony Creek and Pughs Run watersheds. 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 streams.

3.0 WATERSHED CHARACTERIZATION

The Crooked Run, Stony Creek and Pughs Run watersheds are located in Shenandoah County, VA. Stony Creek is the largest of the three watersheds at approximately 72,619 acres. The Pughs Run watershed is approximately 8,637 acres, while the Crooked Run watershed is the smallest of the three at approximately 4,289 acres (**Figure 1-1**). Crooked Run is a tributary of Mill Creek, which drains to the North Fork Shenandoah River. Stony Creek and Pughs Run drain directly to the North Fork Shenandoah River, which joins the Shenandoah River in Front Royal. The Shenandoah River joins the Potomac River in Harpers Ferry, which ultimately drains to the Chesapeake Bay.

3.1. Ecoregion

Crooked Run, Stony Creek and Pughs Run are located predominately in the Northern Limestone/Dolomite Valleys, Northern Sandstone Ridges, and Northern Shale Valleys sub-divisions of the Ridge and Valley USEPA ecoregion (Error! Reference source not found.). The N orthern Limestone/Dolomite Valley ecoregion is characterized by broad, flat to undulating lowlands with karst topography. This area has been extensively farmed due to its fertile soils. Limestone and dolomite commonly underlie this region in addition to calcareous shale. Mesic alfisols and ultisols are found throughout this ecoregion. Due to the fertile soils, farming predominates the wide valleys in this region, with scattered woodlands in steeper areas. Appalachian oak forests are predominant in the north, while oak/hickory/pine forests are predominant in the south. (Woods et al., 1999).

The Northern Sandstone Ridges ecoregion is characterized by steep forested ridges, with high gradient streams flowing off of high ridges into narrow valleys. Streams in this region may be subject to acidification due to poor buffering capacity. Folded, interbedded Paleozoic sandstone and conglomerate compose ridge forming strata. Soils are typically poor and sandy. Appalachian oak forests are predominant in the north, while oak/hickory/pine forests are predominant in the south.

The Northern Shale Valleys ecoregion is characterized by low hills and rolling valleys. Shale, siltstone and fine grained sandstone underlie much of this region. Underlying rocks in this region are not as permeable as those in the Limestone/Dolomite Valley region, so streams in this region are larger with a greater density. Soil erosion is also greater in the Northern Shale Valleys, leading to higher levels of turbidity in waterways and impaired benthic habitat. Farming predominates the region, with woodland areas on steeper slopes. Similar to the other subdivisions of the Ridge and Valley ecoregion, Appalachian oak forests are predominant in the north, while oak/hickory/pine forests are predominant in the south.

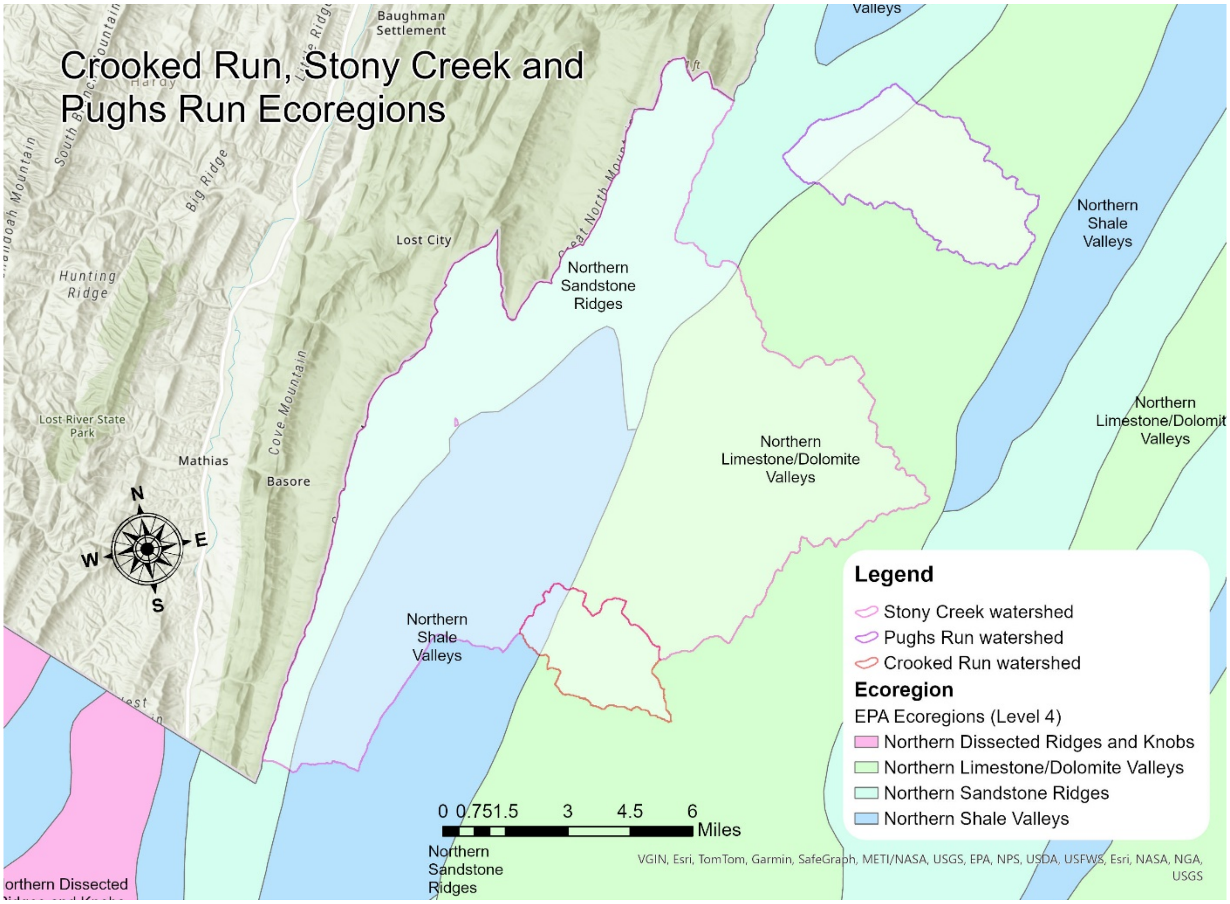


Figure 3-1. Crooked Run, Stony Creek and Pughs Run EPA Level IV Ecoregions.

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. The Crooked Run watershed is comprised of predominantly hydrologic soil group B, which makes up 68% of the soils in the watershed (Error! Reference source not found.). H ydrologic soil group D makes up an additional 22% of the watershed. The remaining 10% of the soils in the watershed are either group A or C. Similarly, hydrologic soil group B comprises 45% of the Stony Creek watershed, while hydrologic soil groups C and D each make up an additional 23% of the watershed. The remainder of the watershed is comprised of soil group A and the combined group C/D. The combined groups indicate a naturally slow infiltration rate due to high water table, rather than a lack of infiltration capacity. The Pughs Run watershed is predominantly comprised of hydrologic soils groups B and C, which make up 40% and 39% of soils in the watershed, respectively. The remaining 20% of the soils in the watershed are either group A or D.

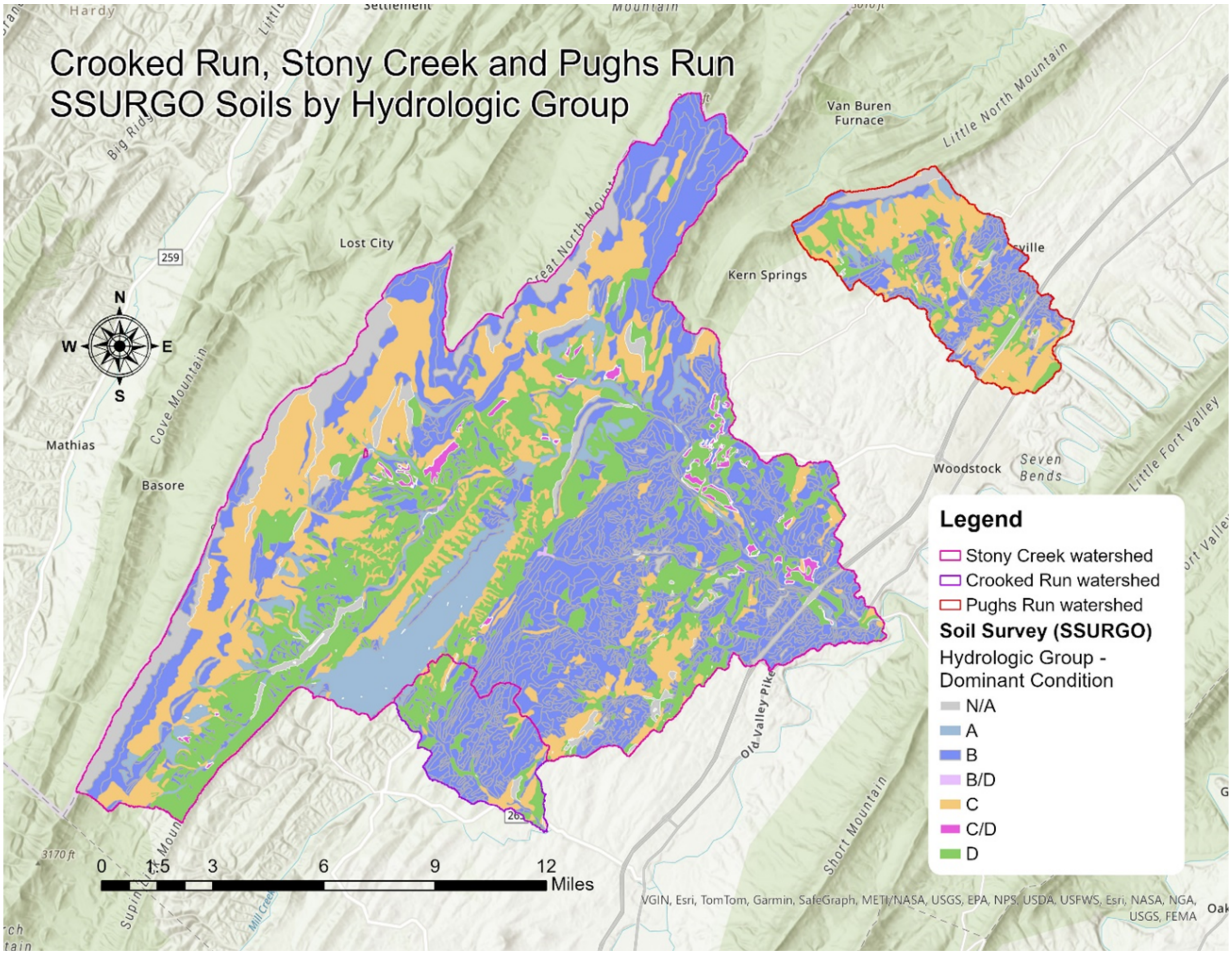


Figure 3-2. Crooked Run, Stony Creek and Pughs Run SSURGO soils by hydrologic group.

3.3. Topography

Topographic information was derived from the U.S. Geologic Survey (USGS) National Elevation Dataset (NED). Slope and elevation were greatest in the western portion of the project area, with the Stony Creek watershed containing the highest ridges and steep slopes (**Figure 3-3 and Figure 3-4**). Pughs and Crooked Runs have similar mean elevations, 369 meters and 350 meters, respectively. Mean elevation in Stony Creek is considerably higher at 446 meters. Similarly, mean slope on Pughs and Crooked Runs was 6.4 meters and 6.8 meters, respectively, while mean slope in Stony Creek was 9.2 meters.

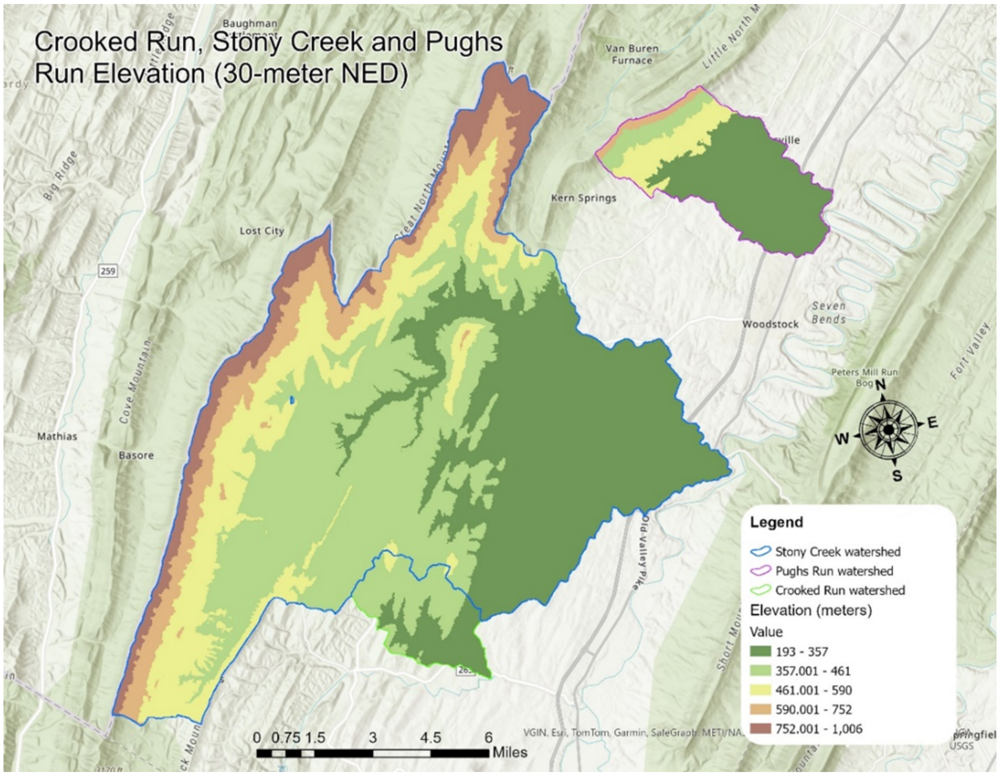


Figure 3-3. Crooked Run, Stony Creek and Pughs Run elevation (30-meter National Elevation Dataset, USGS)

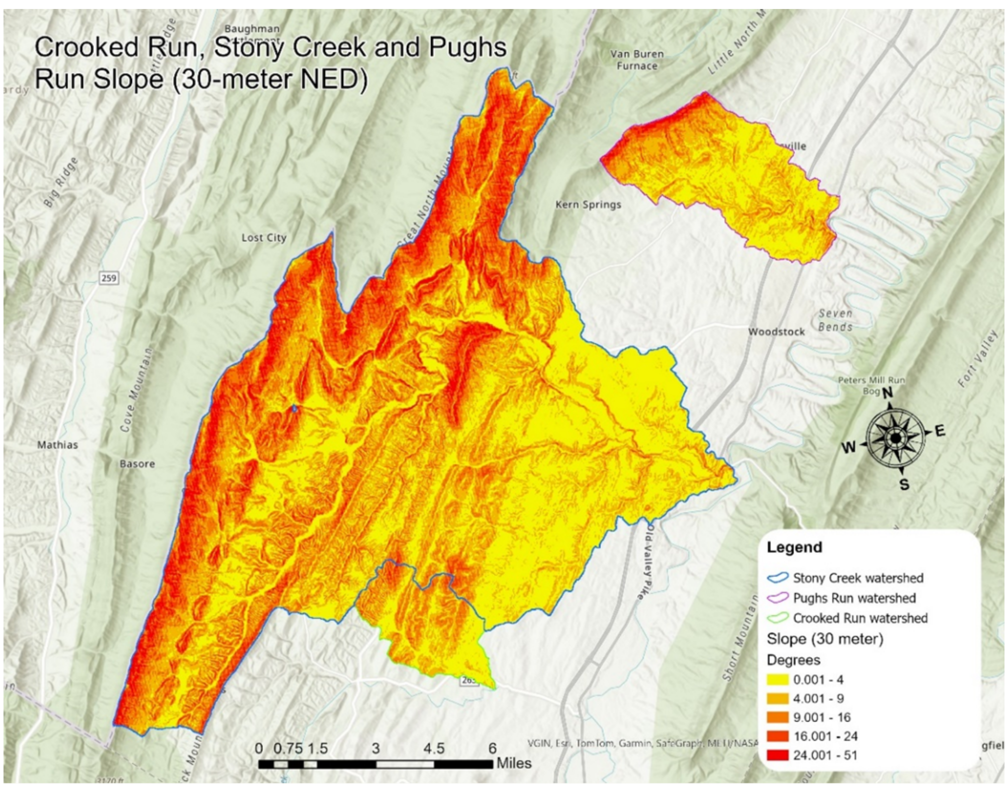


Figure 3-4. Crooked Run, Stony Creek and Pughs Run slope (30-meter National Elevation Dataset, USGS)

3.4. 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 (PRISM, 2024). See Daly et al. 2008 for more information on the PRISM model. Local annual average precipitation generated from the PRISM model for years 2003 to 2023 was 39.40 inches, and the average modelled daily temperature during this time range was 53.4° F. Consideration of seasonal variations and critical conditions is addressed in the section of this report covering the modeling process.

3.5. Land Cover

The 2016 VGIN Virginia Land Cover Dataset (VLCD) land cover dataset was used to determine the land cover distribution throughout the watersheds. **Table 3-1, Table 3-2**, and **Table 3-3** summarize the land cover distributions for each of the impaired watersheds. **Figure 3-5** shows a land cover map of the 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 VGIN dataset contains categories for cropland and pasture, which were subdivided for modeling purposes using the 2022 Nonpoint Source (NPS) Assessment Land Use/Land Cover database maintained by the Virginia Department of Conservation and Recreation (VADCR) (VADCR, 2022). 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 values.

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.

Forest was the predominant land use in the three watersheds, comprising 65% of the Stony Creek watershed, and 43% of the Crooked Run watershed, and 45% of the Pughs Run watershed (**Table 3-1, Table 3-2, Table 3-3**). Hay was the largest agricultural land use in the Pughs Run and Stony Creek watersheds, comprising 19% and 9% of the watersheds, respectively. Hay and pasture both comprised 18% of Crooked Run watershed. There is very little cropland in any of the watersheds, ranging from 5% in the Pughs Run watershed to 10% in the Crooked Run watershed. Developed areas comprised less than 5% of any of the watersheds.

Table 3-1. Land cover distribution in the Crooked Run watershed.

Land Cover Category	Acres	Percent
Water	3	<0.1%
Developed, impervious	119	2.8%
Developed, pervious	12	0.3%
Barren	0	0.0%
Forest	1,830	42.7%
Trees	190	4.1%
Scrub/shrub	0	0.0%
Harvested/disturbed	0	0.0%
Turfgrass	174	4.1%
Hay	773	18.0%
Pasture: Manure Applied	666	15.5%
Pasture: Grazed	1	<0.1%
Pasture: Unimproved	111	2.6%
Conventional Tillage	157	3.7%
Conservation Tillage	247	5.8%
Wetland	1	<0.1%
Total	***4,289***	***100.0%***

Table 3-2. Land cover distribution in the Pughs Run watershed.

Land Cover Category	Acres	Percent
Water	4	0.1%

Land Cover Category	Acres	Percent
Developed, impervious	287	3.5%
Developed, pervious	30	0.4%
Barren	0	<0.1%
Forest	3,873	44.5%
Trees	815	9.5%
Scrub/shrub	11	0.1%
Harvested/disturbed	0	0.0%
Turfgrass	330	3.8%
Hay	1,629	18.7%
Pasture: Manure Applied	301	3.5%
Pasture: Grazed	939	10.8%
Pasture: Unimproved	9	0.1%
Conventional Tillage	158	1.9%
Conservation Tillage	249	3.1%
Wetland	3	<0.1%
Total	***8,637***	***100.0%***

Table 3-3. Land cover distribution in the Stony Creek watershed.

Land Cover Category	Acres	Percent
Water	172	0.2%
Developed, impervious	2,256	3.0%
Developed, pervious	198	0.4%
Barren	0	0.0%
Forest	46,920	64.6%
Trees	3,807	5.3%
Scrub/shrub	150	0.2%
Harvested/disturbed	432	0.6%
Turfgrass	2,327	3.2%
Hay	6,784	9.3%
Pasture: Manure Applied	2,662	3.7%
Pasture: Grazed	1,388	1.9%
Pasture: Unimproved	296	0.4%
Conventional Tillage	2,001	2.7%
Conservation Tillage	3,152	4.3%
Wetland	74	0.1%
Total	***72,619***	***100.0%***

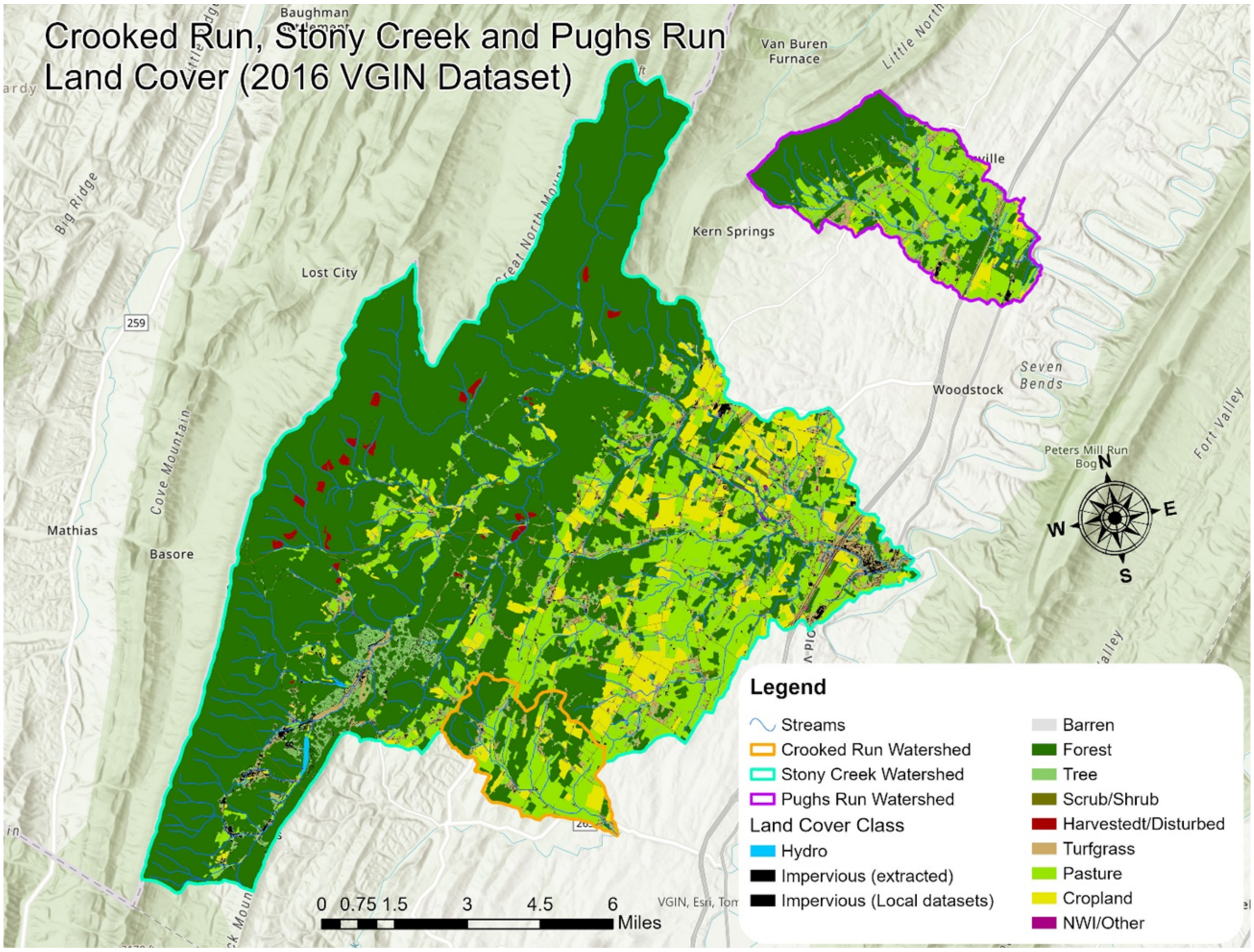


Figure 3-5. 2016 Virginia Geographic Information Network (VGIN) land cover classifications for the Crooked Run, Stony Creek and Pughs Run watersheds.

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 VGIN dataset contains categories for cropland and pasture, which were subdivided for modeling purposes using the 2022 Nonpoint Source (NPS) Assessment Land Use/Land Cover database maintained by the Virginia Department of Conservation and Recreation (VADCR) (VADCR, 2022). 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 (conventional tillage) and low till (conservation tillage), 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-manure applied), pasture-fair (pasture- grazed), and pasture-poor (pasture-unimproved). These categories were simulated with appropriately different curve number and C-factor values.

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.

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3.6. Water Quality and Biological Monitoring Data

Biological, physical, and chemical data from ten (10) monitoring stations within the Crooked Run, Stony Creek and Pughs Run watersheds were used in developing the stressor analysis study. This includes seven (7) benthic and six (6) water quality monitoring stations operated by DEQ within the watershed (three of which are co-located benthic and water quality stations). The data window was limited to a 20-year period (2002-2022). The data from these monitoring stations are explored in the attached stressor identification analysis study. The various monitoring stations are shown in **Figure 3-6**.

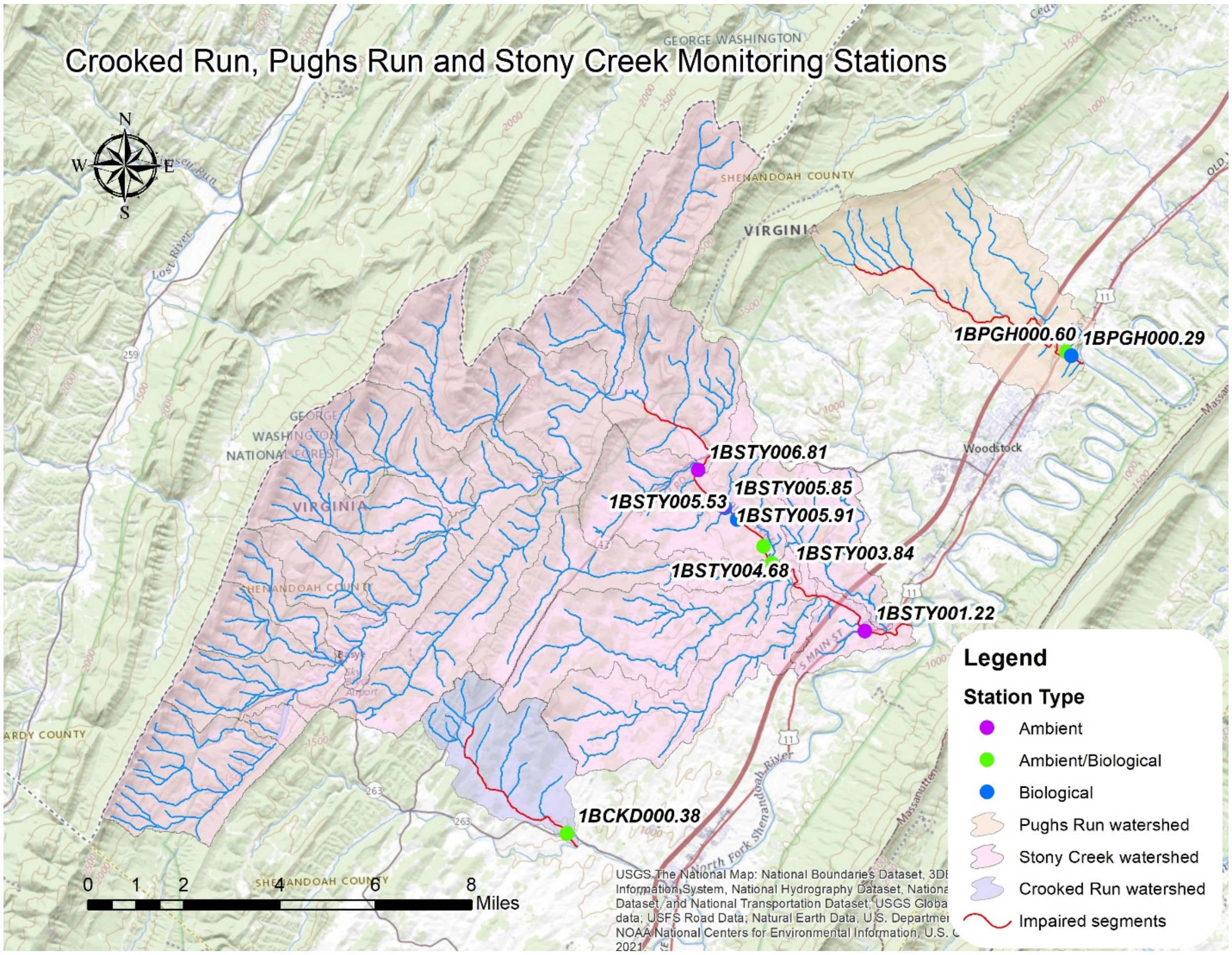

Figure 3-6. Locations of DEQ monitoring stations in the Crooked Run, Stony Creek and Pughs Run watersheds. Note: Only stations sampled between 2002-2022 are shown. Stations located upstream of the impaired segments on Stony Creek are not shown.

From spring 2002 to fall 2022, DEQ conducted 56 benthic assessments at seven (7) stations within the Crooked Run, Pughs Run and Stony Creek watersheds. **Figure 1-2** and **Table 3-4** show the average SCI scores for each station over this 20-year window. In addition, **Table 3-4** includes averages for the 2022 Water Quality Assessment window (2015-2020). For a stream to be placed on Virginia's 303(d) list of impaired waters with a benthic impairment, one sample with a score below 60 within the monitoring window is all that is required. To remove a benthic impairment listing, scores above 60 must be recorded for the most recent fall and spring samples within a given water quality assessment cycle. One of the listing stations for the impairment on Stony Creek has an average VSCI scores above 60 for the 2022 assessment cycle; however, the most recent fall and spring scores within this time frame are not both over 60, and 2021-2022 monitoring downstream indicates that the stream remains impaired.

Table 3-4. Stream condition index scores for Crooked Run, Stony Creek and Pughs Run impaired segments.

Stream	Station	Years Sampled	Samples Collected	SCI Average	2022 WQA (2015-2020) SCI Avg.
Crooked Run	1BCKD000.38	2005-2022	12	46.4	47.4
Pughs Run	1BPGH000.29	2009-2020	3	50.3	54.0
	1BPGH000.60	2013-2022	12	57.5	59.6
Stony Creek	1BSTY004.24	2002-2022	14	58.3	56.0
	1BSTY004.68	2012-2022	5	58.5	N/A
	1BSTY005.53	2012-2013	4	59.9	N/A
	1BSTY005.91	2012-2015	6	65.2	65.1

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 TMDLs in the Crooked Run, Stony Creek and Pughs Run 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 lumped 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, the inherent erodibility of the soils, the 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, and sediment transport takes into consideration the transport capacity of the runoff.

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 is modeled as a linear reservoir to calculate groundwater discharge. GWLF also allows for seepage to a deep saturated zone.

Surface nutrient losses are determined by applying dissolved nitrogen and phosphorus coefficients to surface runoff and a nutrient content coefficient to the sediment yield for pervious source areas. Impervious or urban nutrient inputs are calculated with exponential accumulation and washoff functions. GWLF also includes functionality for manure applications and septic systems.

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**.

Daily rainfall and temperature data were obtained from Oregon State's spatially distributed PRISM model for calibrating the Crooked Run, Stony Creek and Pughs Run models and developing the watershed loads. See **Section 3.4** for 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 10 subwatersheds to obtain a more granular assessment of the pollutant loads throughout the watershed (**Figure 4-1**). The watershed was subdivided based on impairments so that TMDLs could be developed independently for each impaired water. Junctions of streams were used as breaking points to reduce subwatershed size. Locations of monitoring stations were also used to guide subwatershed development to take advantage of available data.

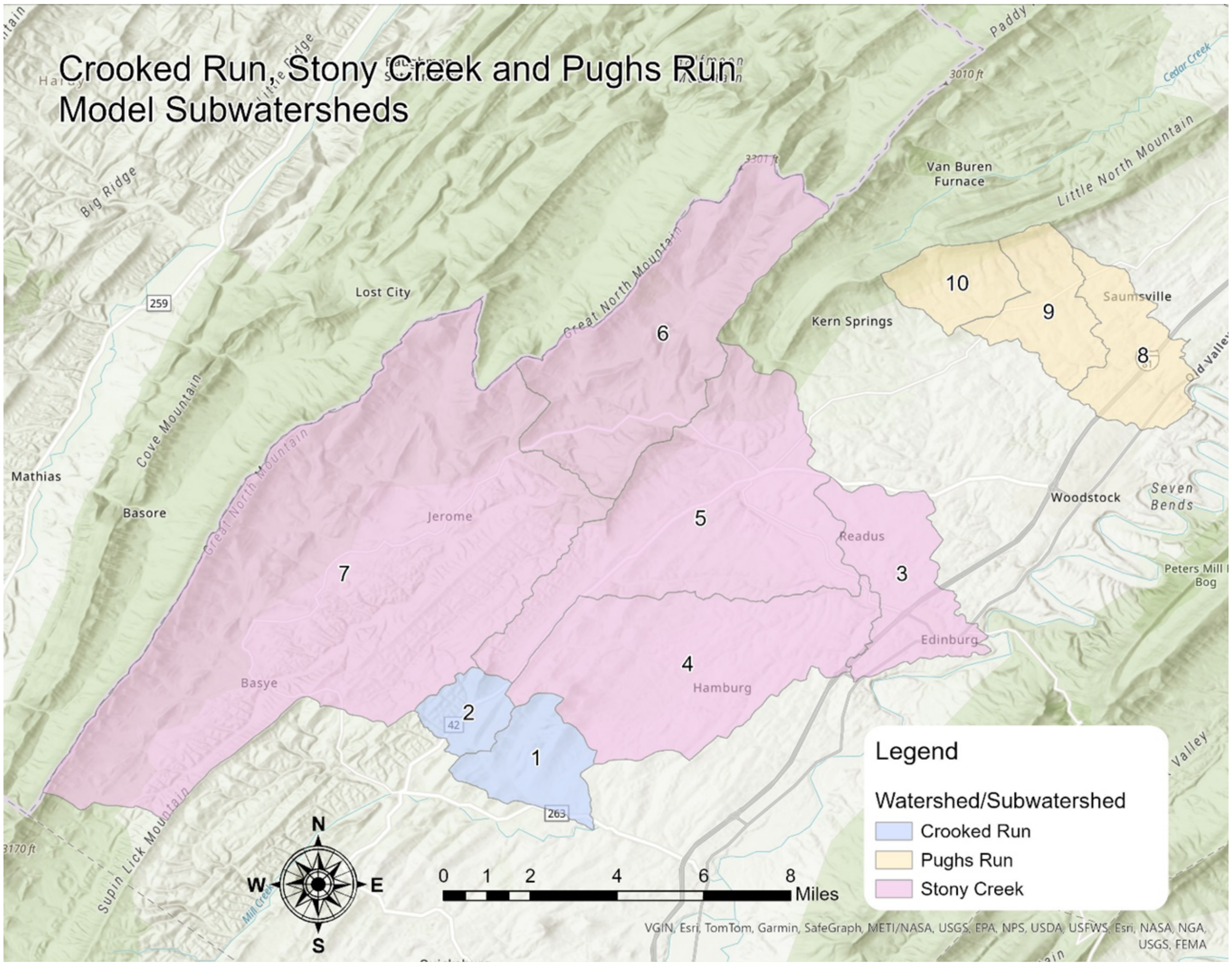

Figure 4-1. Crooked Run, Stony Creek and Pughs Run TMDL model subwatersheds.

Total loads to downstream subwatersheds were summed from the loads of each contributing upstream subwatershed after adjusting for pollutant losses caused by in-stream processes (i.e. sediment deposition, nutrient uptake, etc.) through the development of an attenuation factor. This attenuation factor was applied to the pollutant loads of upstream subwatersheds as their load was conveyed through downstream subwatersheds.

The attenuation factors for transport loss estimates were derived by comparing model outputs of upstream and downstream subwatersheds modeled individually with the results of a combined model run output. The percent difference between the combined watershed model and the sum of its parts represents the transport loss estimate based on the GWLF functions. Since GWLF calculates channel erosion as a function of cumulative flow, the attenuation factor was based only on land-based sources, but then applied to the total land, stream, and permitted sources.

4.3. Source Assessment

Sediment can be delivered to streams by either point or non-point sources. Point sources include permitted sources such as water treatment facilities. Non-point sources encompass all of the other sources in the watersheds. Non-point 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. Non-Point 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 of these impervious surfaces 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 3.5**). Values for various parameters affecting sediment loads were gleaned from literature guidance (CBP, 1998; Haith et al., 1992; Hession et al., 1997). Naturally occurring loads of sediment (i.e. loads not attributed to anthropogenic sources) were also calculated using VGIN 2016 land cover data. These loads from sources such as forest and wetlands were not assigned reductions in the associated sediment TMDLs; however, these loads are included in the load allocations for the watersheds, and will also benefit from the implementation of best management practices

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 of urban streams. The higher flows 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 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

Multiple point sources of sediment exist within the Stony Creek, Pughs Run and Crooked Run watersheds. These point sources are permitted under the Virginia Pollutant Discharge Elimination System (VPDES) program and include the following categories of permits: individual permits, potable water treatment plant general permits, municipal separate storm sewer system (MS4) permits, mixed concrete general permits, industrial stormwater general permits, and domestic sewage general permits. The approaches for determining loads from each of these permits are described below. Typically, wasteload allocations for VPDES general permits in a TMDL are aggregated by permit type. In the Stony Creek watershed, there are several instances in which there is only one active permit for a general permit type in the watershed. In such cases, these loads could not be aggregated. However, as permits are issued in the watershed in the future, the new of expanding loads will be aggregated to the relevant TMDL wasteload allocation.

Table 4-1 through **Table 4-6** show VPDES permits issued in the watersheds by permit type. Aggregated WLAs were established for general permits using benchmark pollutant concentrations noted in associated permit guidance. In the case of industrial stormwater permits, target loading rates established for these facilities in order to meet Chesapeake Bay TMDL goals were used to establish WLAs. Discharge rates for facilities receiving coverage under a VPDES general permit were estimated using different data sources depending on permit type. In cases where a discharge rate has been previously established for a facility (e.g. potable water treatment facilities), this rate was used to develop the loading rate estimate. Similarly, domestic sewage permits have an assumed discharge rate of 1,000 gallons per day, which was used to develop load estimates. In cases wherein typical discharge rates are less clearly established and/or vary widely across facilities (e.g. industrial stormwater permits, mixed concrete permits), discharge monitoring data and/or facility acreages and associated runoff rates were used to develop load estimates. These estimates are not included in the associated tables due to the fact that these loads are aggregated by permit type.

4.3.2.1. VPDES Individual Permits

There are three VPDES individual permits within the study area, all of which are in the Stony Creek watershed. The typical sediment load from these facilities was calculated from discharge monitoring report data, which was used to model existing conditions (**Table 4-1**). The permitted loads, which are included in the wasteload allocation of the TMDL, were calculated based on the permitted discharge and concentration for the facilities.

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

Permit No	Facility Name	Watershed	Design Flow (MGD)	Permitted Conc. (mg/L TSS)	Typical (Existing) Load (lbs/yr TSS)	Permitted Load (TSS)	
						Lbs/yr	Metric tons/yr
VA0020508	Edinburg STP	Stony Creek	0.175	30	874	15,992	7.254
VA0028380	Stoney Creek Sanitary District STP	Stony Creek	0.60	30	1,936	54,829	24.87
VA0077402	George's Chicken LLC	Stony Creek	1.7	20	62,674	103,566	46.98

4.3.2.2. Potable Water Treatment Plant Permit

There is one potable water treatment plant (PWTP) general permit in the Stony Creek watershed, associated with the Edinburg Water Treatment Plant (**Table 4-2**). The permitted load was calculated using the same method as for the VPDES individual permit.

Table 4-2. Sediment load associated with the potable water treatment general permit.

Permit No	Facility Name	Watershed	Estimated Maximum Discharge (MGD)	Permitted Concentration (mg/L TSS)	Permitted Load (TSS)	
					Lbs/yr	Metric tons/yr
VAG640090	Edinburg Water Treatment Plant	Stony Creek	0.016	30	1,462	0.663

4.3.2.3. Industrial Stormwater Permits

There is one industrial stormwater (ISW) general permit in the study area, located in the Stony Creek watershed (**Table 4-3**). Sediment loads from industrial stormwater permits are included in this study. There is not currently a permitted loading rate for sediment for industrial stormwater sources in the general permit. However, the Chesapeake Bay TMDL now requires permittees to assess their nutrient and sediment loadings. As such, DEQ developed a methodology to estimate the loads from ISW permitted areas. To develop existing loads, regulated acres for the permit were separated from the accounting of total acreage for the watershed. Discharge monitoring data for TSS and the annual runoff rate for regulated industrial acres were used to calculate the existing sediment load for the facility. In the TMDL allocation scenario, the allocated loads were calculated using the same methodology, but utilizing the loading rate of 440 lb/ac/yr TSS noted in the general permit, which is the value used to estimate the loading from industrial stormwater facilities in Chesapeake Bay TMDL documentation.

Table 4-3. Industrial stormwater general permit in the study area.

Permit No	Facility Name	Watershed
VAR052460	George's Chicken LLC	Stony Creek

4.3.2.4. Domestic Sewage Permits

There are 45 domestic sewage general permits in the study area (**Table 4-4**). 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 the domestic sewage permits in the TMDL.

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

Permit Number	Watershed	Permitted Load (TSS)	
		Lbs/yr	Metric tons/yr
VAG401547	Crooked Run	91.44	0.042
VAG401675	Crooked Run	91.44	0.042
VAG401048	Pughs Run	91.44	0.042
VAG401220	Pughs Run	91.44	0.042
VAG401433	Pughs Run	91.44	0.042
VAG401523	Pughs Run	91.44	0.042
VAG401810	Pughs Run	91.44	0.042
VAG408385	Pughs Run	91.44	0.042

Permit Number	Watershed	Permitted Load (TSS)	
		Lbs/yr	Metric tons/yr
VAG401066	Stony Creek	91.44	0.042
VAG401075	Stony Creek	91.44	0.042
VAG401097	Stony Creek	91.44	0.042
VAG401115	Stony Creek	91.44	0.042
VAG401133	Stony Creek	91.44	0.042
VAG401228	Stony Creek	91.44	0.042
VAG401244	Stony Creek	91.44	0.042
VAG401267	Stony Creek	91.44	0.042
VAG401270	Stony Creek	91.44	0.042
VAG401272	Stony Creek	91.44	0.042
VAG401276	Stony Creek	91.44	0.042
VAG401324	Stony Creek	91.44	0.042
VAG401339	Stony Creek	91.44	0.042
VAG401342	Stony Creek	91.44	0.042
VAG401354	Stony Creek	91.44	0.042
VAG401399	Stony Creek	91.44	0.042
VAG401403	Stony Creek	91.44	0.042
VAG401422	Stony Creek	91.44	0.042
VAG401434	Stony Creek	91.44	0.042
VAG401436	Stony Creek	91.44	0.042
VAG401451	Stony Creek	91.44	0.042
VAG401588	Stony Creek	91.44	0.042
VAG401651	Stony Creek	91.44	0.042
VAG401689	Stony Creek	91.44	0.042
VAG401718	Stony Creek	91.44	0.042
VAG401722	Stony Creek	91.44	0.042
VAG401736	Stony Creek	91.44	0.042
VAG401820	Stony Creek	91.44	0.042
VAG401856	Stony Creek	91.44	0.042
VAG408182	Stony Creek	91.44	0.042
VAG408188	Stony Creek	91.44	0.042
VAG408236	Stony Creek	91.44	0.042
VAG408240	Stony Creek	91.44	0.042
VAG408380	Stony Creek	91.44	0.042
VAG408383	Stony Creek	91.44	0.042
VAG408473	Stony Creek	91.44	0.042
VAG408505	Stony Creek	91.44	0.042

4.3.2.5. Construction Stormwater Permits

There were four (4) active Virginia Stormwater Management Program (VSMP) permits for construction within the watersheds at the time of TMDL development. A total of eight (8) VSMP permits were issued within the impaired watersheds between 2013 and 2023 (**Table 4-5**). These permits are a potential source of sediment in the impaired streams and were assigned wasteload allocations in the TMDL. To guide sizing the wasteload allocation for these permits, the VSMP construction permits active in the past 10 years in the study watersheds were analyzed. Each permit contains an estimate of the permitted disturbed area, however, this area is generally not disturbed for the entire length of the permit's active status. To account for this discrepancy, the acreage estimated to be disturbed for each permit was divided over the length of the permit's active status (no less than one year). An average annual disturbed acreage was then calculated for each watershed.

There were no permits issued in the Crooked Run watershed during the 10-year data window. To account for VSMP permits that may be issued in the watershed in the future, a wasteload allocation was developed for the watershed based on average annual disturbance acreages in Pughs Run and Stony Creek, adjusted for the total area of the watersheds.

The disturbed acreage associated with construction permits was modeled as barren land cover, and appropriate permit-required erosion and sediment control measures were assumed to be utilized on all construction projects. Erosion and sediment control measures were simulated with an 85% sediment removal efficacy based on Chesapeake Bay Expert Panel Guidance (ESCEP, 2014).

Table 4-5. Disturbed acreage associated with active construction general permits within the watersheds.

Receiving Stream	Number of permits issued (2013-2023)	Currently active permits	Annual average disturbed area (acres)
Pughs Run	1	1	3.78
Stony Creek	7	3	7.20
Crooked Run	0	0	1.12

Table 4-6. Calculations for Crooked Run estimated annual disturbed area for construction general permit allocation.

Watershed	Total watershed acres	Area adjustment factor for Crooked Run	Area adjusted annual disturbance (acres) for Crooked Run
Stony Creek	72,515	0.06	0.42
Pughs Run	8,784	0.48	1.82
Crooked Run	4,239		
Average area adjusted annual disturbance for Crooked Run			**1.12**

4.4. Best Management Practices

Agricultural best management practices (BMPs) reported through the VA Agricultural Cost Share Program that were within their contract lifespan (typically 10-15 years) were accounted for in each watershed. Sediment reduction credits were assigned to the associated land cover type based on the extent of each practice installed. Credited BMPs are shown for each watershed in **Table 4-7**.

Table 4-7. Agricultural BMPs installed in the Crooked Run, Stony Creek and Pughs Run watersheds within their contract lifespan.

Practice description	Practice code	Units	Crooked Run		Pughs Run		Stony Creek	
			Count	Extent	Count	Extent	Count	Extent
Afforestation of Crop, Hay and Pasture Land	FR-1	Acres	1	5	2	6	1	15
Long Term Vegetative Cover on Cropland	SL-1	Acres	1	10	3	17	9	158
CREP Riparian Forest Buffer	CP-22	Acres	0	0	2	7	3	10
CREP Woodland Buffer Filter Area	CRFR-3	Acres	0	0	3	12	3	10
CREP Stream Exclusion with Grazing Land Management	CRSL-6	Lin ft	0	0	1	2,221	1	3,500
Woodland buffer filter area	FR-3	Acres	0	0	2	17	0	0
Stream Exclusion With Grazing Land Management	SL-6	Acres	0	0	5	6,782	15	53,222
Stream Exclusion with Wide Width Buffer and Grazing Land Management	SL-6W	Lin ft	0	0	3	14,125	7	11,204
Animal waste control facilities	WP-4	Count	0	0	2	2	1	1
Loafing lot management system	WP-4B	Count	0	0	2	2	1	1

4.5. Consideration of Critical Conditions and Seasonal Variations

The GWLF model simulated a 19-year period (2004 through 2022) 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 a number of 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 are dependent on whether or not a given month is tagged as part of the growing season. The model is also capable of incorporating data for the land-application of manure in up to two user-set application periods.

4.6. Existing Conditions

Existing sediment loads from the impaired watersheds were simulated in GWLF as described above. Error! Reference source not found. summarizes the resulting loads after applying the a ttenuation factors discussed in **Section 4.2**. While the model is run using weather data from a several year period to capture the 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 snapshot is approximately of April 2024 conditions. Any apparent differences in calculated values are due to rounding.

Table 4-8. Existing sediment loads in the Crooked Ru, Stony Creek and Pughs Run watersheds.

Source	TSS (metric tons/yr)		
	Crooked Run	Stony Creek	Pughs Run
Cropland	200	974	143
Pasture	56.8	929	61.1
Hay	83.9	372	160
Forest	23.3	385	50.2
Harvested Forest	-	41.6	-

Source	TSS (metric tons/yr)		
	Crooked Run	Stony Creek	Pughs Run
Barren	-	9.81	-
Developed Pervious	25.3	140	34.3
Tree	11.1	137	35.2
Developed Impervious	10.6	192	25.7
Streambank Erosion	7.18	2,150	33.9
Domestic Sewage Permits	0.08	1.53	0.25
Construction Permits	0.29	11.9	0.41
Stormwater Industrial Permits	-	3.38	-
Potable Water Treatment Plant Permits	-	0.66	-
VPDES Individual Permits	-	79.1	-
Total	***418***	***5,427***	***543***

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 established numeric criteria since acceptable levels 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 Crooked Run, Stony Creek and Pughs Run 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 both impaired watersheds and unimpaired watersheds with similar characteristics (**Appendix B**). A regression was then developed between the average Virginia Stream Condition Index (VSCI) scores at monitoring stations and the corresponding AllForX ratio for the watershed areas contributing to the monitoring site. This regression was used to quantify the value of AllForX that corresponds to the benthic health threshold (VSCI = 60). **Figure 5-1** shows the regression developed for Crooked Run, Stony Creek and Pughs Run. The allowable pollutant TMDL load was then calculated by applying the AllForX threshold where VSCI = 60 (AllForX = 7.24) to the all-forest simulated pollutant load of the TMDL study watersheds, as summarized in **Table 5-1**.

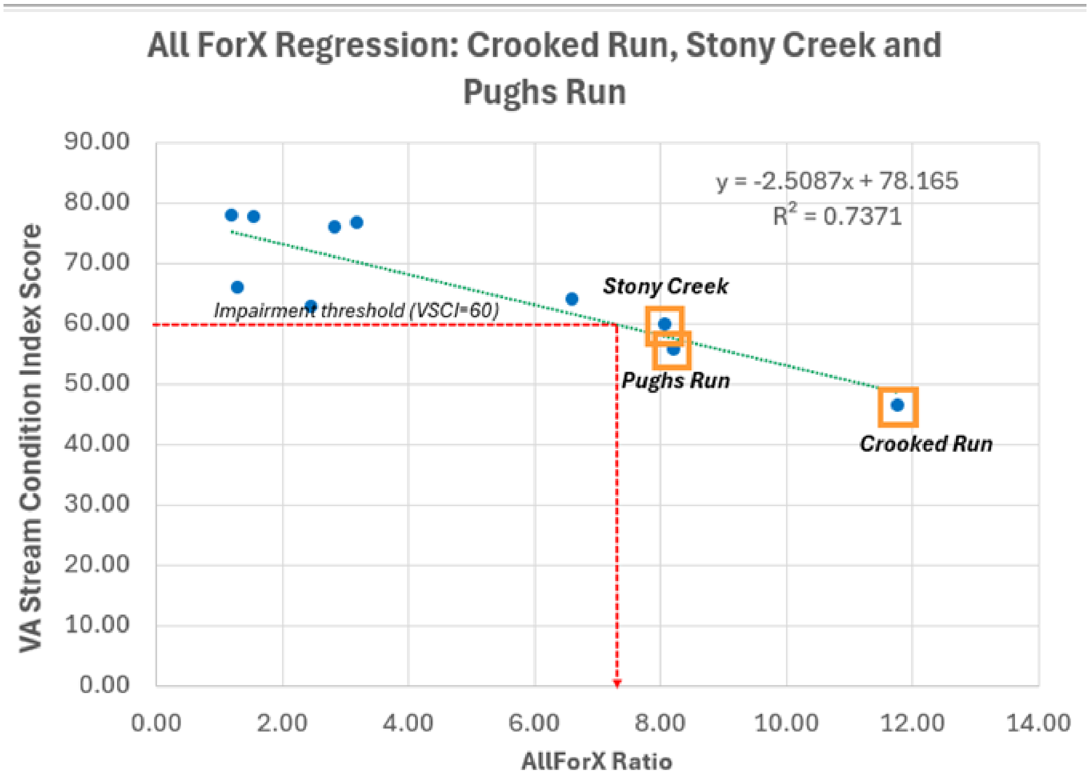

Figure 5-1. Regression between stream condition index and all-forest multiplier for sediment in the Crooked Run, Stony Creek and Pughs Run watersheds. The resulting AllForX target value was 7.24.

Table 5-1. Target sediment loading rates and reductions as determined by AllForX regression for the Crooked Run, Stony Creek and Pughs Run TMDL. Existing loads listed include only non-point sources, and do not include sediment reduction credits for existing BMPs shown in **Table 4-7**.

Impaired Stream	Metric tons/yr			Estimated NPS % Reduction
	TSS Existing	TSS AllForest	TSS Target	
Crooked Run	423	35.9	260	38.5%
Stony Creek	5,468	678	4,911	10.2%
Pughs Run	553	67.4	488	11.7%

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 (non-point 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**. 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 non-point sources of the POC (**Section 6.4**).

For model runs to develop the annual existing loads and target loads using the AllForX methodology, a 19-year period was simulated (2003 through 2023) 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 in an effort to ensure that the final TMDL is protective of water quality in light of 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 TMDL.

6.2. Future Growth

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

6.3. TMDL Calculations

Sediment was determined in the stressor analysis (VADEQ, 2023) as a primary cause of the benthic impairments in each of the impaired watersheds, and TMDLs were developed for sediment in each impaired watershed.

Total loads to downstream subwatersheds were summed from the loads of each contributing upstream subwatershed after adjusting for pollutant losses caused by in-stream processes (i.e. sediment deposition etc.) through the development of an attenuation factor (**Section 4.2**). This attenuation factor was applied to the pollutant loads and point sources of upstream subwatersheds as their load was conveyed through downstream subwatersheds. Permitted loads listed in the WLAs account for the appropriate attenuation factors based on their position in the watershed.

The final sediment average annual loads allocated in the TMDL are presented in **Table 6-1** through **Table 6-3**. GWLF output data, being in monthly increments, is most logically presented as annual aggregates.

Table 6-1. Annual average sediment TMDL components for Crooked Run

Impairment	WLA	LA	MOS	TMDL	Existing Load	Percent Reduction
	Sediment Load (metric tons/yr)					
Crooked Run - TSS (VAV-B48R_CKD01A00)	**5.6**	**228.4**	**26.0**	**260**	418	37.7%
Construction Permits	0.08					
Domestic Sewage Permits	0.29					
Future Growth (2% of TMDL)	5.21					

Table 6-2. Annual average sediment TMDL components for Stony Creek.

Impairment	WLA	LA	MOS	TMDL	Existing Load	Percent Reduction
	Sediment Load (metric tons/yr)					
Stony Creek - TSS (VAV-B49R_STY01A00) (VAV-B49R_STY02A00) (VAV-B49R_STY03A00)	**195.5**	**4,224.4**	**491.1**	**4,911**	5,427	9.5%
Construction Permits	11.88					
Industrial Stormwater Permits	4.10					
Domestic Sewage Permits	1.54					
Potable Water Treatment Plant Permits	0.66					
Individual VPDES Permits *VA0020508* *VA0028380* *VA0077402*	 7.25 24.87 46.98					
Future Growth (2% of TMDL)	98.22					

Table 6-3. Annual average sediment TMDL components for Pughs Run.

Impairment	WLA	LA	MOS	TMDL	Existing Load	Percent Reduction
	Sediment Load (metric tons/yr)					
Pughs Run - TSS (VAV-B50R_PGH01A00)	**10.4**	**428.8**	**48.8**	**488**	**543**	10.2%
Construction Permits	0.41					
Domestic Sewage Permits	0.25					
Future Growth (2% of TMDL)	9.76					

In 2007, the USEPA released a guidance document for developing maximum daily loads (MDLs) for TMDLs (USEPA, 2007). 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 6-3** by 365.24, are converted to MDLs using the following equation:

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

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 6-4**.

Table 6-4. "LTA to MDL multiplier" components for TMDLs.

Watershed	CV of Average Annual Loads	"LTA to MDL Multiplier"
Crooked Run	0.566	2.071
Stony Creek	0.397	1.744
Pughs Run	0.560	2.060

The daily WLA for stormwater permits and future growth allocations were estimated by dividing the annual WLA by 365.24 and using the LTA multiplier. Daily WLA's for all other permits were 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 6-5** through **Table 6-7**.

Table 6-5. Maximum 'daily' sediment loads and components for Crooked Run.

Impairment	WLA	LA	MOS	MDL
	Sediment Load (metric tons/day)			
Crooked Run - TSS (VAV-B48R_CKD01A00)	**0.031**	**1.297**	**0.148**	**1.48**
Construction Permits	*0.0016*			
Domestic Sewage Permits	*0.0002*			
Future Growth (2% of TMDL)	*0.0295*			

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

Impairment	WLA	LA	MOS	MDL
	Sediment Load (metric tons/day)			
Stony Creek - TSS (VAV-B49R_STY01A00) (VAV-B49R_STY02A00) (VAV-B49R_STY03A00)	**0.768**	**20.335**	**2.345**	**23.45**
Construction Permits	*0.0567*			
Industrial Stormwater Permits	*0.0196*			
Domestic Sewage Permits	*0.0042*			
Potable Water Treatment Plant Permits	*0.0018*			
Individual VPDES Permits	*0.2166*			
Future Growth (2% of TMDL)	*0.4690*			

Table 6-7. Maximum 'daily' sediment loads and components for Pughs Run.

Impairment	WLA	LA	MOS	MDL
	Sediment Load (metric tons/day)			
Pughs Run - TSS	**0.058**	**2.420**	**0.275**	**2.75**

Impairment	WLA	LA	MOS	MDL
	Sediment Load (metric tons/day)			
(VAV-B50R_PGH01A00)				
Construction Permits	*0.0023*			
Domestic Sewage Permits	*0.0007*			
Future Growth (2% of TMDL)	*0.0550*			

6.4. Allocation Scenarios

Multiple sediment allocation scenarios were developed to determine possible options for reducing sediment loads in the Crooked Run, Stony Creek and Pughs Run watersheds to the recommended TMDL loads. Feedback from the community engagement meeting participants was used to select preferred allocation scenario for each watershed. Stakeholders recommended scenarios that balanced more costly reductions from growing urban and residential sediment sources with cost effective reductions from agricultural sources. Reductions to hayland were limited based on the availability of best management practices to address runoff from hayland. In Stony Creek, development and streambank erosion were recognized as growing issues with respect to water quality, and stakeholders recommended increasing reductions for these sources during their review of initial reduction scenarios. The sediment allocation scenarios evaluated by meeting participants are presented in **Table 6-8** through **Table 6-10.** The first scenario focuses the greatest reductions on the largest sediment sources in each watershed. The second scenario assigns equal reductions to all sources. The third scenario focuses solely on agricultural sediment sources and the fourth scenario focuses solely on urban/residential sources. In Crooked Run and Pughs Run, solely addressing residential/urban sources would not be sufficient to meet the TMDL for each watershed.

Table 6-8. Allocation scenarios for Crooked Run.

Crooked Run Sediment		**Scenario 1 (preferred)**		**Scenario 2**		**Scenario 3**		**Scenario 4**	
Source	**Existing**	**Red.**	**Allocation**	**Red.**	**Allocation**	**Red.**	**Allocation**	**Red.**	**Allocation**
	TSS (metric tons/yr)	***%***	***TSS (metric tons/yr)***	***%***	***TSS (metric tons/yr)***	***%***	***TSS (metric tons/yr)***	***%***	***TSS (metric tons/yr)***
Cropland	200	56%	87.8	49.4%	100.9	55.6%	88.6	0%	200
Pasture	56.8	54%	26.1	49.4%	28.7	55.6%	25.2	0%	56.8
Hay	83.9	36%	53.7	49.4%	42.5	55.6%	37.2	0%	83.9
Forest	23.3	0%	23.3	0%	23.3	0%	23.3	0%	23.3
Developed Pervious	25.3	40%	15.2	49.4%	12.8	0%	25.3	100%	0
Tree	11.1	0%	11.1	0%	11.1	0%	11.1	0%	11.1
Developed Impervious	10.6	40%	6.4	49.4%	5.35	0%	10.6	100%	0
Streambank Erosion	7.18	30%	5.02	49.4%	3.63	0%	7.18	100%	0
Domestic Sewage General Permits	0.08	0%	0.08	0%	0.08	0%	0.08	0%	0.08
Construction Stormwater General Permits	0.29	0%	0.29	0%	0.29	0%	0.29	0%	0.29
Margin of Safety (10%)	-	-	26.0	-	26.0	-	26.0	-	26.0
Future Growth Set Aside (2%)	-	-	5.21	-	5.21	-	5.21	-	5.21
TOTAL	**418**	**37.8%**	**260**	**37.8%**	**260**	**37.8%**	**260**	**2.8%**	**406***

** Scenario does not meet target sediment reduction goal*

Table 6-9. Allocation scenario for Stony Creek sediment loads.

Stony Creek Sediment		**Scenario 1 (preferred)**		**Scenario 2**		**Scenario 3**		**Scenario 4**	
Source	**Existing**	**Red.**	**Allocation**	**Red.**	**Allocation**	**Red.**	**Allocation**	**Red.**	**Allocation**
	TSS (metric tons/yr)	*%*	*TSS (metric tons/yr)*	*%*	*TSS (metric tons/yr)*	*%*	*TSS (metric tons/yr)*	*%*	*TSS (metric tons/yr)*
Cropland	974	24%	740	23.1%	749	48.7%	500	0%	974
Pasture	929	24%	706	23.1%	714	48.7%	476	0%	929
Hay	372	10%	335	23.1%	286	48.7%	191	0%	372
Forest	385	0%	385	0%	385	0%	385	0%	385
Harvested Forest	41.6	5%	39.6	23.1%	32	0%	41.6	0%	41.6
Barren	9.81	0%	9.81	0%	9.81	0%	9.81	0%	9.81
Developed Pervious	140	18%	115	23.1%	108	0%	140	446%	77.6
Tree	137	0%	137	0%	137	0%	137	0%	137
Developed Impervious	192	25%	144	23.1%	148	0%	192	44.6%	106
Streambank Erosion	2,150	25%	1,613	23.1%	1,653	0%	2,150	44.6%	1,191
Domestic Sewage General Permits	1.53	0%	1.53	0%	1.53	0%	1.53	0%	1.53
Construction Stormwater General Permits	11.9	0%	11.9	0%	11.9	0%	11.9	0%	11.9
Industrial Stormwater General Permits	3.38	0%	4.10	0%	4.10	0%	4.10	0%	4.10
Potable Water Treatment Plant General Permits	0.66	0%	0.66	0%	0.66	0%	0.66	0%	0.66
VPDES Individual Permits									
VA0020508	7.25	0%	7.25	0%	7.25	0%	7.25	0%	7.25
VA0028380	24.9	0%	24.9	0%	24.9	0%	24.9	0%	24.9
VA0077402	47.0	0%	47.0	0%	47.0	0%	47.0	0%	47.0
Margin of Safety (10%)	-	-	491.1	-	491.1	-	491.1	-	491.1
Future Growth (2%)	-	-	98.2	-	98.2	-	98.2	-	98.2
TOTAL	**5,427**	**9.52%**	**4,910**	**9.56%**	**4,909**	**9.54%**	**4,909**	**9.53%**	**4,910**

Table 6-10. Allocation scenario for Pughs Run sediment loads.

Pughs Run Sediment		**Scenario 1 (preferred)**		**Scenario 2**		**Scenario 3**		**Scenario 4**	
Source	**Existing**	**Red.**	**Allocation**	**Red.**	**Allocation**	**Red.**	**Allocation**	**Red.**	**Allocation**
	TSS (metric tons/yr)	*%*	*TSS (metric tons/yr)*	*%*	*TSS (metric tons/yr)*	*%*	*TSS (metric tons/yr)*	*%*	*TSS (metric tons/yr)*
Cropland	143	32%	97.1	25%	107	32%	97.1	0	143
Pasture	61.1	32%	41.5	25%	45.8	32%	41.5	0.0%	61.1
Hay	160	20%	128	25%	120	32%	109	0.0%	160
Forest	50.2	0%	50.2	0.0%	50.2	0.0%	50.2		50.2
Developed Pervious	34.3	15%	29.2	25%	25.7	0.0%	34.3	100.0%	0.00
Tree	35.2	0%	35.2	0.0%	35.2	0.0%	35.2	0.0%	35.2
Developed Impervious	25.7	20%	20.5	25%	19.3	0.0%	25.7	100.0%	0.00
Streambank Erosion	33.9	20%	27.1	25%	25.4	0.0%	33.9	100.0%	0.00
Domestic Sewage General Permits	0.25	0%	0.25	0%	0.25	0%	0.25	0%	0.25
Construction Stormwater General Permits	0.41	0%	0.41	0%	0.41	0%	0.41	0%	0.41
Margin of Safety (10%)	-	-	48.8	-	48.8	-	48.8	-	48.8
Future Growth Set Aside (2%)	-	-	9.76	-	9.76	-	9.76	-	9.76
TOTAL	**543**	**10.24%**	**488**	**10.26%**	**487**	**10.63%**	**486**	**6.50%**	**508 ***

** Scenario does not meet target sediment reduction goal*

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. VADEQ regulates stormwater discharges associated with industrial 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.

As part of the Continuing Planning Process, DEQ staff presents the TMDL WLAs 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€ and Virginia's Public Participation Guidelines for Water Quality Management Planning.

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.

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 Crooked Run, Stony Creek and Pughs Run watersheds.

7.3. Reasonable Assurance

The following activities provide reasonable assurance that these TMDLs will be implemented and water quality will be restored in the impaired 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.

- Agricultural BMP implementation actions – Many 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 and loads. BMPs implemented through state and federal cost share programs are tracked by local, state and federal entities including VADEQ. Thus, the cooperative effort currently in place to ensure that the pollutant reductions associated with these implementation actions will be continued in order to measure progress in meeting sediment TMDL reduction goals.

8.0 PUBLIC PARTICIPATION

Public participation was elicited at every stage of the TMDL development in order to receive input from stakeholders and to apprise the stakeholders of the progress made. A series of three community engagement meetings (CEM) took place during model and allocation development. Meeting participants included representatives from Shenandoah County, the Town of Edinburg, Lord Fairfax SWCD, NRCS, Friends of the Shenandoah River, Friends of the NF Shenandoah River, Shenandoah Riverkeeper, Georges Chicken, and several local landowners. All four community engagement meetings were held at the Shenandoah County Library in Edinburg, VA.

The first community engagement meeting was held on August 19, 2024 to discuss land cover estimates for the watersheds, and point and non point sediment sources. Participants provided feedback on areas of growth in the watersheds and projected development patterns in the future. Agricultural management practices were discussed including cropland tillage, conversion of cropland to hay and pasture, and implementation of measures to control runoff from vineyards. The first meeting was attended by 17 people. The second community engagement meeting (13 attendees, December 16, 2024) discussed updates to sediment load estimates, particularly loads coming from streambank erosion. Participants also discussed the methodology used to establish sediment endpoints for the impaired streams (AllForX) and reviewed a series of sediment allocation scenarios for the watersheds. Participants provided feedback on areas of considerable streambank erosion in the watersheds and discussed the role that weather patterns (periods of drought followed by heavy rain) play in stream health. Following evaluation of allocation scenarios, participants recommended a new scenario be developed that included the largest reductions for the greatest agricultural sources, but also included greater reductions for urban and residential sources. Participants noted that increased development is contributing to increased streambank erosion, which was identified as a primary concern by stakeholders. The third and final community engagement meeting (18 attendees) was held on February 4, 2025. During this meeting, participants reviewed the updated allocation scenarios for the impaired watersheds and discussed plans for the final public meeting.

A public meeting was held on June 18, 2024 to share information about the health of the streams and discuss the TMDL process, including opportunities for public participation. The meeting was held at the Shenandoah County Library in Edinburg VA at 5:30 pm. The meeting was promoted through a large mailing to riparian landowners in addition to emails and meeting fliers and was attended by 40 people.

A second and final public meeting was held on April 9, 2025 to present the draft TMDL document. The public meeting marked the beginning of the official public comment period and was attended by XX watershed residents and other stakeholders. The public comment period ended on May 9, 2025.

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Appendix A: GWLF Model Parameters

Various GWLF parameters used for the Crooked Run, Stony Creek and Pughs Run watershed models are detailed below (Error! Reference source not found.**).**

Table A-1. Watershed GWLF parameters.

GWLF Parameter	**Units**	**Crooked Run**	**Stony Creek**	**Pughs Run**
Recession Coefficient	day^{-1}	0.1090	0.1095	0.1259
Seepage Coefficient	day^{-1}	0.0400	0.0400	0.0400
Leakage Coefficient	day^{-1}	0	0	0
Sediment Delivery Ratio		0.1828	0.1754	0.1798
Unsaturated Water Capacity	cm	0.1209	0.1163	0.1209
Erosivity Coefficient (Nov-Mar)		0.09	0.09	0.09
Erosivity Coefficient (Apr-Oct)		0.30	0.30	0.30
aFactor		0.000148	0.000563	0.000309
Total Stream Length	m	7,003	14,118	5,461
Mean Channel Depth	m	0.4664	0.5264	0.4927

Appendix B: AllForX Development

The method used to set TMDL endpoint loads for the Crooked Run, Stony Creek and Pughs Run is called the “all-forest load multiplier” (AllForX) approach, which has been used in developing many sediment and nutrient 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 or nutrient loads are above an undeveloped condition. After calculating AllForX values for a range of monitoring stations, a regression is developed between the AllForX values and corresponding VSCI scores at those stations. The TMDL target loads are then set as the AllForX value corresponding to the VSCI threshold score of 60.

These AllForX multipliers were calculated for a total of seven watersheds (**Figure B-1**). Comparison watersheds used in addition to the TMDL watersheds in developing the VSCI and AllForX regression were selected to be similar in size and located near the study watersheds to minimize differences in flow regime, soils and other physiographic properties. Additionally, the comparison watersheds must have at least three VSCI data points collected after 2005. The VSCI scores at each station were averaged to create a pooled VSCI score.

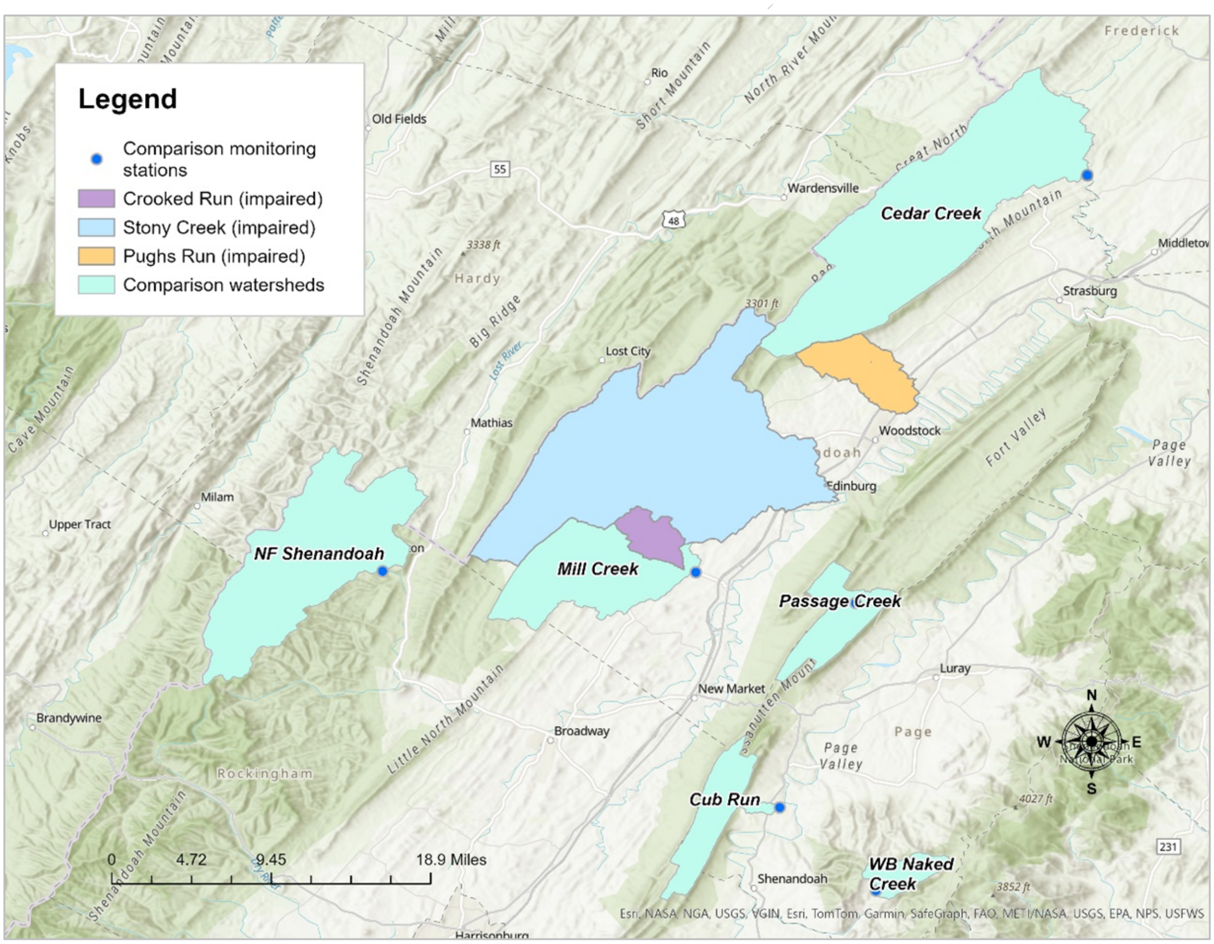

Figure B-1. Comparison watersheds selected for Crooked Run, Stony Creek and Pughs Run AllForX regression.

For the purposes of building the AllForX regression, permitted sources were not included. This was to leave the flexibility of potentially incorporating 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 B-1**.

The AllForX values of sediment loads were plotted against their associated VSCI pooled scores and a linear regression was plotted through the values (**Figure B-2**). The regression resulted in an R^2 value of 0.6967 and was used to quantify the value of AllForX that corresponds to the benthic health threshold (VSCI = 60). The allowable pollutant TMDL load was then calculated by applying the AllForX threshold where VSCI = 60 (AllForX = 7.24) 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 B-1. Model run results for AllForX value development.

Station ID	VASCI avg	TSS (lb/yr)	TSS All-Forested (lb/yr)	TSS AllForX
1BCUB000.40	77.84	199.8	130.2	1.54
1BNFS093.80	76.80	8,452.6	2,651.1	3.19
1BNFS107.86	62.80	2,534.3	1,033.7	2.45
1BNKW001.97	65.93	171.5	134.2	1.28
1BCDR015.40	76.08	2,442.8	863.8	2.83
1BMIL002.20	64.00	1,691.0	256.8	6.59
1BPSG031.99	78.00	43.5	36.4	1.20

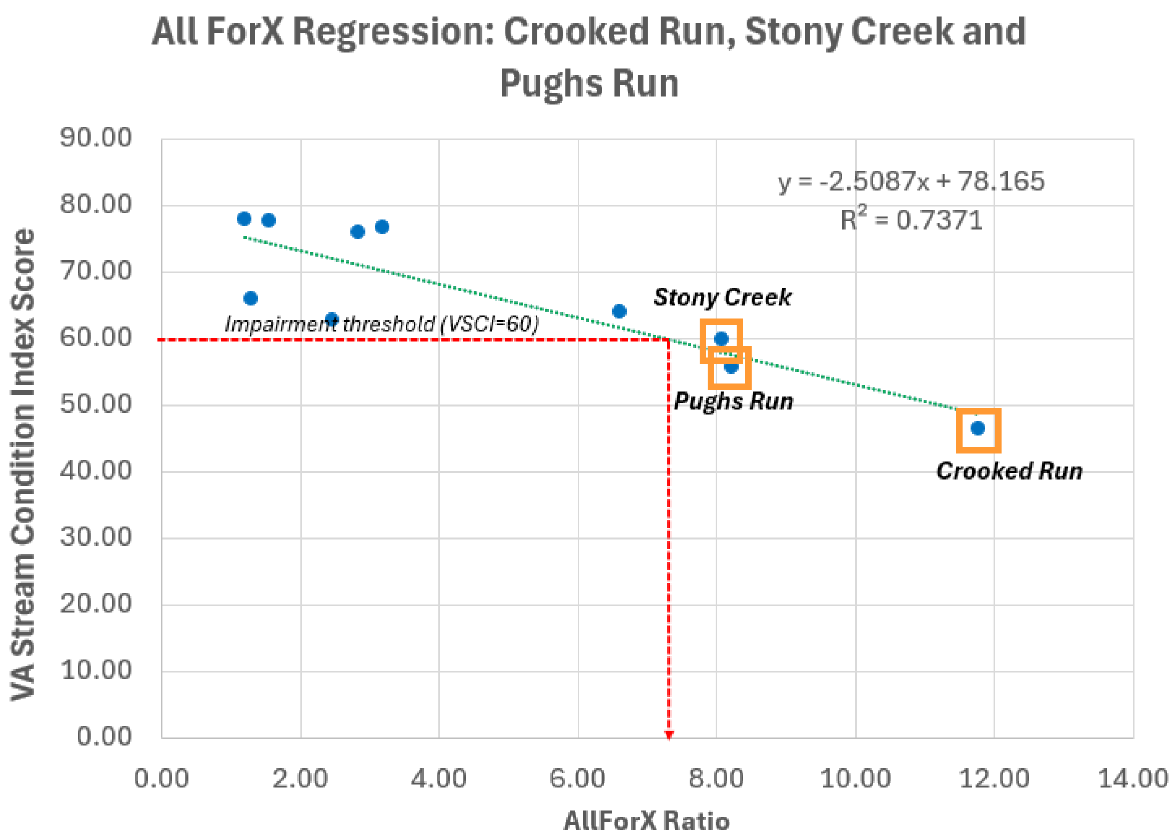

Figure B-2. Regression for sediment in the Crooked Run, Stony Creek and Pughs Run TMDLs, resulting AllForX target value of 7.24.