Benthic TMDL Development for Greendale Creek and Unnamed Tributary to Fleenor Branch located in Washington County, VA

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Table of Contents

Figures

Figures in Appendices

Tables

<u>Tables in Appendices</u>

Acronyms

AllForX	All-Forest Load Multiplier
CADDIS	Causal Analysis Diagnosis Decision Information System
CBP	Chesapeake Bay Program
CREP	Conservation Reserve Enhancement Program
CV	Coefficient of Variation
EQIP	Environmental Quality Incentive Program
GWLF	Generalized Watershed Loading Function
HSG	Hydrologic Soil Group
ISW	Industrial Stormwater
JMU	James Madison University
LA	Load Allocation
LTA	Long-Term Average
MDL	Maximum Daily Load
MOS	Margin of Safety
MS4	Municipal Separate Storm Sewer Systems
NPDES	National Pollutant Discharge Elimination System
NRCS	Natural Resource Conservation Service
POC	Pollutant(s) of Concern
SCS-CN	Soil Conservation Service Curve Number
SSURGO	Soil Survey Geographic database
SWCB	State Water Control Board
SWCD	Soil and Water Conservation District
TAC	Technical Advisory Committee
TMDL	Total Maximum Daily Load
TSS	Total Suspended Sediment
UT	Unnamed Tributary
USEPA	United States Environmental Protection Agency
USLE	Universal Soil Loss Equation
VADEQ	Virginia Department of Environmental Quality
VGIN	Virginia Geographic Information Network
VLCD	Virginia Land Cover Dataset
VPDES	Virginia Pollutant Discharge Elimination System
VSCI	Virginia Stream Condition Index
VSMP	Virginia Stormwater Management Program
WLA	Wasteload Allocation
WQMIRA	Water Quality Monitoring, Information and Restoration Act

1.0 EXECUTIVE SUMMARY

1.1. Background

The Greendale Creek and Unnamed Tributary (UT) to Fleenor Branch (listed as Rich Valley Unnamed Tributary in ATTAINS) watersheds are in Washington County, Virginia. Both Greendale Creek and UT to Fleenor Branch drain to the North Fork of the Holston River. Both Creeks drain to a predominantly rural watershed north and northwest of Abingdon, VA.

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

Greendale Creek and Unnamed Tributary to Fleenor Branch were initially listed as impaired in 2010 and 2020, respectively, due to water quality violations of the general aquatic life (benthic) standard according to Virginia's 2022 305(b)/303(d) Water Quality Assessment Integrated Report (VADEQ, 2022). The impaired segments addressed in this document are shown in **Table** 1-1. The watersheds of the impaired streams are show in **Figure** 1-1.

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

TMDL Watershed	305(b)/303(d) Assessment Unit ID	Cause Group Code	Listing Station	Year Initially Listed
Greendale Creek	VAS-O12R_GRN01A00 (5.03 mi)	O12R-03-BEN	6CGRN003.29	2010
UT to Fleenor Branch	VAS-O12R_XEO01A12 (0.85)	O12R-04-BEN	6CXEO000.25	2020

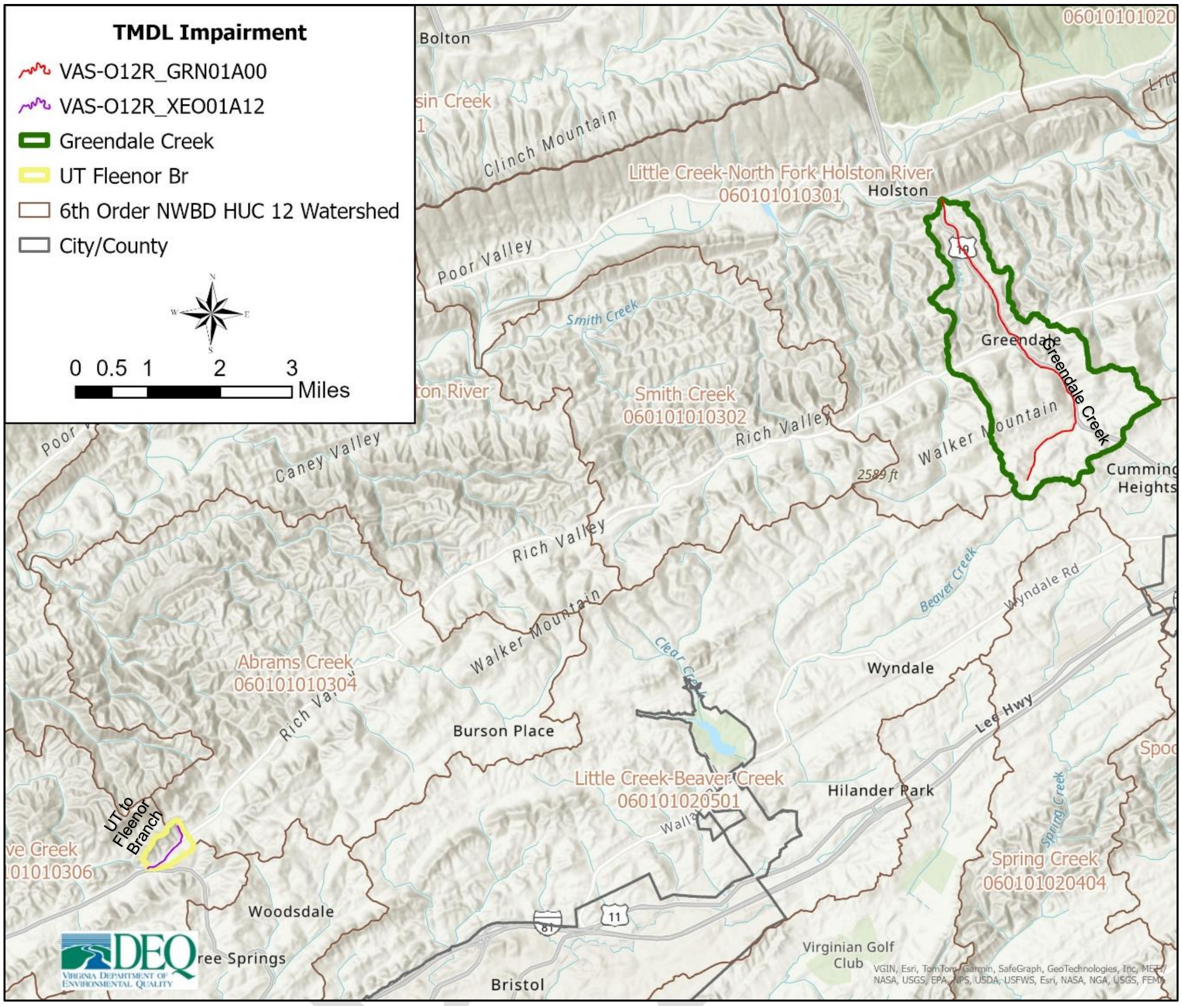

Figure 1-1. Location of the Greendale Creek and UT to Fleenor Branch watersheds and impairments.

1.2. The Problem

1.2.1. Impaired Aquatic Life

The Commonwealth of Virginia establishes designated uses for all the waters in the state. Some of these uses include recreation, fishing, wildlife and aquatic life. Water quality standards have been developed to ensure that some of these uses are met, while others are assessed using narrative criteria. The aquatic life use designation states that all waters of the state must support a healthy and diverse population of aquatic life. The Virginia Department of Environmental Quality (DEQ) determines whether this designated use is met by monitoring the benthic macroinvertebrate community (bugs that live on the bottom of the stream) in our waterways. The health and diversity of these bugs are assessed using the Virginia Stream Condition Index (VSCI). The VSCI is a multimetric index used to derive stream health scores ranging from 0 to 100. Scores below 60 are categorized as impaired. **Figure** 1-2 shows DEQ's biological monitoring stations in the Greendale Creek and UT to Fleenor Branch watersheds, which are color-coded by the average score at each site.

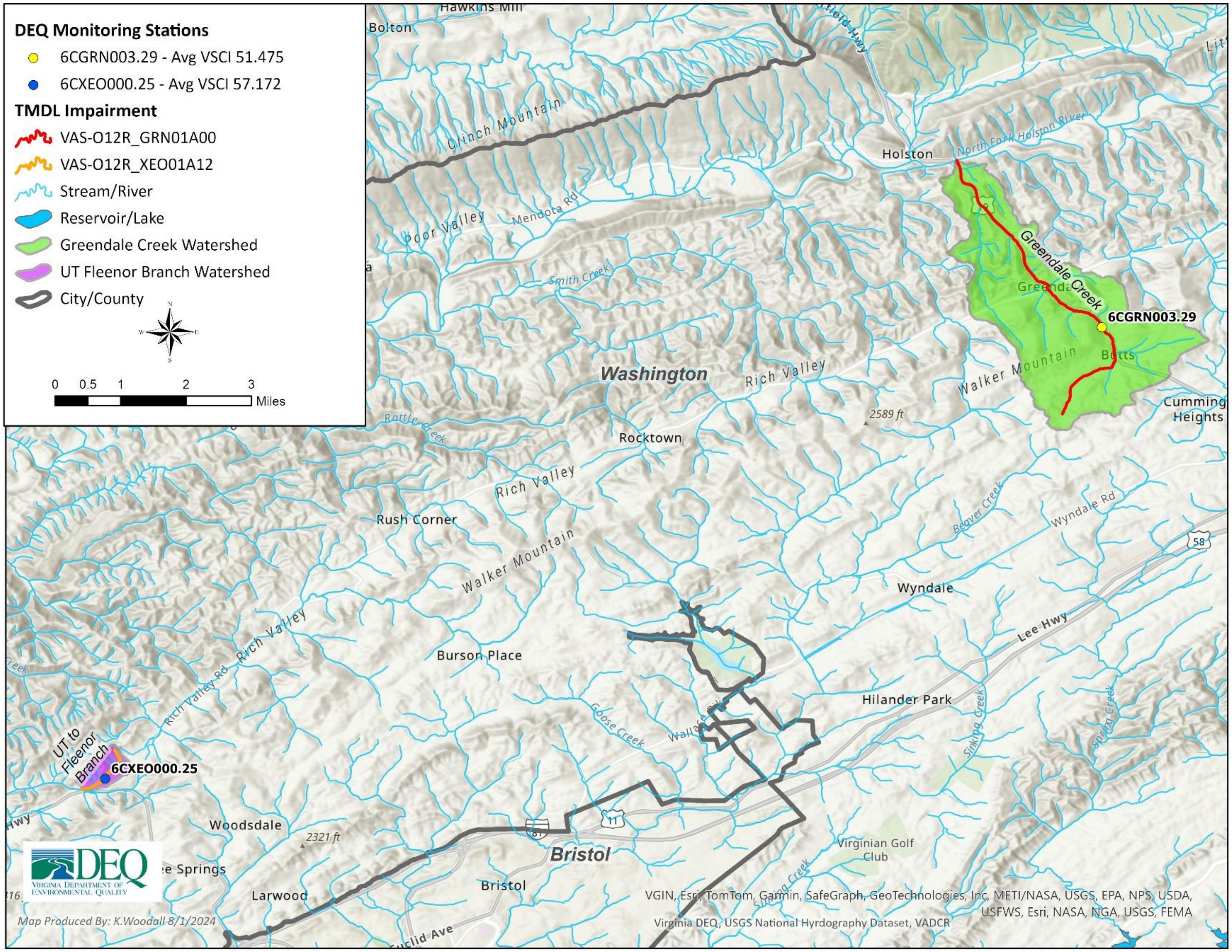

Figure 1-2. Stream health score summaries in the Greendale Creek and UT to Fleenor Branch watersheds.

A benthic stressor analysis was conducted in 2022 to determine the cause(s) of benthic impairment in the Greendale Creek and UT to Fleenor Branch. The study identified sediment as the most probable stressor to aquatic life in the Greendale Creek. In UT to Fleenor Branch, both sediment and phosphorus were identified as the most probable stressors to aquatic life.

1.2.2. Too Much Sediment

Excess sediment was identified as the primary stressor in Greendale Creek and UT to Fleenor Branch. When it rains, sediment is washed off the land into nearby creeks and rivers. The amount of soil that is washed off depends upon how much it rains and the characteristics of the surrounding watershed. Rain falling on highly tilled cropland without a cover crop or a construction site lacking sufficient controls may carry a large amount of sediment to a stream. Conversely, forested land and cropland where no-till practices are used contribute much less sediment to waterways during rainfall events. When soil from overland flow reaches nearby streams, it can fall to the stream bottom as sediment, where it can destroy valuable habitat for aquatic macroinvertebrates that live underneath and between rocks and gravel on the bottom of the stream. Without this valuable habitat, the diversity of aquatic life in a stream may be severely limited.

1.2.3. Too Much Phosphorus

In addition to having too much sediment, UT to Fleenor Branch has too much phosphorus. Phosphorus is a nutrient that helps plants grow. Nonpoint sources of phosphorous include runoff of fertilizers and manures. Phosphorous can also reach our waterways through atmospheric deposition. Just as soil can wash off the land surface into nearby creeks, phosphorus contained in fertilizers or manures that are applied to lawns or farm fields can also wash off. Point sources of phosphorous include industrial and municipal wastewater treatment facilities. In a stream, phosphorus makes algae grow, and those algae reduce oxygen levels in the water when they die and decompose. Excessive levels of algae in the water may produce large daily swings in both dissolved oxygen concentrations and pH. These large shifts can be harmful to aquatic life, thus limiting the diversity of bugs and fish that make up the aquatic community.

1.3. The Study

To study the problem of excess sediment in the Greendale Creek and excess sediment and phosphorus in the UT to Fleenor Branch watersheds, a combination of monitoring data and computer modeling was utilized. Monitoring was used to tell how much sediment and phosphorus are in the streams at any given time and how aquatic life conditions have changed over time. The computer model incorporates monitoring data and was used to estimate where the sediment and phosphorus are coming from and make predictions about how stream conditions would change if those sources were reduced.

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

For this purpose, a computer model called the Generalized Watershed Loading Function model (or GWLF) was used. This model 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 Greendale Creek and the UT to Fleenor Branch, 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.

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

This report summarizes the study and sets goals for a clean-up plan. The study is called a Total Maximum Daily Load (TMDL) study because it determines the maximum amount of sediment and phosphorus 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 Virginia Geographic Information Network (VGIN) 2016 Virginia Land Cover Dataset (VLCD) was used to characterize the current land use. The land cover classification from the VLCD is shown in **Figure** 1-3 and **Figure** 1-4 for each impaired watershed. Based on the VLCD, both the Greendale Creek watershed and the UT to Fleenor Branch are largely forested (over 50%) with a sizable amount of pasture (28%). Note that the pasture classification in the VLCD includes land used for the production of hay. There is no cropland identified in either of the watersheds.

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

The land use distribution was modified (discussed in Section 3.4) to better represent the major nonpoint pollutant sources in the watersheds. The GWLF model was used to determine the relative contribution of sources of sediment and phosphorus in the impaired watersheds. **Figure** 1-5 and **Figure** 1-6 show the distribution of sediment contributions from various sources in the watersheds, as well as phosphorus sources for the UT to Fleenor Branch. There are three domestic sewage discharge general permitted outfalls in the Greendale Creek watershed and none within the UT to Fleenor Branch watershed. In the Greendale Creek and UT to Fleenor Branch watersheds, pastureland (including hay land) covers a greater extent than developed areas (residential and urban), and as such most of the sediment and phosphorus loads are derived from pasture lands.

Land Cover Category	Greendale Creek Watershed	
	Acres	%
Open Water	2	<1%
Impervious Extracted	74	2%
Impervious Local Data	63	2%
Forest	1,832	53%
Tree	233	7%
Shrub\Scrub	61	2%
Harvested\Disturbed	29	<1%
Turf Grass	189	6%
Pasture	981	28%
NWI\Other	<1	<1%
Total	*3,465*	*100%*

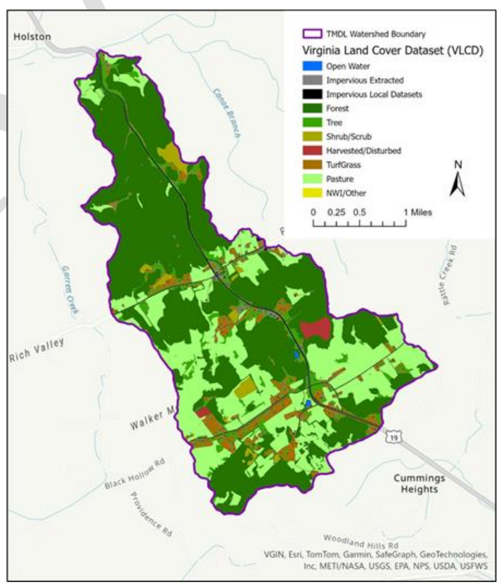

Figure 1-3. Land cover in the Greendale Creek watershed (VGIN, 2016).

Land Cover Category	UT Fleenor Br Watershed	
	Acres	%
Open Water	-	-
Impervious Extracted	<1	<1%
Impervious Local Data	4	2%
Forest	91	54%
Tree	12	7%
Shrub\Scrub	-	-
Harvested\Disturbed	-	-
Turf Grass	14	8%
Pasture	48	28%
NWI\Other	-	-
Total	*169*	*100%*

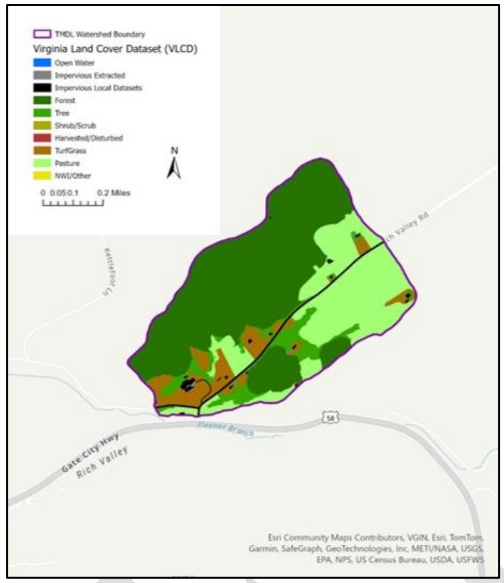

Figure 1-4. Land cover in the Unnamed Tributary to Fleenor Branch watershed (VGIN, 2016).

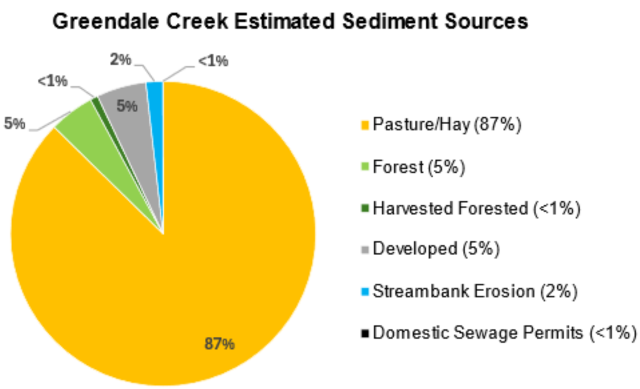

Figure 1-5. Estimated existing sediment load distribution in the Greendale Creek watershed.

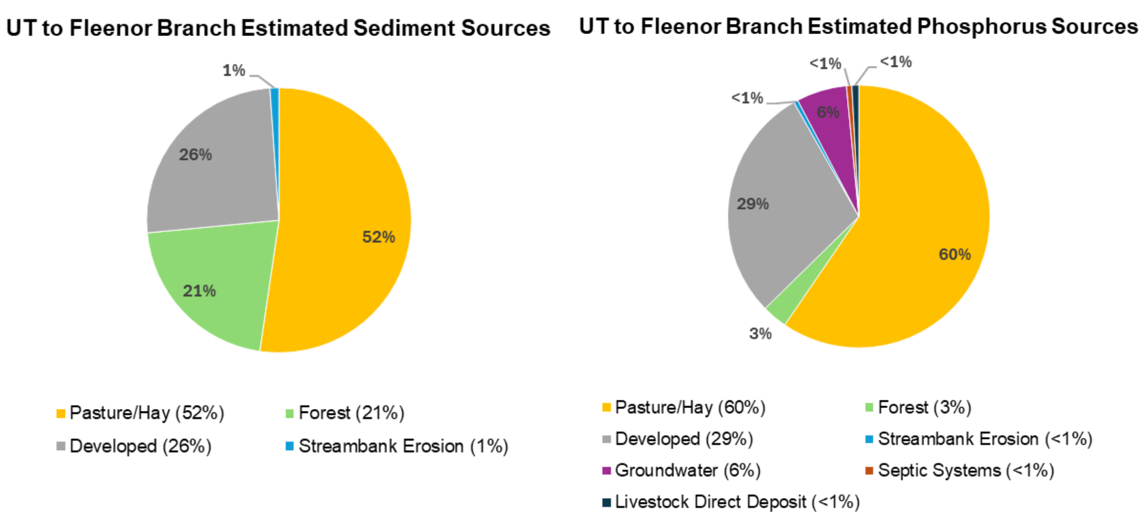

Figure 1-6. Estimated existing sediment and phosphorus load distributions in the UT to Fleenor Branch watershed.

1.5. Future Goals (the TMDL)

The final sediment and phosphorus average annual loads allocated in the TMDL are presented in **Table** 1-2 and **Table** 1-3. Existing loads shown for Greendale Creek and UT to Fleenor Branch exclude the margin of safety and future growth allocations for the watersheds. The margin of safety (MOS) is calculated as 10% of the TMDL. The waste load allocation (WLA) for future growth is calculated as 2% of the TMDL. These annual loads are converted to daily maximum loads as well, as described in **Section 6.3** (**Table** 1-4 and **Table** 1-5). If sediment and phosphorus loads are reduced to these amounts, healthy aquatic life should be restored in these streams.

Table 1-2. Annual average sediment TMDL components for Greendale Creek and the UT to Fleenor Branch.

Impairment	Allocated Permitted Point Sources (WLA) (ton/yr)	Allocated Nonpoint Sources (LA) (ton/yr)	Margin of Safety (MOS) (ton/yr)	Total Maximum Daily Load (TMDL) (ton/yr)	Existing Load (ton/yr)	Overall Reduction (%)
Greendale Creek (VAS-O12R_GRN01A00)	**14**	**606**	**69**	**689**	977	29%
Domestic Sewage Permits	*0.14*					
*Future Growth (2% of TMDL)**	*13.86*					
UT to Fleenor Branch (VAS-O12R_XEO01A12)	**0.22**	**9.71**	**1.10**	**11.03**	19.11	42%
Future Growth (2% of TMDL)	*0.22*					

* Future Growth has been adjusted to ensure exact additivity to the WLA.

Table 1-3. Annual average phosphorus TMDL components for the UT to Fleenor Branch.

Impairment	Allocated Permitted Point Sources (WLA) (ton/yr)	Allocated Nonpoint Sources (LA) (ton/yr)	Margin of Safety (MOS) (ton/yr)	Total Maximum Daily Load (TMDL) (ton/yr)	Existing Load (ton/yr)	Overall Reduction (%)
UT to Fleenor Branch (VAS-O12R_XEO01A12)	**1.2**	**53.9**	**6.1**	**61.2**	151.6	60%
Future Growth (2% of TMDL)	*1.2*					

Table 1-4. Maximum 'daily' sediment loads and components for Greendale Creek and the UT to Fleenor Branch.

Impairment	Allocated Permitted Point Sources (WLA) (ton/day)	Allocated Nonpoint Sources (LA) (ton/day)	Margin of Safety (MOS) (ton/day)	Maximum Daily Load (MDL) (ton/day)
Greendale Creek (VAS-O12R_GRN01A00)	**0.069**	**3.033**	**0.345**	**3.447**
UT to Fleenor Branch (VAS-O12R_XEO01A12)	**0.0013**	**0.0552**	**0.0063**	**0.0628**

Table 1-5. Maximum 'daily' phosphorus loads and components for the UT to Fleenor Branch.

Impairment	Allocated Permitted Point Sources (WLA) (lbs/day)	Allocated Nonpoint Sources (LA) (lbs/day)	Margin of Safety (MOS) (lbs/day)	Maximum Daily Load (MDL) (lbs/day)
UT to Fleenor Branch (VAS-O12R_XEO01A12)	**0.0061**	**0.2687**	**0.0305**	**0.3053**

1.5.1. Allocation Scenarios

Two allocation scenarios are proposed for each of the sediment and phosphorus TMDLs (Tables 1-6 through 1-8). No reductions were assigned to forest or permitted sources. Scenario 1 assigns equal percent reductions from all other sediment sources, while Scenario 2 uses lower percent reductions from developed sources (stormwater runoff from residential areas) than the other sources. This approach is reasonable because pasture is the largest source of sediment and phosphorus in these watersheds, and agricultural, septic, and timber harvesting practices are typically more cost efficient than residential practices. Having some reductions allocated to residential sources allows for future implementation to target best management practices (BMPs) that address both agricultural and residential sources.

Table 1-6. Allocation scenario for Greendale Creek sediment loads.

Greendale Creek Sediment		**Scenario 1**		**Scenario 2**	
Source	Existing	Red.	Allocation	Red.	Allocation
	TSS (tons/yr)	*%*	*TSS (tons/yr)*	*%*	*TSS (tons/yr)*
Pasture/Hay	853.17	39.9	512.76	41.9	495.69
Forest	46.49	-	46.49	-	46.49
Harvested Forested	8.10	39.9	4.87	41.9	4.71
Developed	51.43	39.9	30.91	5.0	48.86
Streambank Erosion	17.48	39.9	10.51	41.9	10.16
Domestic Sewage Permits	-	-	0.14	-	0.14
Future Growth (2%)	-	-	13.86	-	13.86
MOS (10%)	-	-	68.90	-	68.90
TOTAL	**976.67**		**688.44**		**688.81**
	0% red.		**29.5%**		**29.5%**

Table 1-7. Allocation scenario for UT to Fleenor Branch sediment loads.

UT to Fleenor Branch Sediment		**Scenario 1**		**Scenario 2**	
Source	Existing	Red.	Allocation	Red.	Allocation
	TSS (tons/yr)	*%*	*TSS (tons/yr)*	*%*	*TSS (tons/yr)*
Pasture/Hay	10.00	62.4	3.76	63.6	3.64

UT to Fleenor Branch Sediment		**Scenario 1**		**Scenario 2**	
Source	Existing	Red.	Allocation	Red.	Allocation
	TSS (tons/yr)	*%*	*TSS (tons/yr)*	*%*	*TSS (tons/yr)*
Forest	4.04	-	4.04	-	4.04
Harvested Forested	0	-	-	-	-
Developed	4.86	62.4	1.83	60.0	1.95
Streambank Erosion	0.21	62.4	0.08	63.6	0.08
Future Growth (2%)	-	-	0.22	-	0.22
MOS (10%)	-	-	1.10	-	1.10
TOTAL	**19.11**		**11.03**		**11.03**
	0% red.		**42.3%**		**42.3%**

Table 1-8. Allocation scenario for UT to Fleenor Branch phosphorus loads.

UT to Fleenor Branch Phosphorus		**Scenario 1**		**Scenario 2**	
Source	Existing	Red.	Allocation	Red.	Allocation
	TP (lb/yr)	*%*	*TP (lb/yr)*	*%*	*TP (lb/yr)*
Pasture/Hay	90.3	71.0	26.1	85.7	12.9
Forest	4.7	-	4.7	-	4.7
Developed	44.1	71.0	12.8	40.0	26.4
Streambank Erosion	0.8	71.0	0.2	85.7	0.1
Groundwater	9.4	-	9.4	-	9.4
Septic Systems	1.0	71.0	0.3	85.7	0.2
Livestock Direct Deposit	1.3	71.0	0.4	85.7	0.2
Future Growth (2%)	-	-	1.2	-	1.2
MOS (10%)	-	-	6.1	-	6.1
TOTAL	**151.6**		**61.2**		**61.2**
	0% red.		**59.6%**		**59.6%**

1.6. Public Participation

Public participation was elicited at every stage of the TMDL study to receive input from stakeholders and to apprise the stakeholders of progress made. Two public meetings and two community engagement meetings (CEM) were held as part of this TMDL development process. Meeting participants included representatives from the Department of Transportation (VDOT) and the Holston River Soil and Water Conservation District.

The first public meeting (6 attendees, April 2, 2024) was held at Greendale Elementary School in Abingdon, VA. This meeting introduced attendees to DEQ's water quality planning process, the TMDL purpose and process, review benthic monitoring data collected from the study watersheds, discuss the impairments, and review the preliminary results of the stressor analysis. The public comment period ended on May 2, 2024; no comments were received.

The first community engagement meeting (5 attendees, May 29, 2024) was held at Greendale Elementary School in Abingdon, VA. This meeting was held to discuss land cover, the watershed model, and explain how goals are set for reducing the pollutants.

The final community engagement meeting (9 attendees, August 13th, 2024) was held at the Virginia Department of Environmental Quality's office in Abingdon, VA.

The final public meeting (9 attendees, August 13th, 2024) was held at the Virginia Department of Environmental Quality's office in Abingdon, VA. The public comment period ended on September 12, 2024; no comments were received.

1.7. Reasonable Assurance

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

1.8. What Happens Next

This report sets the clean-up goals for Greendale Creek and Unnamed Tributary to Fleenor Branch, but the next step is a clean-up plan (or Implementation Plan) that lays out how those goals will be reached. Clean-up plans set intermediate goals and describe actions that should be taken to improve water quality in the impaired streams. Some of the potential actions that could be included in an implementation plan for the Greendale Creek and Unnamed Tributary to Fleenor Branch watersheds are listed below:

- Fence out cattle from streams and provide alternative water sources
- Conduct stream bank restoration projects in areas where banks are actively eroding
- Leave a band of 35 – 100 ft along the stream natural (a riparian buffer) so that it buffers or filters out sediment from farm, residential land, silviculture harvesting, roadways, or other developed lands

Frequently Asked Question:

How will the TMDL be implemented? For point sources, no TMDL reductions are proposed and the TMDL will be implemented as needed in the future through discharge permits. For nonpoint sources, TMDL reductions will be implemented through best management practices (BMPs). Landowners will be asked to voluntarily participate in state and federal programs that help defer the cost of BMP installation.

- 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 can be made available through various grant programs, including an annual funding opportunity through the National Fish and Wildlife Foundation’s Chesapeake Bay Stewardship Fund program. Please be aware that the state or federal government will not fix the problems with the impaired streams. It is primarily the responsibility of individual landowners and local governments to take the actions necessary to improve these streams. The role of state agencies is to help with developing the plan and find money to support implementation, but making the improvements is up to those that live in the watershed. By increasing education and awareness of the problem, and by working together to each do our part, we can make the changes necessary to improve the streams.

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

2.0 INTRODUCTION

2.1. Watershed Location and Description

The Greendale Creek watershed is approximately 3,464 acres and the unnamed tributary (UT) to Fleenor Branch watershed is approximately 169 acres. Both watersheds are in Washington County (**Figure** 1-1). Greendale Creek is a direct tributary of the North Fork Holston River. The unnamed tributary flows into Fleenor Branch, which is a tributary of Cove Creek, and indirectly the North Fork Holston River. Both study watersheds are tributaries of the Gulf of Mexico.

2.2. Designated Uses and Applicable Water Quality Standards

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

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

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

Greendale Creek and the UT Fleenor Branch currently do not support the aquatic life designated use based on biological monitoring of the benthic macroinvertebrate community.

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

The following general standard protects the aquatic life use:

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

Specific substances to be controlled include, but are not limited to: floating debris, oil scum, and other floating materials; toxic substances (including those which bioaccumulate); substances that produce color, tastes, turbidity, odors, or settle to form sludge deposits; and substances which nourish undesirable or nuisance aquatic plant life. Effluents which tend to raise the temperature of the receiving water will also be controlled" (SWCB, 2023).

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 requirements through the publishing of an Integrated 305(b)/303(d) Water Quality Assessment Report every two years. Each report assesses water quality by evaluating monitoring data from a six-year window. The assessment window for the most recent 2020 305(b)/303(d) Integrated Water Quality Assessment Report was from January 1, 2013, through December 31, 2018. According to VADEQ's applicable Water Quality Assessment Guidance (VADEQ, 2023), 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), Greendale Creek and the UT Fleenor Branch (Rich Valley Unnamed Tributary) are listed as impaired (**Table** 1-1, **Figure** 1-1). Data collected to evaluate streams in the watersheds are collected by VADEQ and other government officials.

The study streams are impaired for failure to support the aquatic life use (i.e., a benthic impairment). Greendale Creek was initially listed as impaired on Virginia's 303(d) in 2010, and the UT Fleenor Branch was listed in 2020. Average VSCI scores that led to each stream's listing are displayed in **Table** 2-1.

Table 2-1. Average VSCI scores used to assess stream health for the study streams.

Stream	Monitoring Station	Years Sampled	Samples Collected	VSCI Average
Greendale Creek	6CGRN003.29	2007-2018	4	51.5
UT Fleenor Branch	6CXEO000.25	2009- 2019	7	54.5

2.4. TMDL Development

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

2.4.1. Pollutants of Concern

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

In 2022, a stressor identification analysis study was conducted to determine the POC(s) contributing to the benthic impairments in the Greendale Creek and UT Fleenor Branch watersheds (JMU and WSSI, 2022). 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 both impaired tributaries. In the unnamed tributary to Fleenor Branch, an additional probable stressor of total phosphorus (TP) was identified.

3.0 WATERSHED CHARACTERIZATION

3.1. Ecoregion

The UT Fleenor Branch lies entirely within the Southern Limestone/Dolomite Valleys and Low Rolling Hills EPA Level IV ecoregion (Figure 3-1). Greendale Creek lies within the Southern Shale Valleys and the Southern Limestone/Dolomite Valleys and Low Rolling Hills EPA Level IV ecoregions. Farming predominates in both ecoregions, with scattered woodlands occurring in steeper areas. The Southern Limestone/Dolomite Valleys and Low Rolling Hills is characterized by broad, undulating, fertile valleys that are extensively farmed and is underlain by Ordovician and Cambrian limestone and dolomite (Woods et al., 1999). Karst features including sinkholes and underground streams have developed in the underlying limestone/dolomite, and as a result, drainage density is low. The Southern Shale Valleys is characterized by rolling valleys and low hills and is underlain by Brallier, Rome, Elbrook, Chemung, and Clinton formations (Woods et al., 1999).

3.2. Soils

The Soil Survey Geographic (SSURGO) database (NRCS, 2024) containing county-level detailed soils data were used for the purpose of characterizing the soils in the study area. Hydrologic soil groups (HSG) were the primary soil aspect considered for this characterization, and they describe soil texture in terms of potential for surface runoff and infiltration rates. Soils in hydrologic group "A" pass a larger proportion of rainfall through to ground water than soils in hydrologic group "B." Soils in hydrologic group "C" have a low rate of infiltration and moderately high runoff potential when thoroughly wet. Soils in hydrologic group "D" inhibit infiltration such that a large proportion of rainfall contributes to surface runoff and therefore a more direct path to stream channels. These processes have consequences for the washoff rate of pollutants from the land surface. Figure 3-2 presents the distribution of the soil groups in the study areas. Hydrologic group "C" soils are the largest contribution in the UT Fleenor Branch watershed with 41% of the entire area. Hydrologic groups "B", "B/D", and "A" cover 29%, 18%, and 12% of the area, respectively. The Greendale Creek watershed is dominated by hydrologic group "B" soils (92%).

3.3. Climate

Daily rainfall and temperature data for the watershed was obtained from Oregon State's spatially distributed PRISM model (Parameter-Elevation Regressions on Independent Slopes Model), which interpolates available datasets from a range of monitoring networks and is used as the official spatial climate data sets of the USDA. PRISM was utilized to obtain a more exact estimate of historical weather within the watershed, rather than relying on a nearby gauge outside of the watershed (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 49.1 inches, and the average modelled daily temperature during this time range was 45.8° F. Consideration of seasonal variations and critical conditions is addressed in Section 4.5.

3.4. Land Cover/Land Use

The Virginia statewide Land Cover Dataset (VLCD), which consists of 1 meter resolution digital land classifications, from the Virginia Geographic Information Network (VGIN) was used to characterize land use in the watershed (**Figure** 3-3). **Table** 3-1 and **Table** 3-2 summarize the land cover distributions for each of the impaired watersheds.

The VLCD contains two different types of impervious land cover: extracted and local datasets. The local dataset's 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. The VLCD 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 VLCD was treated in the model as 80% developed impervious and 20% developed pervious. The 'NWI/other' land cover type in the VLCD is based on the combined National Wetlands Inventory and Tidal Marsh Inventory datasets and represents all identified wetland areas in those datasets. The VLCD 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 by county and by VAHU6 watersheds for acres of land in conventional and conservation tillage as well as hay and three quality-based categories of pasture. The ratio of conventional to conservation tillage for each modelled watershed was used to divide the VLCD cropland acres for that watershed 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 VLCD 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.

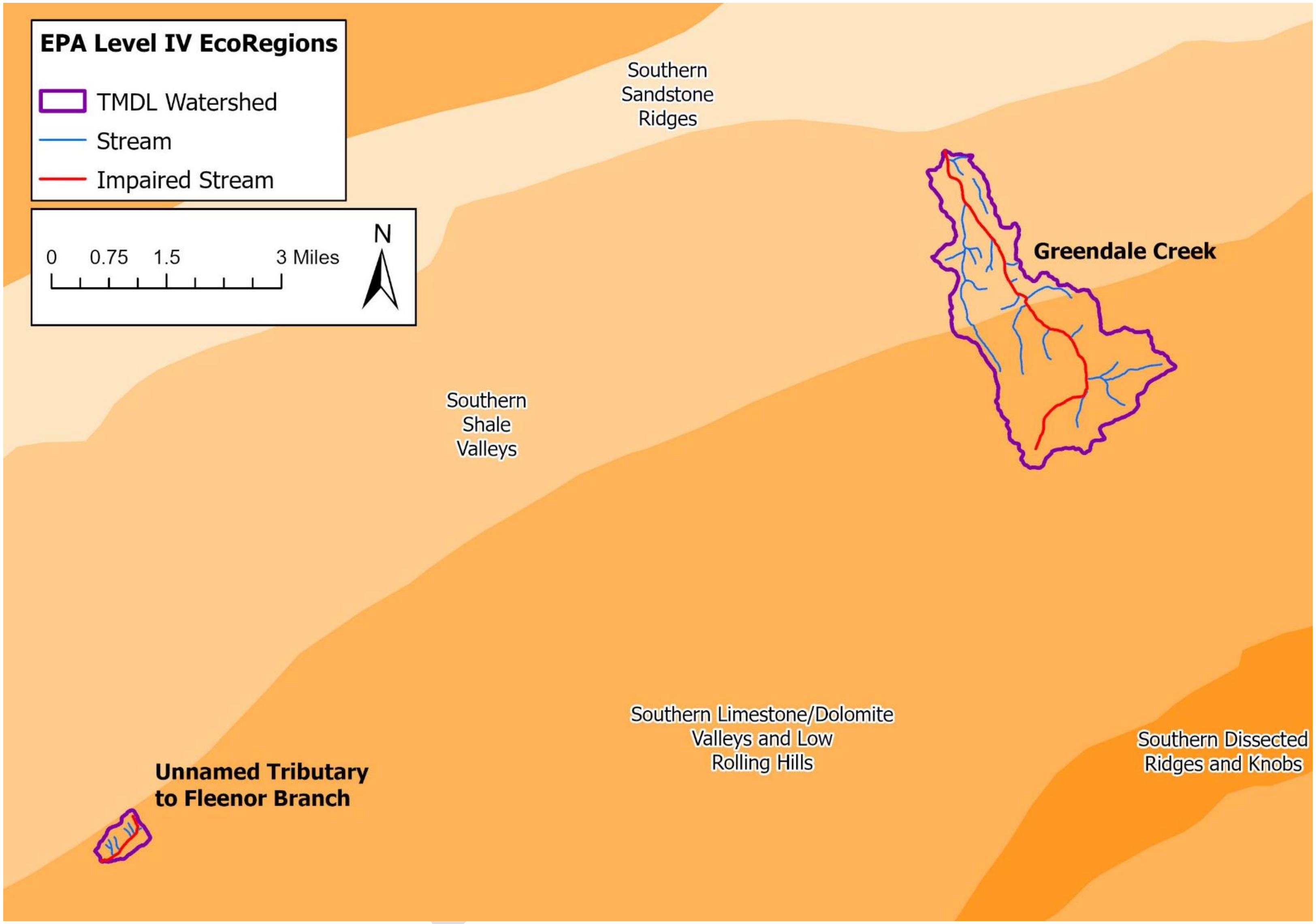

Figure 3-1. USEPA ecoregions included in the TMDL watersheds.

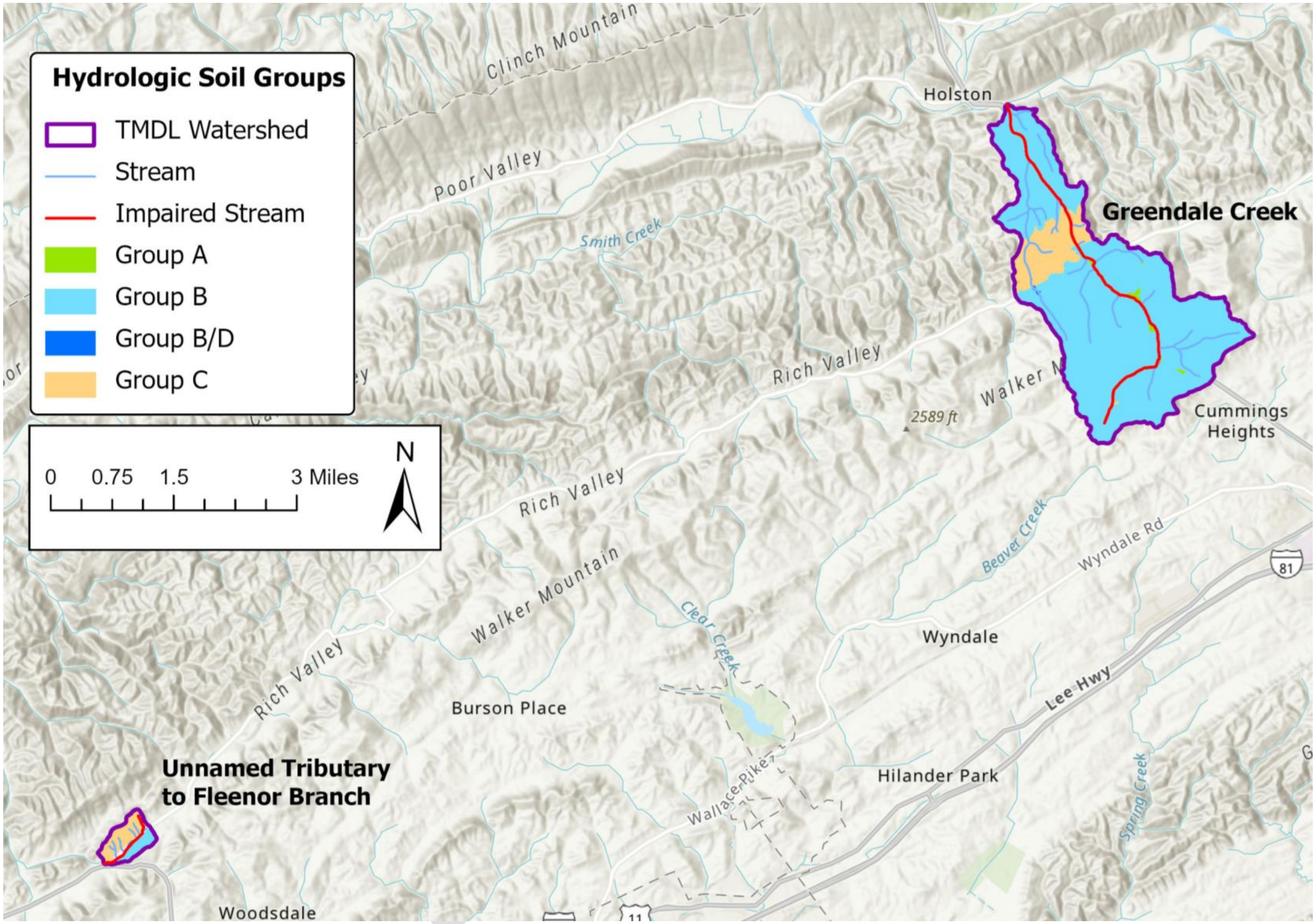

Figure 3-2. SSURGO hydrologic soil groups throughout the TMDL watersheds.

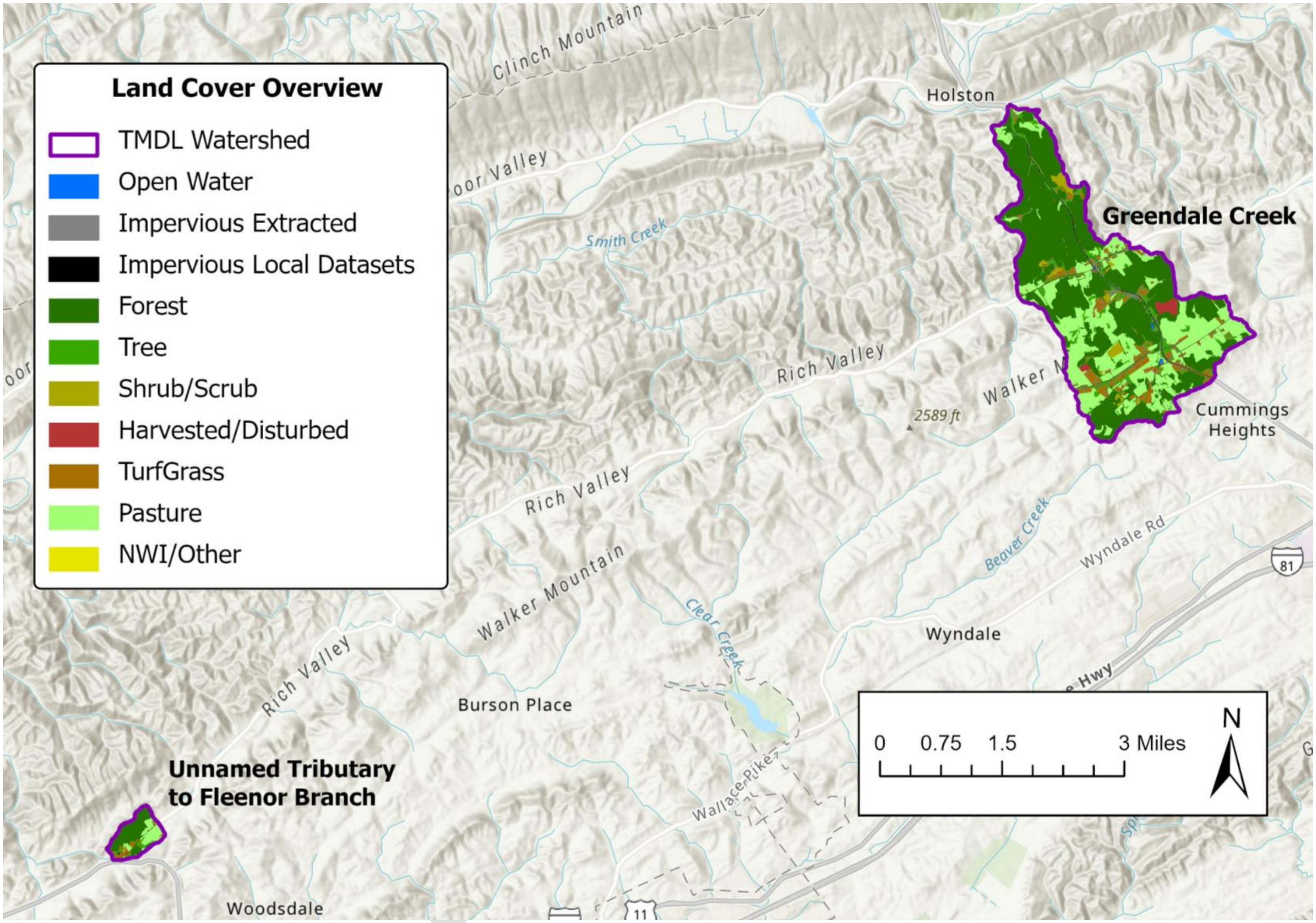

Figure 3-3. Land cover distribution used in the watershed models (VGIN, 2016).

Table 3-1. Land cover distribution in the Greendale Creek watershed.

General Land Use Category	2016 VLCD Land Cover Category	Acres	Percentage	Total Acres	Total Percentage
Cropland	Cropland	-	0	-	0
Pasture/Hay	Pasture	981	28	981	28
Forest	Forest	1,832	53	1,893	55
	Shrub	61	2		
Harvested Forest	Harvested/ Disturbed	29	1	29	1
Developed	Tree	233	7	559	16
	Turfgrass	189	5		
	Impervious Extracted	74	2		
	Impervious External	63	2		
Barren	Barren	-	0	-	0
Water and Wetlands	Water	2	<1	3	<1
	Wetland	<1	<1		
Total		*3,465*	*100*	*3,465*	*100*

Table 3-2. Land cover distribution in the UT to Fleenor Branch watershed.

General Land Use Category	2016 VLCD Land Cover Category	Acres	Percentage	Total Acres	Total Percentage
Cropland	Cropland	-	0	-	0
Pasture/Hay	Pasture	48	28	48	28
Forest	Forest	91	54	91	54
	Shrub	-	0		
Harvested Forest	Harvested/ Disturbed	-	0	-	0
Developed	Tree	12	7	30	18
	Turfgrass	14	8		
	Impervious Extracted	<1	<1		
	Impervious External	4	2		
Barren	Barren	-	0	-	0
Water and Wetlands	Water	-	0	-	0
	Wetland	-	0		
Total		*169*	*100*	*169*	*100*

3.5. Water Quality and Biological Monitoring Data

DEQ has monitored and evaluated the state of the benthic macroinvertebrate community at two monitoring stations within the TMDL watersheds. The data from these monitoring stations are described in detail in the stressor identification analysis report (JMU and WSSI, 2022). A summary of data collected from the benthic monitoring stations is provided in **Table** 3-3. The locations of the benthic monitoring stations are shown in **Figure** 3-4**.**

Table 3-3. Summary of benthic data collected in the study watersheds.

TMDL Watershed	Benthic Station ID	Location	Year(s) Sampled
Greendale Creek	6CGRN003.29	North of Carvosso Church	2007-2018
UT to Fleenor Branch	6CXEO000.25	at Valley Institute	2009-2019

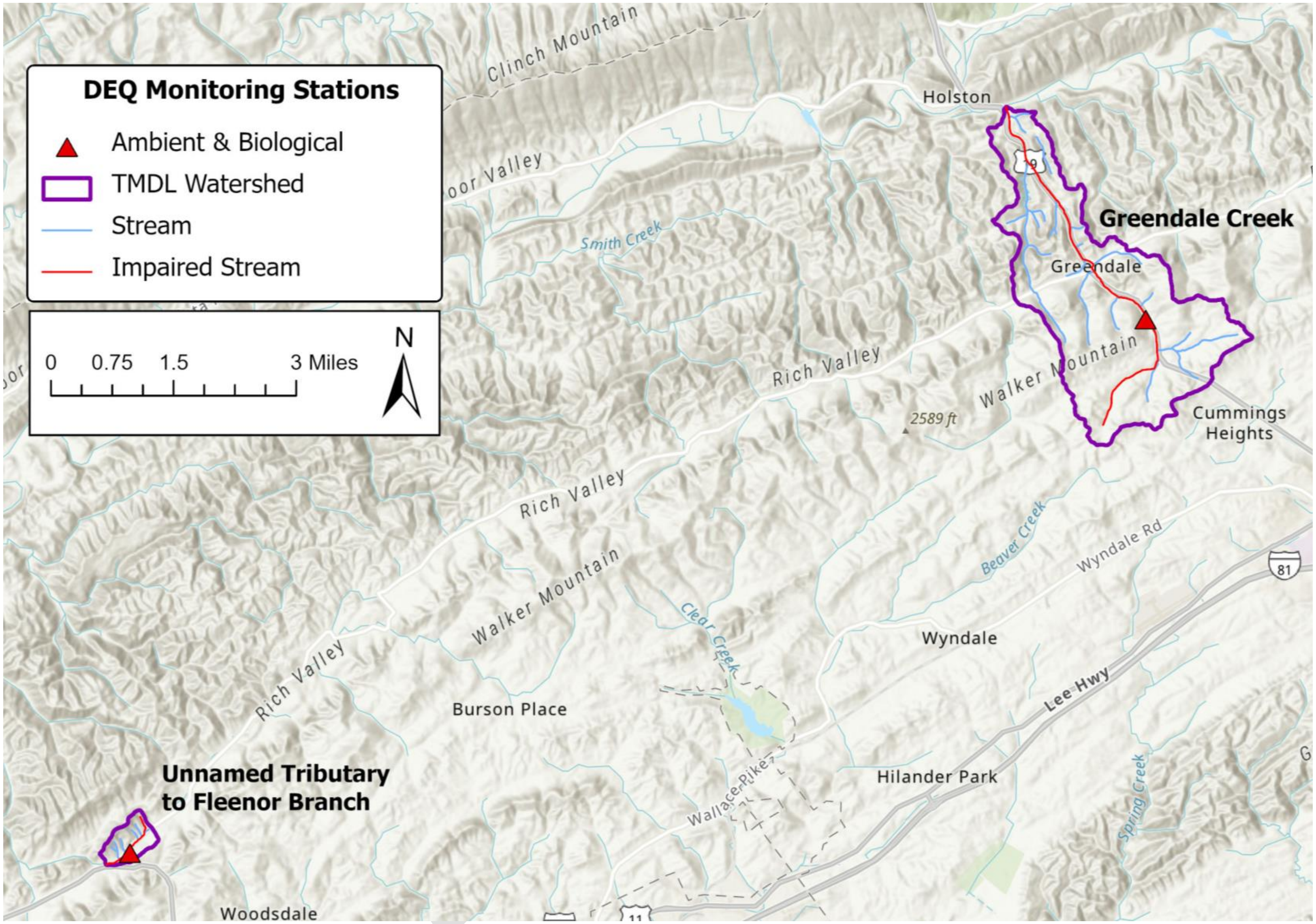

Figure 3-4. Locations of DEQ monitoring stations in the TMDL watersheds.

4.0 MODELING PROCESS

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

4.1. Model Selection and Description

The model selected for development of the sediment TMDL in the Greendale Creek watershed and the sediment and phosphorus TMDLs in the UT Fleenor Branch watershed 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 monthly runoff, sediment, and nutrient yields for the watershed. The model allows for multiple land cover categories to be incorporated, but spatially it is lumped because it does not account for the spatial distribution of sources and has no method of spatially routing sources within the watershed. 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. When appropriate data is available for comparison, though, calibration can improve the accuracy of GWLF (Dai et al., 2000). However, absence of flow data in Greendale Creek and the UT to Fleenor Branch, as well as in the many comparison watersheds in this study led to the decision to simulate loads in a non-calibrated model.

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

Stream bank and channel erosion is calculated using an algorithm by Evans et al. (2003) as incorporated in the ArcView GWLF version (AVGWLF) (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, soil erodibility factors, and the mean slope of the watershed.

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

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 Greendale Creek and UT Fleenor Branch models and developing the watershed loads. See **Section 3.3** for information on the PRISM model.

4.3. Source Assessment

Sediment and phosphorus 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 the other, non-permitted sources in the watersheds, including natural background contributions such as undisturbed forest. Non-point sediment and phosphorus are primarily from surface runoff (anywhere not captured and converted to point sources) and erosion happening within and on the banks of streams. Phosphorus in particular can be either bound to and transported with eroded sediment or dissolved in water directly.

4.3.1. Non-Point Sources

4.3.1.1. Surface Runoff

Sediment and its attached phosphorus 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 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. Surface applications of manure and other fertilizers are also subject to being suspended and transported in runoff water. In addition to the phosphorus attached to mobilized particles, phosphorus can also be dissolved in water. Surface runoff can 'pick up' soluble phosphorus and then contribute directly to dissolved phosphorus in streams.

VGIN 2016 land cover data was used to determine the distribution of different land cover types in the watersheds (see **Section 3.4**). Values for various parameters affecting sediment and phosphorus loads were gleaned from literature guidance (CBP, 1998; Haith et al., 1992; Hession et al., 1997). Naturally occurring loads of sediment and phosphorous (i.e. loads not attributed to anthropogenic sources) were also calculated using VGIN 2016 land cover data.

4.3.1.2. Streambank Erosion

Sediment is transported in stream systems as part of their natural processes. However, changes to the landscape can alter these processes, in turn changing the balance of sediment mobilization and deposition within the stream system.

Increases in impervious areas can increase the amount and rate of flow in streams following rainfall events, which provides more erosive power to the streams and increases the channel erosion potential. This is often the cause of the entrenchment, or downcutting, of urban streams – disconnecting higher flow events from the surrounding floodplain. The higher flows are then increasingly confined to the channel, thus mobilizing 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.

4.3.1.3. Groundwater

Shallow surface groundwater interacts with phosphorus both dissolved in percolating runoff and attached to the soil particles it moves around. The higher the concentration of soil-phosphorus and dissolved phosphorus in runoff water, the higher the levels of phosphorus in shallow groundwater. Groundwater can contribute directly to streamflow through upwelling, taking its dissolved phosphorus with it and adding to the overall total phosphorus (TP) load in the streams.

4.3.1.4. Residential Septic Systems

Residential septic systems are designed so that their drainfields dissipate the effluent over an area to be adsorbed to soil particles and used by plant roots and microorganisms. When systems are failing, they can discharge nutrient-rich waste to the surface where it is easily transported to surface waters during runoff events, or directly to surface waters if they are located nearby.

The number of residences with septic systems in the Greendale Creek watershed was not estimated since failing septic systems are considered a source of bacteria or nutrient loads to a waterbody, but not sediment. Washington County parcels data and aerial imagery were used to estimate the number of septic systems in the UT to Fleenor Branch watershed. All houses in the UT to Fleenor Branch watershed were assumed to have septic systems that may contribute phosphorus loads to the stream (**Table** 4-1). Residences with failing (ponded) septic systems were estimated based on a failure rate of 3.3%, derived from the assumption that each septic system fails, on average, once during an expected lifetime of 30 years. Census data (US Census Bureau, 2016) for the locality were used as the reference for number of persons per household, which was applied to the number of residences on septic systems to obtain a population distribution to be input to GWLF.

Table 4-1. Estimated numbers of residences with septic systems.

Watershed	Functioning Septic Systems	Ponded Septic Systems
UT to Fleenor Branch	5	1

4.3.2. Point Sources

Three permitted point sources of sediment exist within the Greendale Creek watershed and no point sources of sediment or phosphorus discharge in the UT to Fleenor Branch watershed. The three point sources in the Greendale Creek watershed are permitted under the Virginia Pollutant Discharge Elimination System (VPDES) program and include domestic sewage general permits

(**Table** 4-2). The domestic sewage general permit specifies a maximum flow rate of 1,000 gallons per day at a sediment concentration of 30 mg/L. These permit limits were used to calculate a wasteload allocation of 0.046 tons/yr TSS for each permit.

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

Permit Number	Receiving Stream
VAG400088	Greendale Creek
VAG409011	Greendale Creek
VAG409026	Greendale Creek

4.4. Best Management Practices

One best management practice (BMP) that is still within its practice lifespan has been included in the Greendale Creek watershed model. Other BMPs exist within the Greendale Creek watershed but contribute only nutrient reductions without an associated sediment reduction. Only one BMP has been installed in the UT to Fleenor Branch watershed, and it is still within its practice lifespan. Many BMPs have associated removal efficacies defined in the literature, which can be applied to the raw pollutant accumulation loads for the land areas draining to the BMP. Other BMPs can be simulated as a change in land cover over the treated acreage, such as planting a riparian buffer and turning previous pastureland into forested areas. The BMPs included in the watershed models are detailed in **Table** 4-3

Table 4-3, along with their various removal efficacies. The efficiencies used by the DEQ NPS BMP Program were used to guide the TSS and TP removal estimates.

Table 4-3. BMPs installed in the Greendale Creek and UT to Fleenor Branch watersheds.

BMP Code	BMP Type	Extent Installed	Efficacy method (fraction removal, other)	TSS Removal (tons/year)	TP Removal (tons/year)
Greendale Creek					
SL-6W	Stream Exclusion with Wide Width Buffer and Grazing Land Management	331 ln ft (24.8 ac benefitted)	0.40 TSS	6	NA
UT to Fleenor Branch					
WP-4	Animal Waste Control Facility	1 system	0.75 TP	-	24

4.5. Consideration of Critical Conditions and Seasonal Variations

The GWLF model simulated a roughly 20-year period (2004 through 2023) 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 a given month is tagged as part of the growing season.

4.6. Existing Conditions

Existing sediment and phosphorus loads from the impaired watersheds were simulated in GWLF as described above. **Table** 4-4 and **Table** 4-5 summarize the resulting loads. 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 land cover is from 2016, and BMPs included are reflective of conditions in March 2023. These dates reflect the collected water quality monitoring data used to determine the necessity of developing this TMDL and to gauge the existing conditions in the model results. The monitoring window for sediment data analyzed for this study ran through March 2023.

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

Land Cover Category	Existing TSS (tons/yr)
Pasture/Hay	853
Forest	47
Harvested Forest	8
Developed	51
Streambank Erosion	18
Total	*977*

Table 4-5. Existing sediment and phosphorus loads in the UT to Fleenor Branch watershed, accounting for known BMPs (not including MOS or FG detailed in Section 6.0).

Land Cover Category	Existing TSS (tons/yr)	Existing TP (lb/yr)
Pasture/Hay	10.0	90.3
Forest	4.0	4.7

Developed	4.9	44.1
Streambank Erosion	0.2	0.8
Groundwater	-	9.4
Septic Systems	-	1.0
Livestock Direct Deposition	-	1.3
Total	*19.1*	*151.6*

5.0 SETTING TARGET SEDIMENT AND PHOSPHORUS 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 designated uses. However, sediment and phosphorus do not have numeric criteria established as the acceptable level of these materials is expected to vary from stream to stream based on a range of contributing factors. Therefore, an alternative method must be used to determine the water quality target for sediment and phosphorus TMDLs.

5.1. Greendale Creek Sediment TMDL

The method used to set the TMDL endpoint load for the Greendale Creek watershed 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 the Greendale Creek watershed and six (6) comparison watersheds of similar size and within the same ecoregion as the Greendale Creek watershed (**Appendix B**). A regression was then developed between the Virginia Stream Condition Index (VSCI) scores at the Greendale Creek monitoring station and the corresponding AllForX ratio calculated for each contributing watershed.

Figure 5-1 shows the regression developed to set the Greendale Creek target loading rate. Based on the regression, a VSCI score of 60 corresponded to a target AllForX ratio of 11.25. This means that Greendale Creek is expected to achieve consistently healthy benthic conditions if sediment loads are less than 11.25 times the all-forested simulation of the watershed. The AllForX target of 11.25 was then used to determine the allowable pollutant TMDL loads in Greendale Creek (**Table** 5-1).

Table 5-1. Target sediment loading rate and reduction as determined by AllForX regression for the Greendale Creek TMDL. Existing loads listed exclude the margin of safety and future growth set-asides, as discussed in Section 6.0.

Impaired Stream	TSS Existing (tons/yr)	TSS All-Forested (tons/yr)	TSS Target (tons/yr)	Estimated % Reduction
Greendale Creek	977	61	689	29%

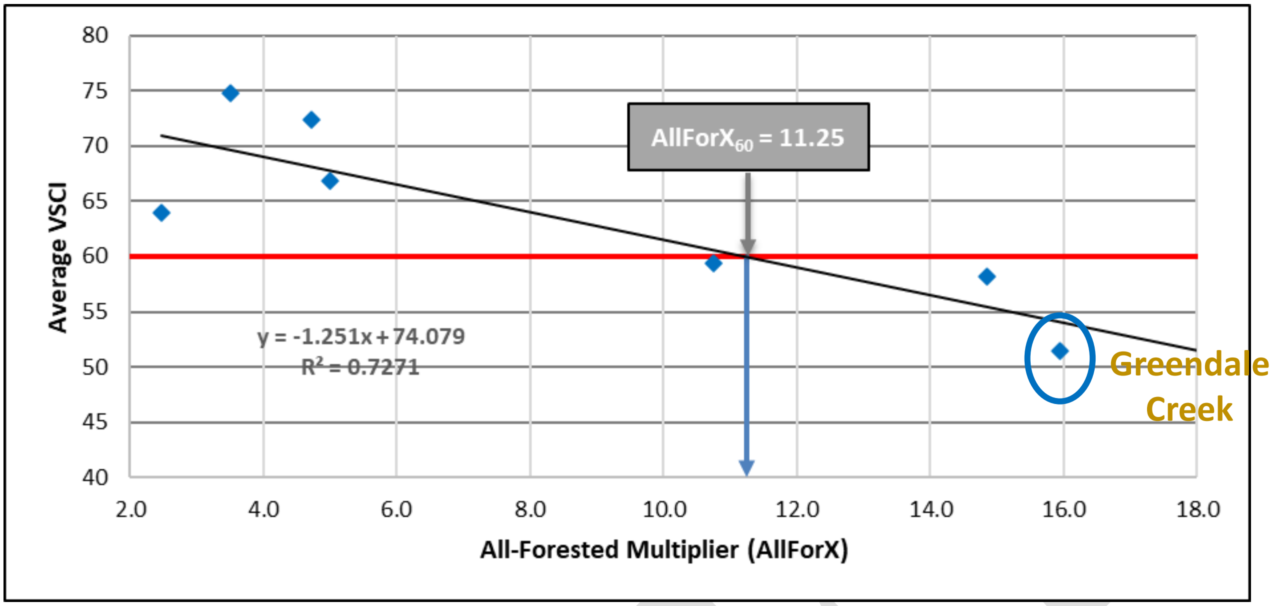

Figure 5-1. Regression between the average VSCI scores and all-forest multiplier for sediment, resulting in an AllForX target ratio of 11.25 in the Greendale Creek TMDL.

5.2. UT to Fleenor Branch Sediment TMDL

The AllForX approach recommends the selection of comparison watersheds that are between ½ to 2 times the size of and within 30 miles of the impaired watershed. Since there are no comparison watersheds available that meet these criteria for the UT to Fleenor Branch because of its small size, the reference watershed approach was used to develop the target sediment load for the sediment TMDL. The reference watershed approach pairs an unimpaired stream with the impaired stream. The reference watershed is selected based on similarity of land use, topography, ecology, and soils characteristics with those of the impaired watershed. This approach assumes that reduction of the stressor loads in the impaired watershed to the level of loads in the reference watershed will result in elimination of the benthic impairment.

Plank Camp Creek (PLC) watershed was selected as the reference watershed to develop the target sediment load for the UT to Fleenor Branch sediment TMDL development. Plank Camp Creek watershed is approximately 17 miles from the UT to Fleenor Branch watershed. It also lies within the Southern Limestone/Dolomite Valleys and Low Rolling Hills EPA Level IV ecoregion. Plank Camp Creek watershed has a land use distribution of 68% forest, 24% agricultural, and 8% developed, compared to a 54% forest, 28% agricultural, and 18% developed in UT to Fleenor Branch watershed (**Table** 3-2). In addition, the soils and non-forested slopes of the two watersheds were comparable.

The GWLF model was used to create inputs for the Plank Camp Creek watershed. The area was scaled down, or area-adjusted, to equal the watershed area of the UT to Fleenor Branch (169 acres) while preserving the reference watershed land use distribution. Sediment loads were simulated for all individual land uses and then summed to provide an annual average sediment load in the area-adjusted reference Plank Camp Creek watershed. The area-adjusted sediment load of 11 tons/yr from the non-impaired Plank Camp Creek watershed is used as the TMDL sediment endpoint for the UT to Fleenor Branch watershed (**Table** 5-2).

Table 5-2. Target sediment loading rate and reduction as determined by the reference watershed for the UT to Fleenor Branch TMDL. Existing loads listed exclude the margin of safety and future growth set-asides, as discussed in Section 6.0.

Plank Creek Representation	TSS Existing (tons/yr)	TSS area-adjusted PLC (tons/yr)	TSS Target (tons/yr)	Estimated % Reduction
UT to Fleenor Branch	19	11	11	42%

5.3. UT to Fleenor Branch Phosphorus TMDL

A review was conducted of previous TP TMDLs in Virginia that used a TP concentration to set the endpoints, the Virginia DEQ probabilistic monitoring screening level optimal and sub-optimal thresholds, EPA recommendations for Eco-Region XI, and percentile concentrations from Cove Creek water quality monitoring station 6CCOV002.44, a non-impaired downstream watershed (**Table** 5-3). The TP endpoint was set at an average annual in-stream concentration of 0.05 mg/L based on the 90th percentile concentration at the Cove Creek station 6CCOV002.44. This endpoint is protective of the benthic community, as it is a value in the mid-range of TP endpoints used in previous TMDLs and came from Cove Creek, the neighboring non-impaired reference watershed. **Table** 5-4 shows the TP target and estimated percent reduction for the UT to Fleenor Branch.

Table 5-3. Potential TP endpoints considered for the UT to Fleenor Branch.

Studies and Statistics	TP (mg/L)
TP TMDL Endpoints from previous studies	
Pitts Creek (VA) - EPA recommended	0.030
Parker Creek (VA)	0.100
Jackson River (VA) – periphyton/ortho-P	0.038
– TP equivalent	0.063
Little Otter River (VA)	0.070
Virginia DEQ Probabilistic Monitoring Screening Levels	
Optimal	<0.02
Sub-optimal	<0.05
EPA Recommendations for Ecoregion XI (based on 25th percentile)	
Ridge and Valley (67)	0.010
Aggregate ecoregion XI	0.010
Downstream Station 6CCOV002.44 Samples (count = 30); non-impaired	
Average	0.031
90th percentile	0.050

Table 5-4. Target phosphorus loading rate and reduction to meet the TMDL endpoint of an average TP concentration of 0.05 mg/L. Existing loads listed exclude the margin of safety and future growth set-asides, as discussed in Section 6.0.

Watershed	UT to Fleenor Branch		Cove Creek 90th-% TP (mg/L)	TP load for Average TP conc = 0.05 mg/L (tons/yr)	Estimated % Reduction
	TP Existing Average TP concentration (mg/L)	Corresponding TP load (lb/yr)			
UT to Fleenor Branch	0.11	151.6	0.05	61.2	60%

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. As described in **Section 4.3.2**, there are three domestic sewage permits in the Greendale Creek watershed and no permitted sources of the POCs in the UT to Fleenor Branch watershed**.** The margin of safety (MOS) is determined based on the characteristics of the watershed and the model used to develop the TMDL loads (see **Section 6.1**). The overall load allocation (LA) is then calculated by subtracting the total WLA and MOS from the TMDL. Various allocation scenarios are typically developed to show different breakdowns of how this LA can be divided among the various non-point sources of the POC (**Section 6.4**). Naturally occurring loads of sediment and phosphorus from sources such as forest, and naturally occurring loads of phosphorus from groundwater, are included in the LA. However, these loads were not assigned reductions in the associated sediment and phosphorus TMDLs for the watersheds.

For model runs to develop the annual existing loads and target loads using the AllForX methodology, a 20-year period was simulated (2004 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 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 sediment TMDLs. This is a typical value used in sediment TMDLs throughout the state to account for unavoidable uncertainties in the modeling process.

6.2. Future Growth

An allocation of 2% of the total load is specifically set aside for future growth within each 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 as a primary cause of the benthic impairments in both impaired watersheds. TMDLs were developed for sediment in both impaired watersheds. Phosphorus was also determined in the stressor analysis as a primary cause of the benthic impairment in the UT to Fleenor Branch.

The final sediment and phosphorus 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. Any apparent differences in calculated values are due to rounding. Existing loads shown for Greendale Creek and UT to Fleenor Branch exclude the margin of safety and future growth allocations for the watersheds.

Table 6-1. Annual average sediment TMDL components for Greendale Creek.

Impairment	WLA (tons/yr)	LA (tons/yr)	MOS (tons/yr)	TMDL (tons/yr)	Existing Load (tons/yr)	Reduction (%)
Greendale Creek (VAS-O12R_GRN01A00)	**14**	**606**	**69**	**689**	977	29%
Domestic Sewage Permits	*0.14*					
*Future Growth (2% of TMDL)**	*13.86*					

* Future Growth has been adjusted to ensure exact additivity to the WLA.

Table 6-2. Annual average sediment TMDL components for UT to Fleenor Branch.

Impairment	WLA (tons/yr)	LA (tons/yr)	MOS (tons/yr)	TMDL (tons/yr)	Existing Load (tons/yr)	Reduction (%)
UT to Fleenor Branch (VAS-O12R_XEO01A12)	**0.22**	**9.71**	**1.10**	**11.03**	19.11	42%
Future Growth (2% of TMDL)	*0.22*					

Table 6-3. Annual average phosphorus TMDL components for UT to Fleenor Branch.

Impairment	WLA (lb/yr)	LA (lb/yr)	MOS (lb/yr)	TMDL (lb/yr)	Existing Load (lb/yr)	Reduction (%)
UT to Fleenor Branch (VAS-O12R_XEO01A12)	**1.2**	**53.9**	**6.1**	**61.2**	151.6	60%
Future Growth (2% of TMDL)	*1.2*					

In 1991, the USEPA released a support document that included guidance for developing maximum daily loads (MDLs) for TMDLs (USEPA, 1991). A methodology detailed therein was used to determine the MDLs for the watersheds. The long-term average (LTA) daily loads, derived by dividing the average annual loads in **Table** 6-1 through **Table** 6-3 by 365.25, are converted to MDLs using the following equation:

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

where Z_p = pth percentage point of the normal standard deviation, and
σ_y = sqrt(ln(CV^2+1)), with CV = coefficient of variation of the data.

The variable Z_p was set to 1.645 for this TMDL development, representing the 95th percentile. The CV values and final calculated multipliers to convert LTA to MDL values are summarized in **Table** 6-4 and **Table** 6-5.

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

Watershed	CV of Average Annual Loads	"LTA to MDL Multiplier"
Greendale Creek	0.439	1.83
UT to Fleenor Branch	0.570	2.08

Table 6-5. "LTA to MDL multiplier" components for TP TMDL.

Watershed	CV of Average Annual Loads	"LTA to MDL Multiplier"
UT to Fleenor Branch	0.435	1.82

The daily WLA was estimated as the annual WLA divided by 365.25. The daily MOS was estimated as 10% of the MDL. Finally, the daily LA was estimated as the MDL minus the daily MOS minus the daily WLA. These results are shown in **Table** 6-6 through **Table** 6-8**.**

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

Impairment	WLA (tons/day)	LA (tons/day)	MOS (tons/day)	MDL (tons/day)
Greendale Creek (VAS-O12R_GRN01A00)	**0.069**	**3.033**	**0.345**	**3.447**
Domestic Sewage Permits	*0.00038*			
*Future Growth**	*0.06862*			

* Future Growth has been adjusted to ensure exact additivity to the WLA.

Table 6-7. Maximum 'daily' sediment loads and components for UT to Fleenor Branch.

Impairment	WLA (tons/day)	LA (tons/day)	MOS (tons/day)	MDL (tons/day)
UT to Fleenor Branch (VAS-O12R_XEO01A12)	**0.0013**	**0.0552**	**0.0063**	**0.0628**
Future Growth	*0.0013*			

Table 6-8. Maximum 'daily' phosphorus loads and components for UT to Fleenor Branch.

Impairment	WLA (lb/day)	LA (lb/day)	MOS (lb/day)	MDL (lb/day)
UT to Fleenor Branch (VAS-O12R_XEO01A12)	**0.0061**	**0.2687**	**0.0305**	**0.3053**
Future Growth	*0.0061*			

6.4. Allocation Scenarios

Various scenarios were run to determine possible options for reducing the sediment loads in Greendale Creek and UT to Fleenor Branch and phosphorus loads in UT to Fleenor Branch to the recommended TMDL loads. Two allocation scenarios were developed for each watershed. Scenario 1 has equal reductions from anthropogenic sources, Scenario 2 shows selected allocation scenarios that targeted higher reductions from the larger sources (agricultural sources, in both watersheds) and lower reductions from less significant sources. This methodology is reasonable because more of the burden is placed on the greater contributing areas and agricultural practices for reducing sediment are typically more cost efficient than residential practices. Having some reductions allocated to residential sources allows for future implementation to target BMPs that address both agricultural and residential sources. The sediment and phosphorus allocation scenarios are presented in **Table** 6-9 through **Table** 6-11**.**

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

Greendale Creek Sediment		**Scenario 1**		**Scenario 2**	
Source	Existing	Red.	Allocation	Red.	Allocation
	TSS (tons/yr)	*%*	*TSS (tons/yr)*	*%*	*TSS (tons/yr)*
Pasture/Hay	853.17	39.9	512.76	41.9	495.69
Forest	46.49	-	46.49	-	46.49
Harvested Forested	8.10	39.9	4.87	41.9	4.71

Greendale Creek Sediment		**Scenario 1**		**Scenario 2**	
Source	Existing	Red.	Allocation	Red.	Allocation
	TSS (tons/yr)	*%*	*TSS (tons/yr)*	*%*	*TSS (tons/yr)*
Developed	51.43	39.9	30.91	5.0	48.86
Streambank Erosion	17.48	39.9	10.51	41.9	10.16
Domestic Sewage Permits	-	-	0.14	-	0.14
Future Growth (2%)	-	-	13.86	-	13.86
MOS (10%)	-	-	68.90	-	68.90
TOTAL	**976.67**		**688.44**		**688.81**
	0% red.		**29.5%**		**29.5%**

Table 6-10. Allocation scenario for UT to Fleenor Branch sediment loads.

UT to Fleenor Branch Sediment		**Scenario 1**		**Scenario 2**	
Source	Existing	Red.	Allocation	Red.	Allocation
	TSS (tons/yr)	*%*	*TSS (tons/yr)*	*%*	*TSS (tons/yr)*
Pasture/Hay	10.00	62.4	3.76	63.6	3.64
Forest	4.04	-	4.04	-	4.04
Harvested Forested	0	-	-	-	-
Developed	4.86	62.4	1.83	60.0	1.95
Streambank Erosion	0.21	62.4	0.08	63.6	0.08
Future Growth (2%)	-	-	0.22	-	0.22
MOS (10%)	-	-	1.10	-	1.10
TOTAL	**19.11**		**11.03**		**11.03**
	0% red.		**42.3%**		**42.3%**

Table 6-11. Allocation scenario for UT to Fleenor Branch phosphorus loads.

UT to Fleenor Branch Phosphorus		**Scenario 1**		**Scenario 2**	
Source	Existing	Red.	Allocation	Red.	Allocation
	TP (lb/yr)	*%*	*TP (lb/yr)*	*%*	*TP (lb/yr)*
Pasture/Hay	90.3	71.0	26.1	85.7	12.9
Forest	4.7	-	4.7	-	4.7
Developed	44.1	71.0	12.8	40.0	26.4
Streambank Erosion	0.8	71.0	0.2	85.7	0.1
Groundwater	9.4	-	9.4	-	9.4
Septic Systems	1.0	71.0	0.3	85.7	0.2
Livestock Direct Deposit	1.3	71.0	0.4	85.7	0.2
Future Growth (2%)	-	-	1.2	-	1.2

UT to Fleenor Branch Phosphorus		**Scenario 1**		**Scenario 2**	
Source	Existing	Red.	Allocation	Red.	Allocation
	TP (lb/yr)	*%*	*TP (lb/yr)*	*%*	*TP (lb/yr)*
MOS (10%)	-	-	6.1	-	6.1
TOTAL	**151.6**		**61.2**		**61.2**
	0% red.		**59.6%**		**59.6%**

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. After DEQ approves the TMDL study, staff will present the study to the State Water Control Board (SWCB) and request that the SWCB adopt TMDL WLAs as part of the Water Quality Management Planning Regulation (9 VAC 25-720), in accordance with §2.2-4006A.14 and §2.2-4006B of the Code of Virginia. DEQ's public participation procedures relating to TMDL development can be found in DEQ's Guidance Memo No. 14-2016 (DEQ, 2014).

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.

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). When possible, plant trees and shrubs to create a forested riparian buffer, which are especially effective at removing pollutants, cooling the water, and improving stream habitat.

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

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

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

7.3. Reasonable Assurance

The following activities provide reasonable assurance that these TMDLs will be implemented, and water quality will be restored in the Greendale Creek and UT to Fleenor Branch watersheds.

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

monitoring benthic macroinvertebrates and habitat in accordance with its biological monitoring program stations throughout the watershed.

- Current implementation actions – A few voluntary and subsidized best management practices have already been installed in these watersheds. The Soil and Water Conservation Districts and NRCS are actively working in these areas to promote and implement additional practices that can reduce sediment loads.

8.0 PUBLIC PARTICIPATION

Public participation was elicited at every stage of the TMDL study to receive input from stakeholders and to apprise the stakeholders of progress made. Two public meetings and two community engagement meetings (CEM) were held as part of this TMDL development process.

The first public meeting (6 attendees, April 2, 2024) was held at Greendale Elementary School in Abingdon, VA. This meeting introduced attendees to DEQ's water quality planning process, the TMDL purpose and process, review benthic monitoring data collected from the study watersheds, discuss the impairments, and review the preliminary results of the stressor analysis. The public comment period ended on May 2, 2024; no comments were received.

The first community engagement meeting (5 attendees, May 29, 2024) was held at Greendale Elementary School in Abingdon, VA. This meeting was held to discuss land cover, the watershed model, and explain how goals are set for reducing the pollutants.

The final community engagement meeting (9 attendees, August 13th, 2024) was held at the Virginia Department of Environmental Quality's office in Abingdon, VA.

The final public meeting (9 attendees, August 13th, 2024) was held at the Virginia Department of Environmental Quality's office in Abingdon, VA. The public comment period ended on September 12, 2024; no comments were received.

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Appendix A - GWLF Model Parameters

Various GWLF parameters used for the Greendale Creek and UT Fleenor Branch watershed models are detailed below (**Table** A-1).

Table A-1. GWLF watershed parameters.

GWLF Parameter	Units	Greendale Creek	UT Fleenor Branch
Recession Coefficient	day^{-1}	0.0349	0.3342
Seepage Coefficient	day^{-1}	0.04	0.04
Leakage Coefficient	day^{-1}	0	0
Sediment Delivery Ratio		0.1794	0.1970
Unsaturated Water Capacity	cm	0.1493	0.1313
Erosivity Coefficient (Nov-Apr)		0.12	0.14
Erosivity Coefficient (May-Oct)		0.34	0.41
aFactor		0.00028	0.00032
Total Stream Length (m)	m	24,850	2,861
Mean Channel Depth (m)	m	0.50	0.21

Appendix B - AllForX Development

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

These AllForX multipliers were calculated for a total of six watersheds (**Figure B-2**). 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 watershed to minimize differences in flow regime, soils, and other physiographic properties. Additionally, the comparison watersheds must have adequate and recent VSCI data for a watershed to be a useful data point. The VSCI scores at each station post-2013 (representing the past 10 years) were included in the analysis. These watersheds included both unimpaired and impaired streams to represent a wide distribution of current conditions.

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 were plotted against their associated average VSCI scores, and a linear regression was plotted through the values (**Figure** B-1). The regression for sediment (TSS) resulted in an R^2 value of 0.727. The regression was used to quantify the value of AllForX that corresponds to the benthic health threshold (VSCI = 60) for sediment. Based on the regression, an average VSCI score of 60 corresponded to a target AllForX ratio of 11.25. This means that the TMDL stream is expected to achieve consistently healthy benthic conditions if sediment loads are less than 11.25 times the simulated load of an all-forested watershed. The allowable sediment TMDL load was then calculated by applying the AllForX threshold where VSCI = 60 (11.25) 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 Average VSCI AllForX value development.

Station ID	VSCI avg	TSS (tons/yr)	TSS All-Forested (tons/yr)	TSS AllForX Ratio

GRN	51.5	977	61	16.0
LTL	66.8	243	49	5.0
PLC	72.3	195	41	4.7
MFH	59.4	458	43	10.8
COB	63.9	191	77	2.5
PAT	74.8	232	66	3.5
PLU	58.2	1,499	101	14.9

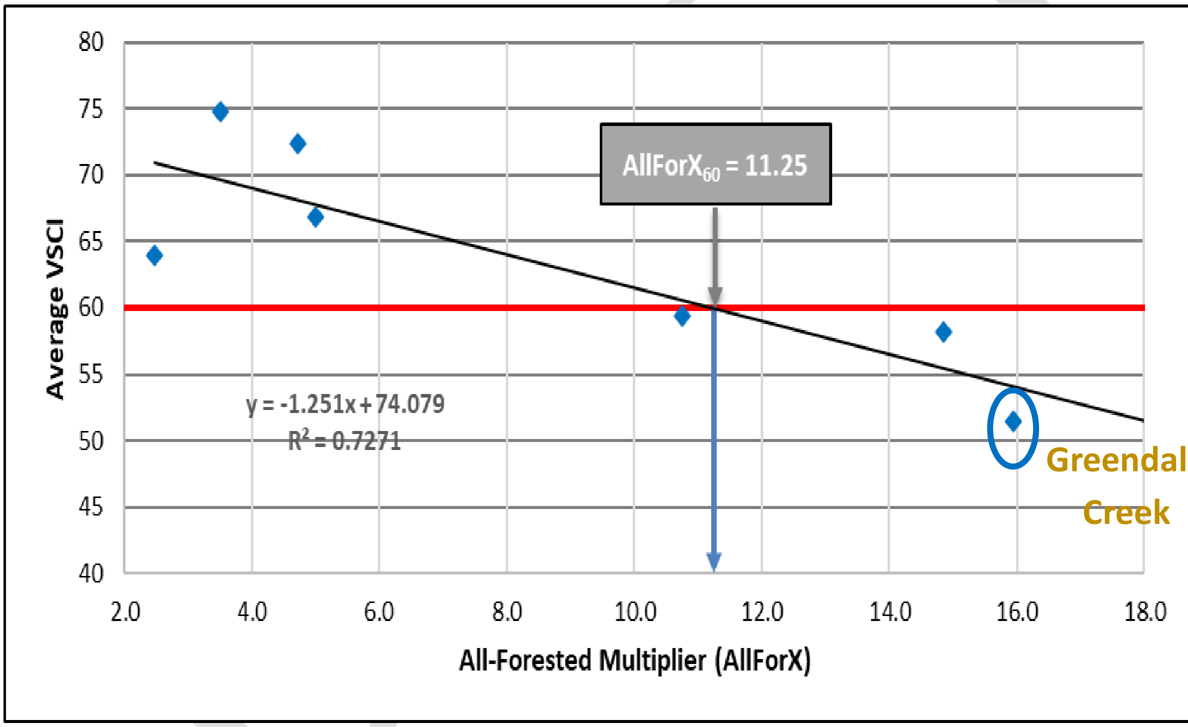

Figure B-1. Regression between the average VSCI scores and all-forest multiplier for sediment, resulting in an AllForX target ratio of 11.25 in the Greendale Creek TMDL.

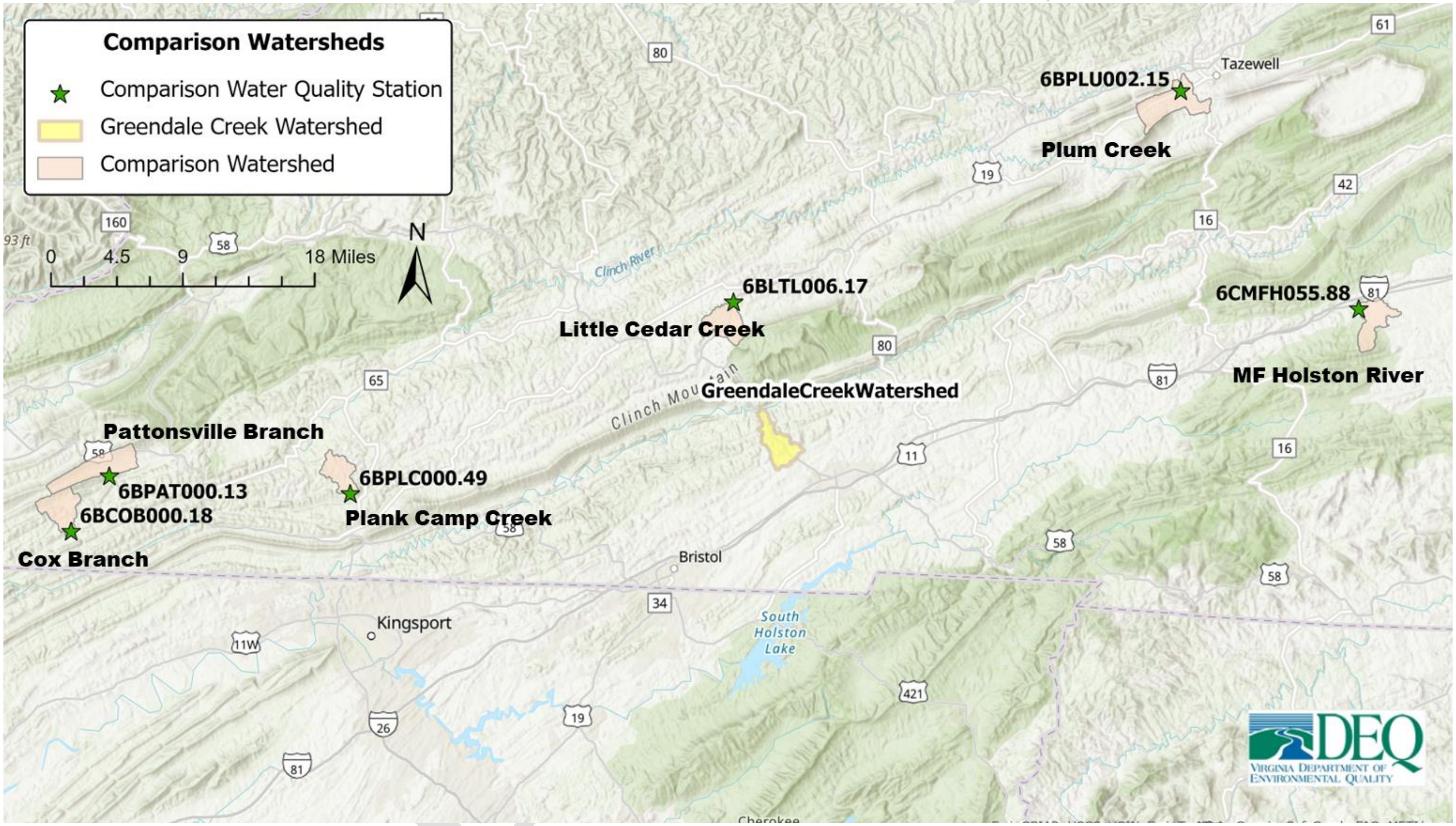

Figure B-2**. Watersheds evaluated in developing the AllForX regression.**