Benthic TMDL Study on Deep Run, Dover Creek, and Upham Brook Watersheds in Henrico and Goochland Counties and the City of Richmond

Community Engagement Meeting #2

02/29/2024, 2:00 pm

Virginia DEQ-PRO Training Room

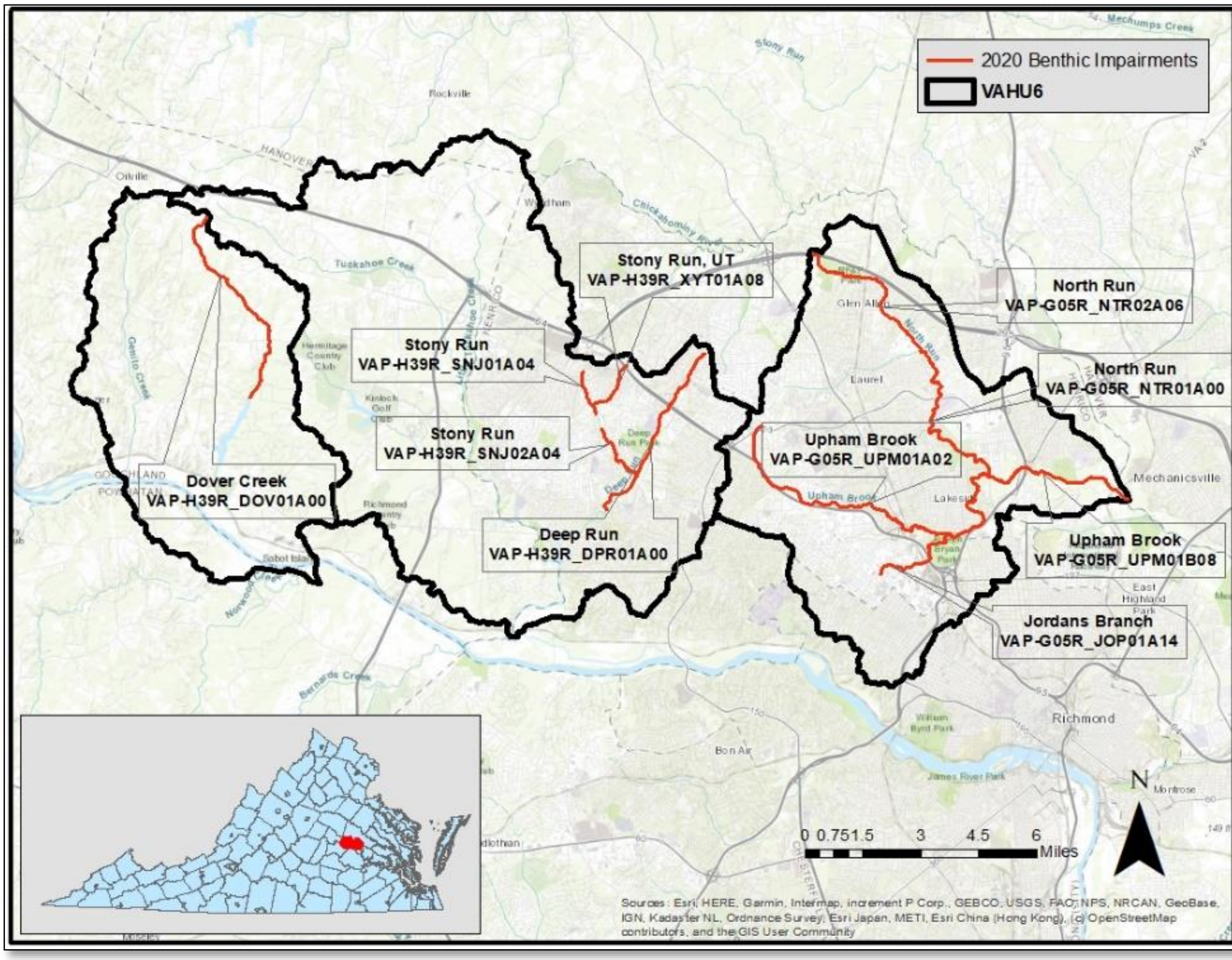

Figure 1. Map of the impairments to be addressed in this study along with the VAHU6 watershed boundaries.

Findings of the Stressor Identification Analysis

A formal causal analysis approach developed by the EPA, known as CADDIS (Causal Analysis Diagnosis Decision Information System) was used to identify the most probable stressors in the study streams. The stressor analysis, performed by faculty at James Madison University and discussed in the first Community Engagement Meeting, is located on the DEQ website under the heading TMDLs Under Development. The stressor analysis determined that sediment was a probable stressor in each of the impaired stream segments (Figure 1). Phosphorus was a probable stressor in Dover Creek, Stony Run, and Upham Brook. Dissolved oxygen (DO), pH, and organic matter were probable stressors in North Run due to natural wetland conditions and will not be incorporated into the load reductions.

Land Cover

In the previous meeting, land cover data was presented from the VGIN VLCD dataset, which was published in 2016 based on 2014 conditions. Since that meeting, the Chesapeake Bay Program (CBP) 2017/2018 land use/landcover (LULC) dataset was identified as a more current dataset of similarly high resolution and quality as the older VLCD. The CBP 2017/2018 data set was used to determine the land cover distribution throughout the watershed (**Table 1**, **Figure 2** through **Figure 6**). Additional data on soil properties and slope lengths are incorporated spatially with the land cover data and serve as the primary spatial inputs to model surface erosion calculations.

The CBP dataset contains many different sub-categories which have been lumped where logical based on the variety of morel parameters and capabilities to simplify the modeling inputs and outputs. The Impervious land cover category comprises roads and structures and is based on locally developed datasets covering specifically building footprints, roads, and other known impervious areas. Developed – Impervious and Developed-Pervious are additional developed areas identified as predominantly impervious or pervious, respectively, in the dataset. For the final model usage, Impervious and Developed-Impervious are combined. Forest is a set of land covers in the dataset identified as strictly forest, where several subcategories of Tree are smaller or thinner stands of trees identified as tree cover over another land cover, such as turf grass. Tree canopy over impervious land cover was categorized with other impervious land cover groups. The ‘NWI/other’ land cover type in the dataset is based on the combined National Wetlands Inventory and Tidal Marsh Inventory datasets and represents all identified wetland areas in those datasets. The CBP dataset contains categories for cropland and pasture, which were subdivided for modeling purposes using the 2020 Nonpoint Source (NPS) Assessment Land Use/Land Cover database maintained by the Virginia Department of Conservation and Recreation (VADCR) (VADCR, 2020). The VADCR NPS land use database includes acreage estimates 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 subwatershed was used to divide the 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 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.

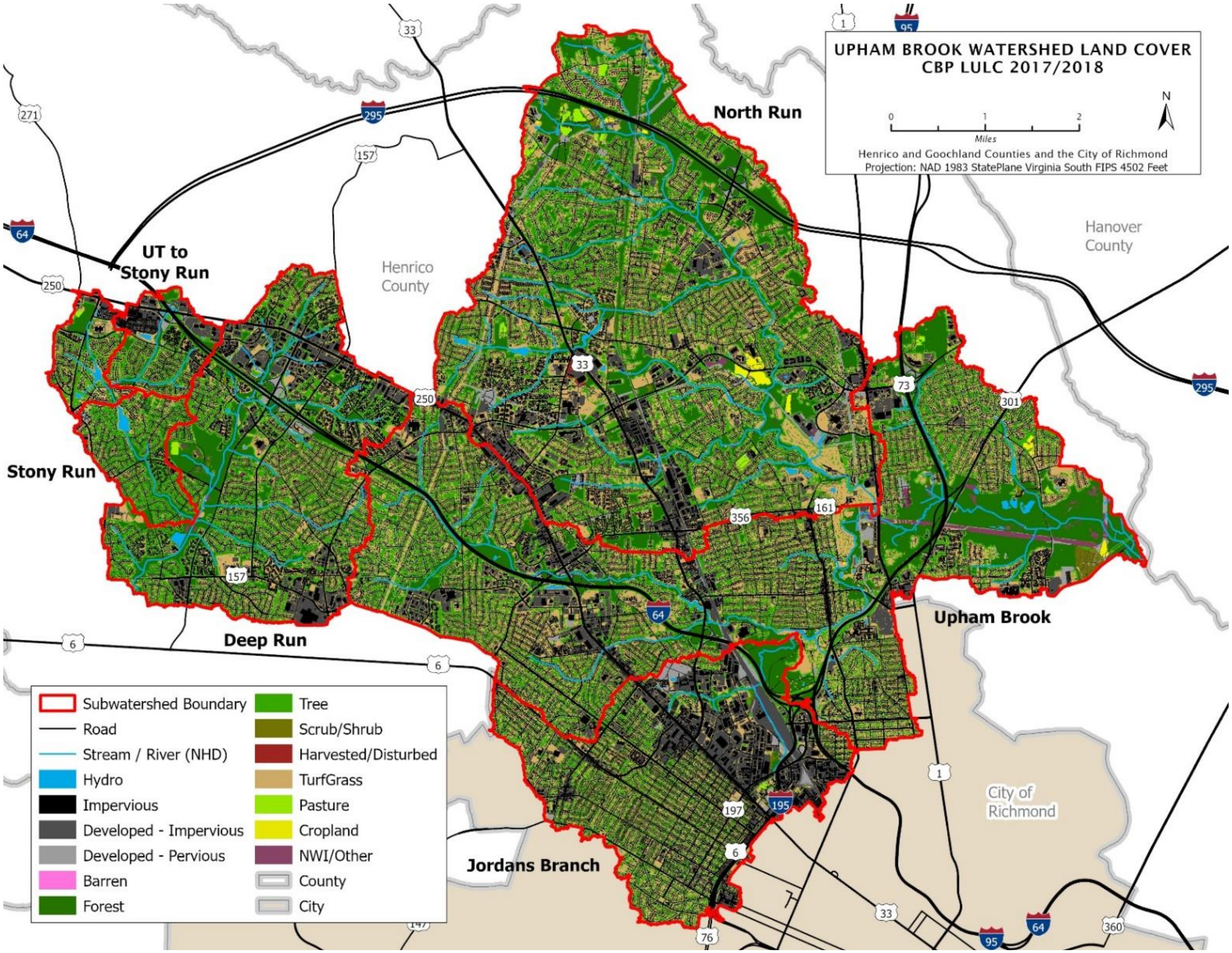

Figure 2. Chesapeake Bay Program 2017/2018 land use/landcover distribution in the Upham Brook, North Run, and Jordans Branch TMDL study areas. Deep Run, Stony Run, and Stony Run UT are included on the east side of this figure due to proximity, but highlighted in a separate map.

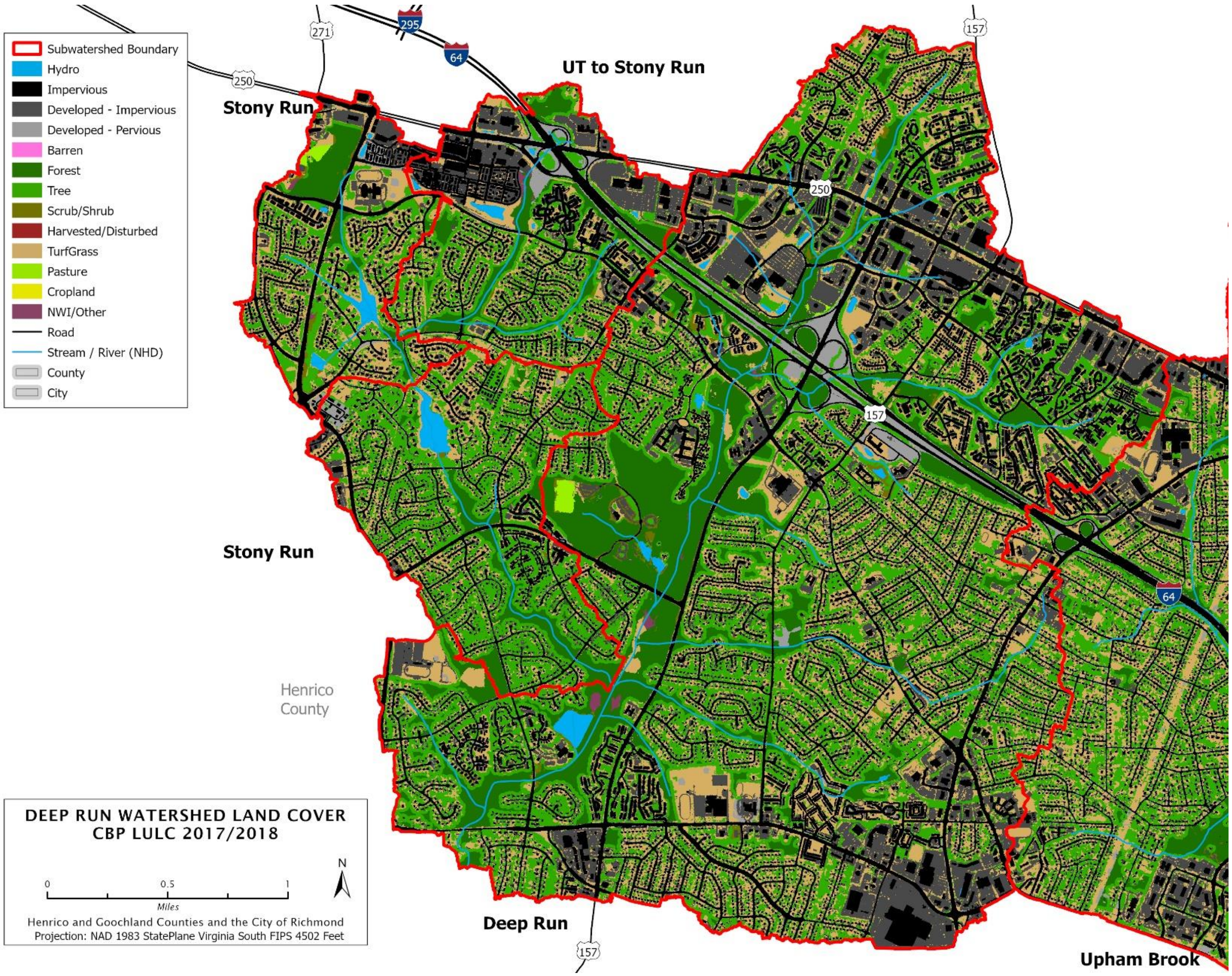

Figure 3. Chesapeake Bay Program 2017/2018 land use/landcover distribution in the Deep Run, Stony Run, and Stony Run UT TMDL study areas.

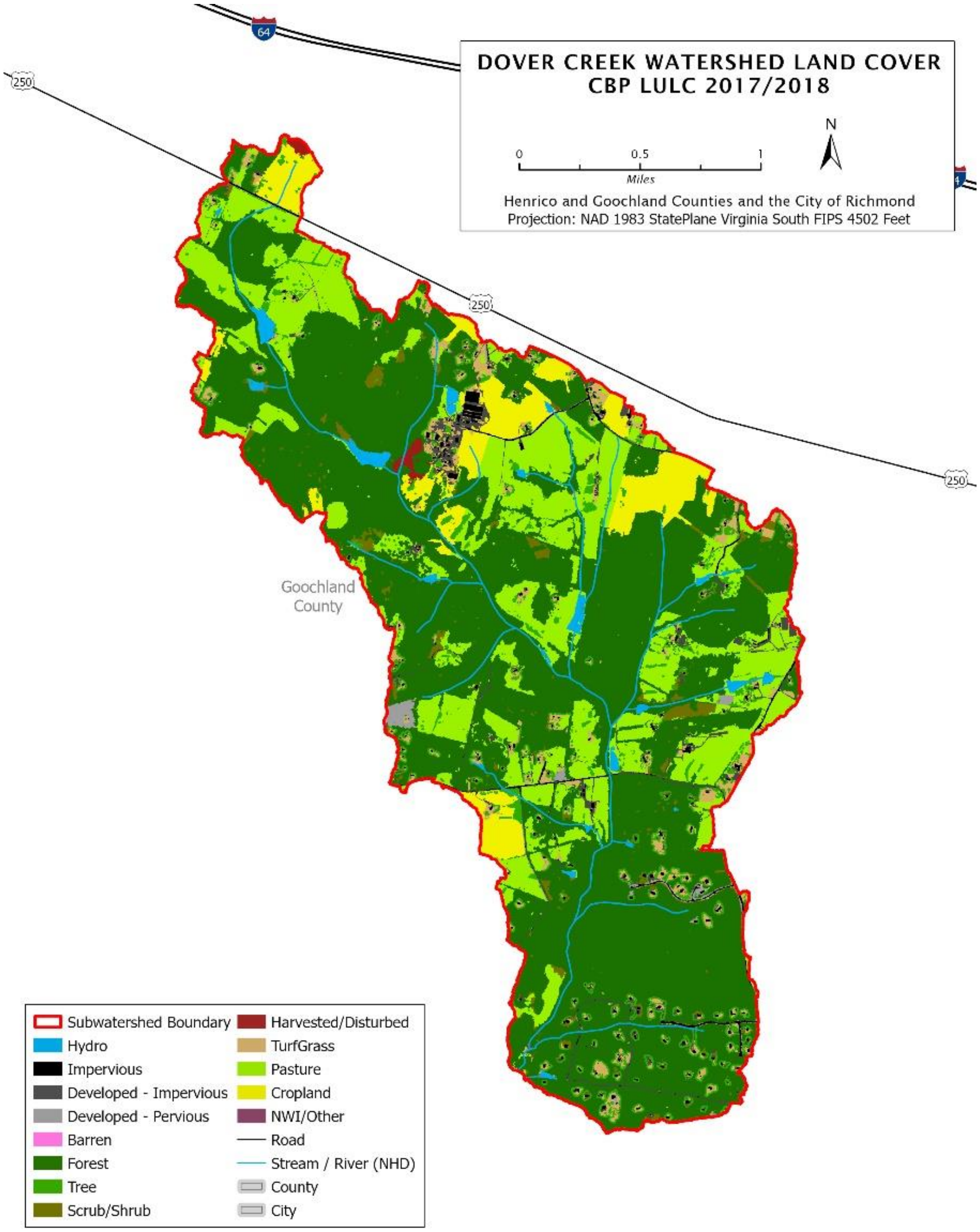

Figure 4. Chesapeake Bay Program 2017/2018 land use/landcover distribution in the Dover Creek TMDL study area.

Table 1. Chesapeake Bay Program 2017/2018 land use/landcover by watershed. Note that the land cover areas are additive. This means that the area of upstream watersheds is included in the total area for the downstream watersheds that they drain into. For example, since North Run flows into Upham Brook, the area of the North Run watershed is fully included as part of the total area of Upham Brook.

Land Cover Category	Upham Brook		North Run		Jordans Branch		Deep Run		Stony Run		Stony Run UT		Dover Creek	
	Acres	%	Acres	%	Acres	%	Acres	%	Acres	%	Acres	%	Acres	%
Cropland	63.5	*0.3%*	47.5	*0.4%*	0.0	*0.0%*	0.0	*0.0%*	0.0	*0.0%*	0.0	*0.0%*	190.4	*6.0%*
Hay	64.9	*0.3%*	53.7	*0.5%*	3.3	*0.1%*	6.9	*0.1%*	2.3	*0.1%*	0.0	*0.0%*	452.2	*14.2%*
Pasture	0.0	*0.0%*	0.0	*0.0%*	0.0	*0.0%*	3.9	*0.1%*	1.3	*0.1%*	0.0	*0.0%*	179.7	*5.7%*
Forest	3,059.8	*12.1%*	1,437.1	*13.2%*	148.6	*3.7%*	641.5	*10.1%*	152.7	*8.5%*	56.9	*9.3%*	1,880.7	*59.2%*
Trees	5,217.0	*20.6%*	2,391.3	*22.0%*	642.7	*15.9%*	1,647.6	*26.1%*	518.3	*29.0%*	130.4	*21.3%*	152.2	*4.8%*
Shrub	116.4	*0.5%*	49.3	*0.5%*	8.1	*0.2%*	35.3	*0.6%*	8.8	*0.5%*	2.5	*0.4%*	54.7	*1.7%*
Harvested/ Disturbed	7.9	*0.0%*	8.0	*0.1%*	0.0	*0.0%*	0.0	*0.0%*	0.0	*0.0%*	0.0	*0.0%*	8.4	*0.3%*
Water	119.0	*0.5%*	55.3	*0.5%*	2.5	*0.1%*	49.2	*0.8%*	27.6	*1.5%*	4.6	*0.8%*	32.3	*1.0%*
Wetland	127.3	*0.5%*	18.4	*0.2%*	0.2	*0.0%*	8.2	*0.1%*	2.7	*0.1%*	1.7	*0.3%*	0.9	*0.0%*
Barren	0.0	*0.0%*	0.0	*0.0%*	0.0	*0.0%*	0.0	*0.0%*	0.0	*0.0%*	0.0	*0.0%*	0.0	*0.0%*
Turfgrass	6,014.9	*23.8%*	2,743.4	*25.3%*	818.3	*20.2%*	1,217.1	*19.2%*	337.7	*18.9%*	101.0	*16.5%*	88.8	*2.8%*
Developed (Pervious)	917.2	*3.6%*	411.5	*3.8%*	151.0	*3.7%*	172.3	*2.7%*	51.5	*2.9%*	26.1	*4.3%*	18.2	*0.6%*
Developed (Impervious)	9,601.3	*37.9%*	3,632.2	*33.5%*	2,271.8	*56.1%*	2,542.1	*40.2%*	685.9	*38.3%*	288.8	*47.2%*	116.1	*3.7%*
Total	**25,309.4**	***100%***	**10,847.6**	***100%***	**4,046.5**	***100%***	**6,324.2**	***100%***	**1,788.8**	***100%***	**612.1**	***100%***	**3,174.6**	***100%***

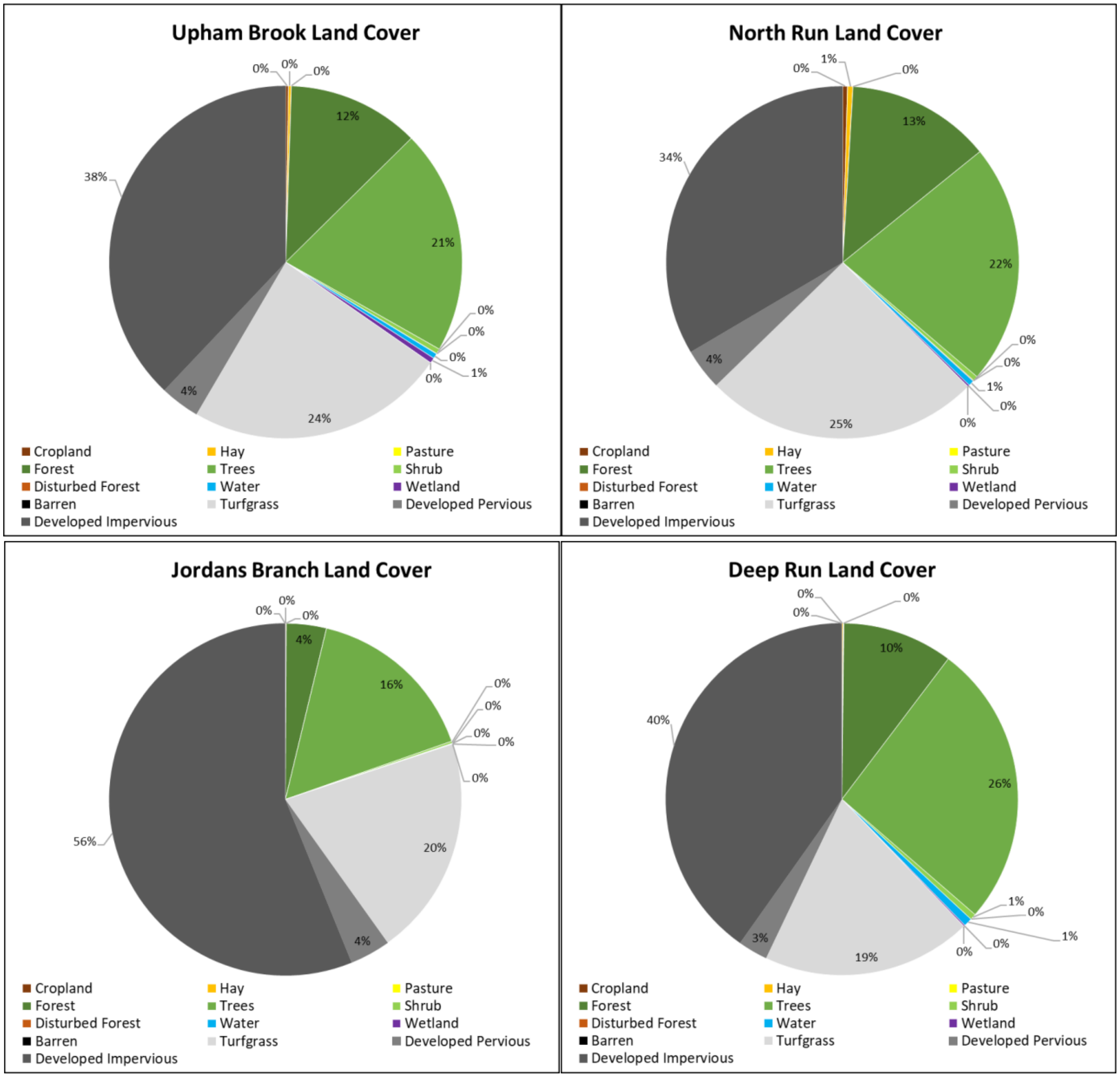

Figure 5. Land Cover Distributions for the Upham Brook, North Run, Jordans Branch, and Deep Run Watersheds

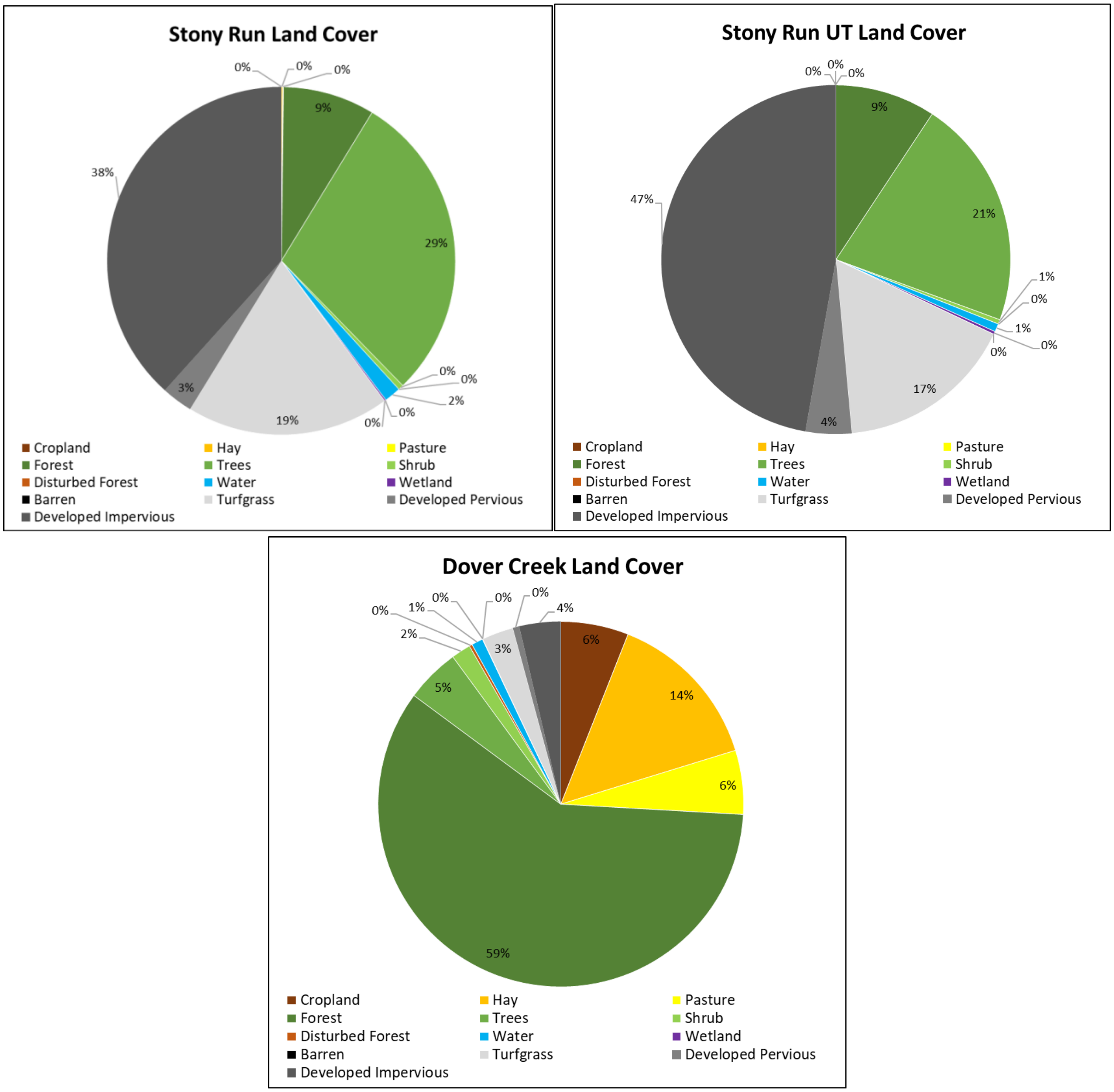

Figure 6. Land Cover Distributions for the Jordans Branch, Deep Run, Stony Run, Stony Run UT, and Dover Creek Watersheds

Residential Septic Systems

Residential septic systems, especially when not functioning properly, can be a source of phosphorus to watersheds. Residences with failing septic systems are often 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 for the localities was used as the reference for number of persons per household, which was then applied to the number of residences on septic systems, based on VDH and county-provided datasets, to obtain a population distribution for input to GWLF. A preliminary distribution of properties with septic systems is currently being used for the GWLF model, and we are interested in gathering any more information for use as we move forward.

Table 2. Known Septic Systems in each TMDL watershed. Note that the counts for more downstream watersheds also include the counts from the upstream watersheds that flow into them.

Stream Name	Number of Known Septic Systems
Upham Brook	118
North Run	78
Jordans Branch	2
Deep Run	18
Stony Run	2
Stony Run UT	2
Dover Creek	108

Questions:
Is there any additional information available on septic systems, septic failures, and/or straight pipes in the watershed?

Do the numbers of known septic systems in each subwatershed seem close?

Does the 3.3% failure rate for septic systems seem reasonable for these watersheds?

Permitted Sources

There are five active industrial stormwater (ISW) general permits in the study area (**Table 3**). ISW permit-covered facilities located in the Chesapeake Bay watershed are required to assess their nutrient and sediment loadings and complete discharge monitoring to ensure compliance with target nutrient and sediment loading values from their facilities. As such, DEQ developed a methodology to estimate the loads from ISW permitted areas. During model simulations, the regulated acreages for the permits will be separated from the accounting of total acreages for the watershed. To develop existing loads, the regulated industrial acres for each permit are included in the model at the same loading rate as other developed, impervious acres. The allocated loads to be used in developing the TMDL are calculated using the same methodology but utilize the loading rate of 440 lb/ac/yr TSS and 1.5 lb/ac/yr TP noted in the general permit, which was used to estimate the loading from industrial stormwater facilities for Chesapeake Bay TMDL documentation.

Table 3. Industrial Stormwater General Permits in the study area.

Permit No.	Facility Name	Receiving Stream
VAR051167	Johns Manville	North Run
VAR050885	AMF Bakery Systems*	Upham Brook
VAR051821	TRANSFLO Terminal Services TTSI	Upham Brook
VAR051056	CSX Transportation Inc – Bryan Park Terminal	Upham Brook
VAR051027	Liphart Steel Company Incorporated	Jordans Branch

* Permit was closed 10/2023. The facility was permitted to discharge during the monitoring and assessment phases of the process, and is accounted for, but due to the permit being closed, it is given no WLA.

There are two mixed concrete general permits in the study area (**Table 4**). These facilities are a permitted source of sediment in the watershed (at 30 mg/L). The sediment waste load allocations for these facilities are calculated using a method developed by DEQ based on the permitted sediment discharge concentration and average flow rate from discharge monitoring report data.

Table 4. Mixed Concrete General Permits in the study area.

Permit No	Facility Name	Receiving Stream
VAG110227	Bryan Park Ready Mix Concrete Plant	Jordans Branch
VAG110201	Smyrna Ready Mix Concrete	Jordans Branch

There is one VPDES potable water treatment plant (PWTP) general permit within the study area, (**Table 5**). The existing loads will be calculated based on DMR data and permitted loads will be calculated using the permitted TSS concentration and flow rates for the permit.

Table 5. Sediment load associated with the potable water treatment general permit.

Permit No	Facility Name	Receiving Stream
VAG640064	Henrico County Water Treatment Plant	Deep Run

There are four Municipal Separate Storm Sewer System (MS4) permits within the TMDL watersheds (**Table 6**). These areas are potential sources of sediment and phosphorus and will be assigned waste load allocations in the TMDL. The loads will be based on the extent and type of land cover within the boundaries of the permitted areas.

Table 6. MS4 permits within the study area.

Permit No.	Permitted Entity
VA0063177	City of Richmond
VA0088617	Henrico County
VAR040107	J Sargeant Reynolds
VA0092975	VDOT

There are currently 61 active Virginia Stormwater Management Program (VSMP) permits for construction within the study area (**Table 7**). These permits are a potential source of sediment and phosphorus and will be assigned waste load allocations in the TMDL. 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). Any active permits in process of termination were excluded because, at that stage in the permitting cycle, all areas are stabilized.

Table 7. VSMP Construction General Permits in the study area.

Receiving Stream	Estimated Potential Disturbed Area (ac/yr)
Upham Brook	203.5
North Run	87.8
Jordans Branch	25.7
Deep Run	40.3
Stony Run	10.7
Stony Run UT	6.43

Appropriate erosion and sediment control measures are assumed to be utilized on all construction projects, and for developing final WLAs for the allocation scenarios, loads are proposed to be simulated with an 85% sediment removal efficacy based on Chesapeake Bay Expert Panel Guidance (ESCEP, 2014).

Questions:
Are there any permitted sources that we are missing?

Do the acreage estimates for construction related disturbance seem reasonable?

Are you aware of any stormwater or sanitary sewer overflows that have occurred from 2000 to now?

Do the stormwater control measures on construction projects in this watershed achieve 85% reduction before leaving the sites? In other words, are those assumptions described here what we need to use in our model?

Estimated Existing Pollutant Loads

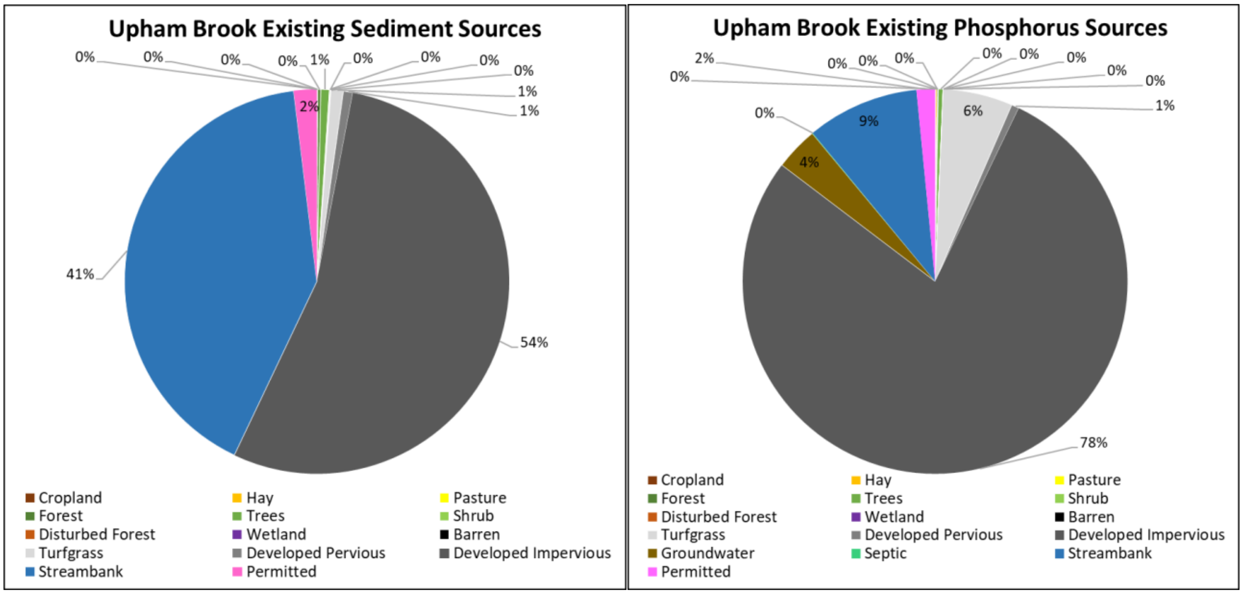

Figure 7. Existing Sediment and Phosphorus Sources in the Upham Brook Watershed (inclusive of loads from Jordans Branch and North Run).

Table 8. Existing Sediment and Phosphorus Loads in the Upham Brook Watershed (inclusive of loads from Jordans Branch and North Run).

Land Cover Category	Upham Brook			
	TSS (lb/yr)	*%*	*TP (lb/yr)*	*%*
Cropland	7,222	0.1%	10	0.1%
Hay	1,225	0.0%	22	0.1%
Pasture	0	0.0%	0	0.0%
Forest	31,638	0.3%	17	0.1%
Trees	84,652	0.7%	72	0.4%
Shrub	8,935	0.1%	1	0.0%
Disturbed Forest	2,024	0.0%	1	0.0%
Wetland	4,666	0.0%	0	0.0%
Barren	0	0.0%	0	0.0%
Turfgrass	124,008	1.0%	1,065	5.8%
Developed Pervious	94,841	0.8%	116	0.6%
Developed Impervious	6,471,414	54.1%	14,237	78.2%
Groundwater	-	0.0%	663	3.6%
Septic	-	0.0%	9	0.1%
Streambank	4,908,418	41.0%	1,718	9.4%
Permitted	231,203	1.9%	283	1.6%
Total	*11,970,245*	*100.0%*	*18,213*	*100.0%*

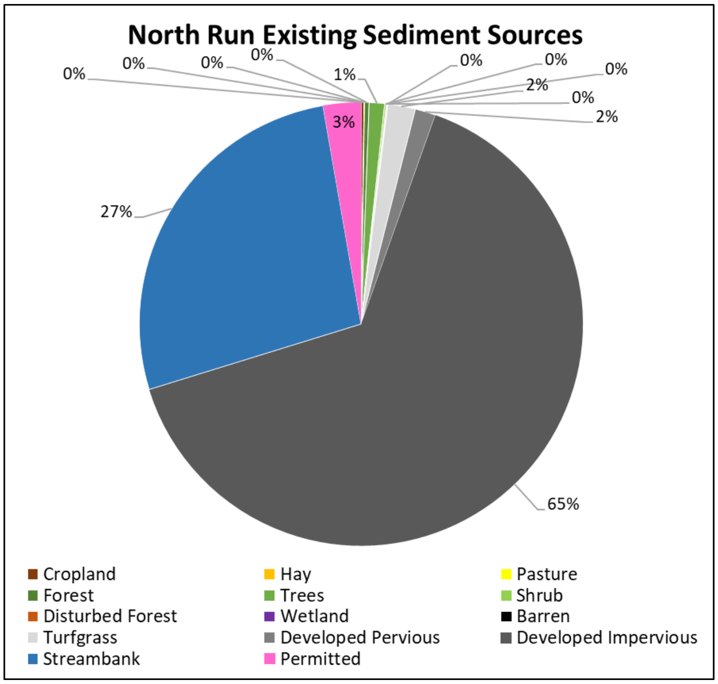

Figure 8. Existing Sediment Sources in the North Run Watershed

Table 9. Existing Sediment Loads in the North Run Watershed

Land Cover Category	**North Run**	
	TSS (lb/yr)	***%***
Cropland	8,142	0.2%
Hay	1,347	0.0%
Pasture	0	0.0%
Forest	12,931	0.3%
Trees	42,797	1.1%
Shrub	4,978	0.1%
Disturbed Forest	2,607	0.1%
Wetland	1,185	0.0%
Barren	0	0.0%
Turfgrass	76,909	2.0%
Developed Pervious	57,396	1.5%
Developed Impervious	2,480,277	64.8%
Streambank	1,034,449	27.0%
Permitted	105,340	2.8%
Total	*3,832,359*	*100.0%*

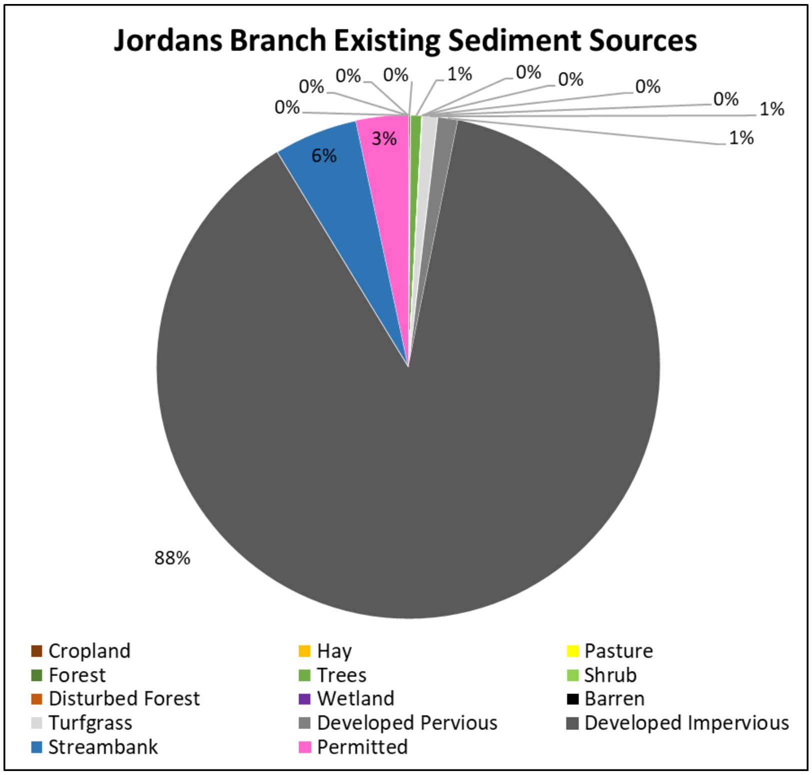

Figure 9. Existing Sediment Sources in the Jordans Branch Watershed

Table 10. Existing Sediment Loads in the Jordans Branch Watershed

Land Cover Category	**Jordans Branch**	
	TSS (lb/yr)	***%***
Cropland	5	0.0%
Hay	150	0.0%
Pasture	0	0.0%
Forest	2,316	0.1%
Trees	12,662	0.7%
Shrub	242	0.0%
Disturbed Forest	0	0.0%
Wetland	28	0.0%
Barren	0	0.0%
Turfgrass	17,229	1.0%
Developed Pervious	22,584	1.3%
Developed Impervious	1,537,683	88.1%
Streambank	93,873	5.4%
Permitted	58,404	3.4%
Total	*1,745,178*	*100.0%*

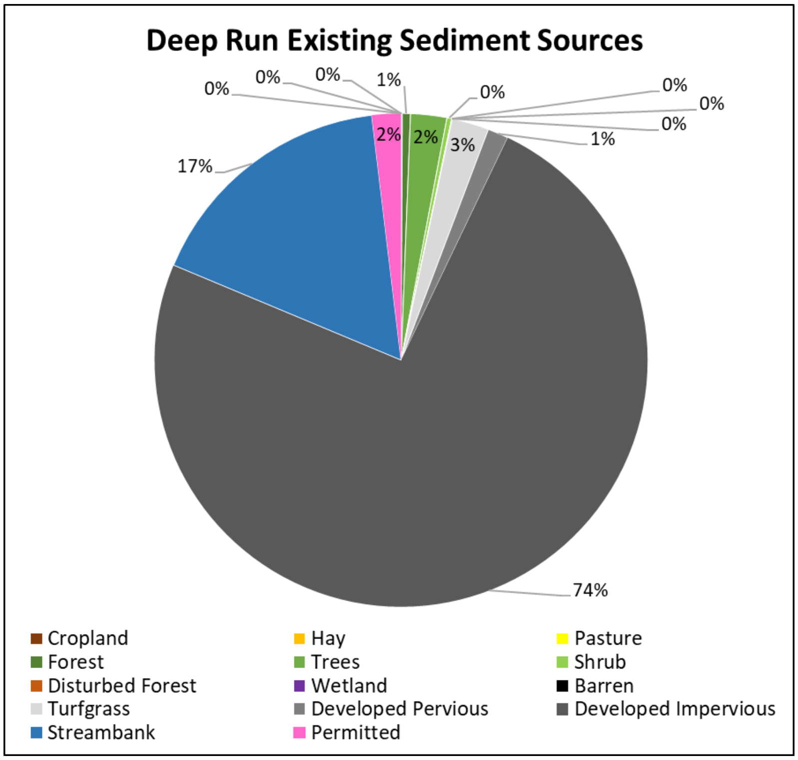

Figure 10. Existing Sediment Sources in the Deep Run Watershed (inclusive of loads from Stony Run).

Table 11. Existing Sediment Loads in the Deep Run Watershed (inclusive of loads from Stony Run).

Land Cover Category	Deep Run	
	TSS (lb/yr)	*%*
Cropland	19	0.0%
Hay	220	0.0%
Pasture	1,609	0.1%
Forest	12,017	0.5%
Trees	53,759	2.4%
Shrub	6,974	0.3%
Disturbed Forest	0	0.0%
Wetland	783	0.0%
Barren	0	0.0%
Turfgrass	55,074	2.4%
Developed Pervious	30,728	1.4%
Developed Impervious	1,678,815	74.2%
Streambank	380,453	16.8%
Permitted	43,104	1.9%
Total	*2,263,555*	*100.0%*

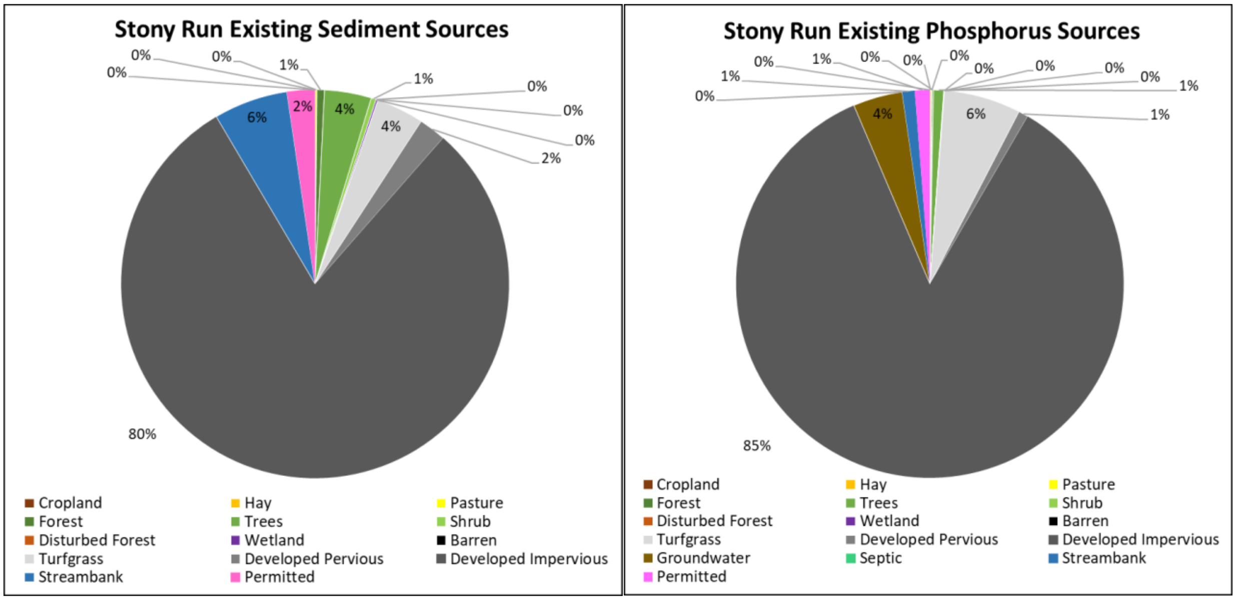

Figure 11. Existing Sediment and Phosphorus Sources in the Stony Run Watershed (inclusive of loads from UT Stony Run).

Table 12. Existing Sediment and Phosphorus Loads in the Stony Run Watershed (inclusive of loads from UT Stony Run).

Land Cover Category	**Stony Run**			
	TSS (lb/yr)	***%***	***TP (lb/yr)***	***%***
Cropland	0	0.0%	0	0.0%
Hay	114	0.0%	1	0.1%
Pasture	738	0.1%	1	0.1%
Forest	3,428	0.6%	1	0.1%
Trees	21,521	3.9%	10	0.9%
Shrub	2,257	0.4%	0	0.0%
Disturbed Forest	0	0.0%	0	0.0%
Wetland	844	0.2%	0	0.0%
Barren	0	0.0%	0	0.0%
Turfgrass	21,810	4.0%	73	6.4%
Developed Pervious	12,471	2.3%	9	0.8%
Developed Impervious	440,539	80%	969	85.2%
Groundwater	-	0.0%	47	4.1%
Septic	-	0.0%	0	0.0%
Streambank	33,989	6.2%	12	1.0%
Permitted	12,821	2.3%	14	1.2%
Total	*550,533*	*100.0%*	*1,138*	*100.0%*

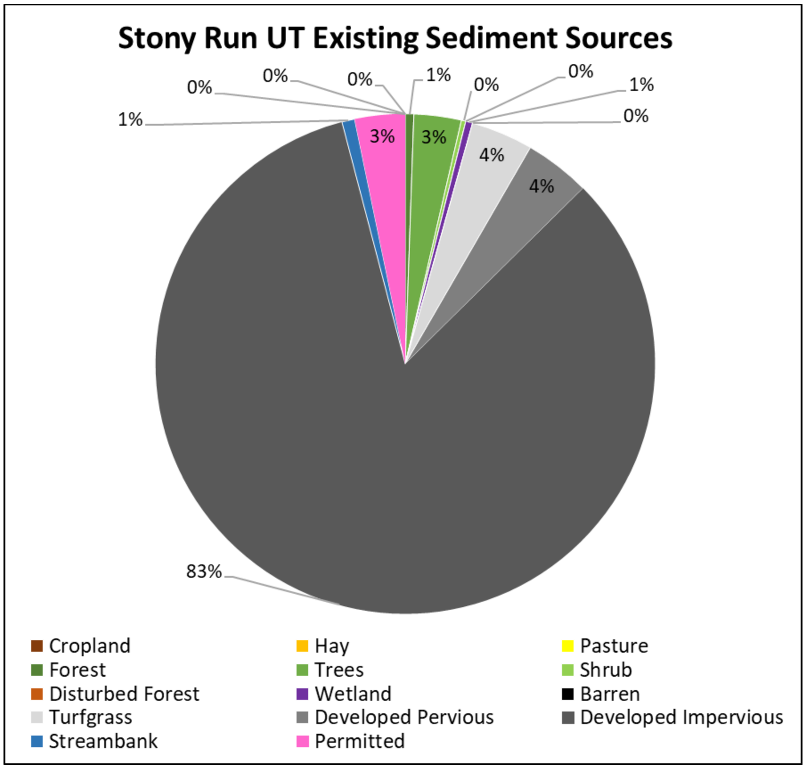

Figure 12. Existing Sediment Sources in the Stony Run UT Watershed

Table 13. Existing Sediment Loads in the Stony Run UT Watershed

Land Cover Category	**Stony Run UT**	
	TSS (lb/yr)	***%***
Cropland	0	0.0%
Hay	0	0.0%
Pasture	0	0.0%
Forest	1,260	0.5%
Trees	7,037	3.1%
Shrub	660	0.3%
Disturbed Forest	0	0.0%
Wetland	1,027	0.4%
Barren	0	0.0%
Turfgrass	9,197	4.0%
Developed Pervious	9,784	4.3%
Developed Impervious	191,366	83.3%
Streambank	1,905	0.8%
Permitted	7,475	3.3%
Total	*229,712*	*100.0%*

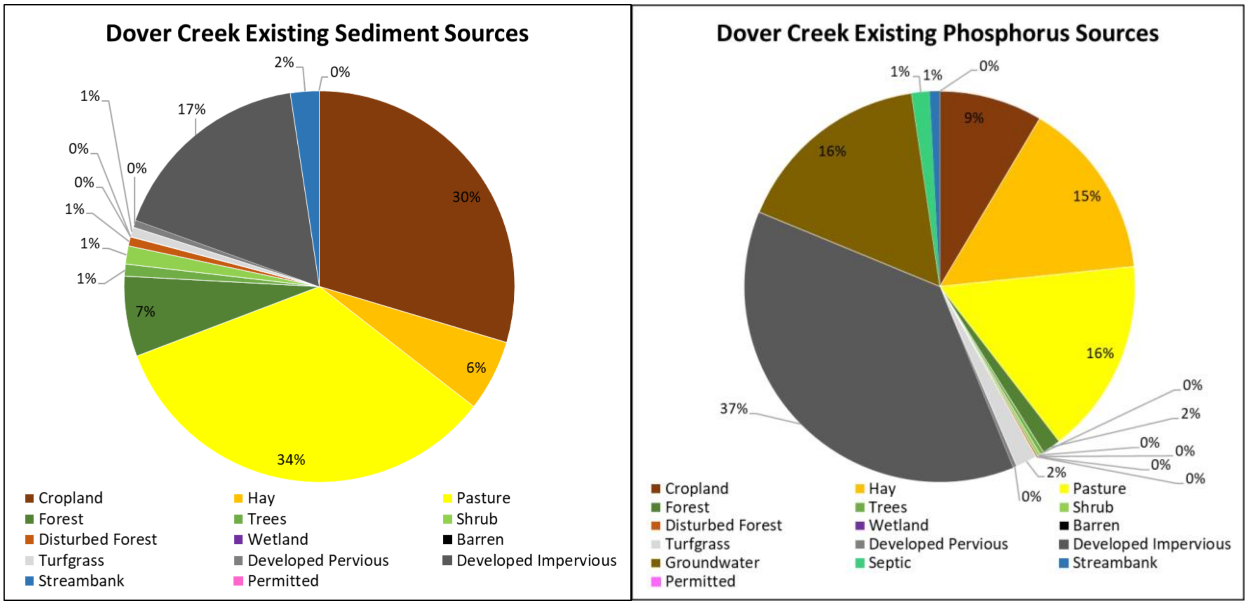

Figure 13. Existing Sediment and Phosphorus Sources in the Dover Creek Watershed

Table 14. Existing Sediment and Phosphorus Loads in the Dover Creek Watershed

Land Cover Category	**Dover Creek**			
	TSS (lb/yr)	***%***	***TP (lb/yr)***	***%***
Cropland	162,597	29.6%	47	8.5%
Hay	32,308	5.9%	82	14.8%
Pasture	185,139	33.7%	90	16.2%
Forest	36,372	6.6%	9	1.5%
Trees	5,468	1.0%	2	0.3%
Shrub	8,200	1.5%	1	0.2%
Disturbed Forest	4,126	0.8%	1	0.2%
Wetland	112	0.0%	0	0.0%
Barren	0	0.0%	0	0.0%
Turfgrass	4,380	0.8%	10	1.7%
Developed Pervious	3,320	0.6%	2	0.3%
Developed Impervious	93,868	17.1%	207	37.3%
Groundwater	-	0.0%	91	16.5%
Septic	-	0.0%	8	1.5%
Streambank	13,111	2.4%	5	0.8%
Permitted	0	0.0%	0	0.0%
Total	*548,999*	*100.0%*	*553*	*100.0%*

Best Management Practices (BMPs)

To ensure credit is given for prior work completed in the watershed, data on existing BMPs within the watershed tracked by DEQ or the Department of Conservation and Recreation (DCR) was compiled (**Table 15**) and associated reductions to sediment and/or phosphorus loading will be subtracted from the existing loads.

Table 15. BMP data within the study area between 2000 and 2023. Note that the BMP counts are not additive between the watersheds. Each watershed only counts the BMPs that exist solely in that watershed. For example, the BMPs listed under North Run are not counted again under Upham Creek (even though North Run flows into Upham Creek). Alternatively, the BMPs that exist solely in the Upham Creek watershed are not counted in the North Run or Jordans Branch counts (even though North Run and Jordans Branch flow into Upham Creek).

Receiving Stream	Practice	Count
Upham Brook	Bioretention	7
	Dry Extended Detention Ponds	31
	Grazing Land Management (SL-10)	2
	Filtering Practices	13
	Infiltration Trenches	4
	Permeable Pavement	2
	Proprietary Ex Situ Shallow Pressure	2
	Proprietary Stormwater Treatment	35
	RMF Shallow Pressure	1
	Septic Tank Pumpout (RB-1)	1
	Urban Stream Restoration	1
	Urban Vegetated Treatment Area	2
	Wet Pond	7
North Run	Bioretention	8
	Dry Extended Detention Ponds	84
	Filtering Practices	18
	Infiltration Trenches	1
	Nutrient Management Plan Writing and Revision (NM-1)	5
	Nutrient Management Plan Implementation and Record Keeping (NM-2)	5
	Late Winter Split Application of Nitrogen on Small Grains (NM-4)	5
	NSF 40 Shallow Pressure	1
	NSF 40	3
	Proprietary Ex Situ Shallow Pressure	4
	Proprietary Ex Situ	1
	Proprietary Stormwater Treatment	35
	Reduction of Impervious Surface	1
	Septic Effluent Shallow Pressure	2
	Continuous High Residue Minimal Soil Disturbance Tillage System (SL-15A)	4
	Urban Stream Restoration	1
	Urban Vegetated Treatment Area	5
	Wet Ponds	15
Jordans Branch	Dry Extended Detention Ponds	12
	Filtering Practices	2

Receiving Stream	Practice	Count
	Infiltration Trenches	1
	Permeable Pavement	1
	Proprietary Stormwater Treatment	7
	Urban Nutrient Management Plan	2
	Vegetated Open Channels	2
	Wet Ponds	1
Deep Run	Bioretention	2
	Dry Extended Detention Ponds	37
	Filtering Practices	10
	Infiltration Trenches	1
	Proprietary Ex Situ Shallow Pressure	1
	Proprietary Stormwater Treatment	29
	RMF	1
	Urban Vegetated Treatment Area	2
	Wet Ponds	20
Stony Run	Bioretention	4
	Dry Extended Detention Ponds	8
	Dry Well	1
	Filtering Practices	1
	Proprietary Stormwater Treatment	8
	Rain Garden	1
	Urban Vegetated Treatment Area	1
	Wet Ponds	1
Stony Run UT	Dry Extended Detention Ponds	9
	Filtering Practices	1
	Wet Ponds	7
Dover Creek	Nutrient Management Plan Writing and Revision (NM-1)	5
	Nutrient Management Plan Writing and Revisions (NM-1A)	7
	NSF 40	1
	Septic Tank Pumpout	2
	Stream Exclusion With Grazing Land Management (SL-6)	7
	Small Grain and Mixed Cover Crop for Nutrient Management and Residue Management (SL-8B)	2

TMDL Modeling Approach

The computational model selected to develop sediment and phosphorus TMDLs in the Henrico and Goochland County Stream watersheds is the Generalized Watershed Loading Function (GWLF) model. GWLF is widely used throughout Virginia in developing sediment and nutrient TMDLs. It is a continuous simulation model operating on a daily timestep for water balance calculations to generate monthly sediment and nutrient yields for the watershed. 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.

Some of the parameters and capabilities that GWLF incorporates:

- 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.
- Landscape erosion is calculated based on the Universal Soil Loss Equation (USLE), which incorporates the erosivity of rainfall in the watershed area, the inherent erodibility of the soils, the length and steepness of runoff slopes receiving flowing water, as well as factors for cover and conservation practices that affect the impact of rainfall and runoff on the landscape.
- Impervious or urban sediment and nutrient inputs are calculated with exponential accumulation and washoff functions.
- A delivery ratio is applied to the overall sediment supply, and sediment transport takes into consideration the transport capacity of the runoff.
- Streambank and channel erosion rates are calculated using an algorithm incorporating stream discharge, fraction of developed land 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 modeled along with interactions of evapotranspiration, infiltration from the surface to the unsaturated zone, percolation from the unsaturated zone to the shallow saturated zone, and 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.
- Functionality is also included for manure applications and septic systems.

TMDL Modeling Inputs

Subwatersheds

The TMDL study area was divided into 18 subwatersheds to obtain a more granular assessment of the pollutant loads throughout the watershed (**Figure 14**). The watershed was subdivided based on impairments so that TMDLs could be developed for each impaired reach of the stream. Locations of monitoring stations were used to guide subwatershed development to take advantage of available data. Junctions of streams were also used as breaking points to reduce subwatershed size.

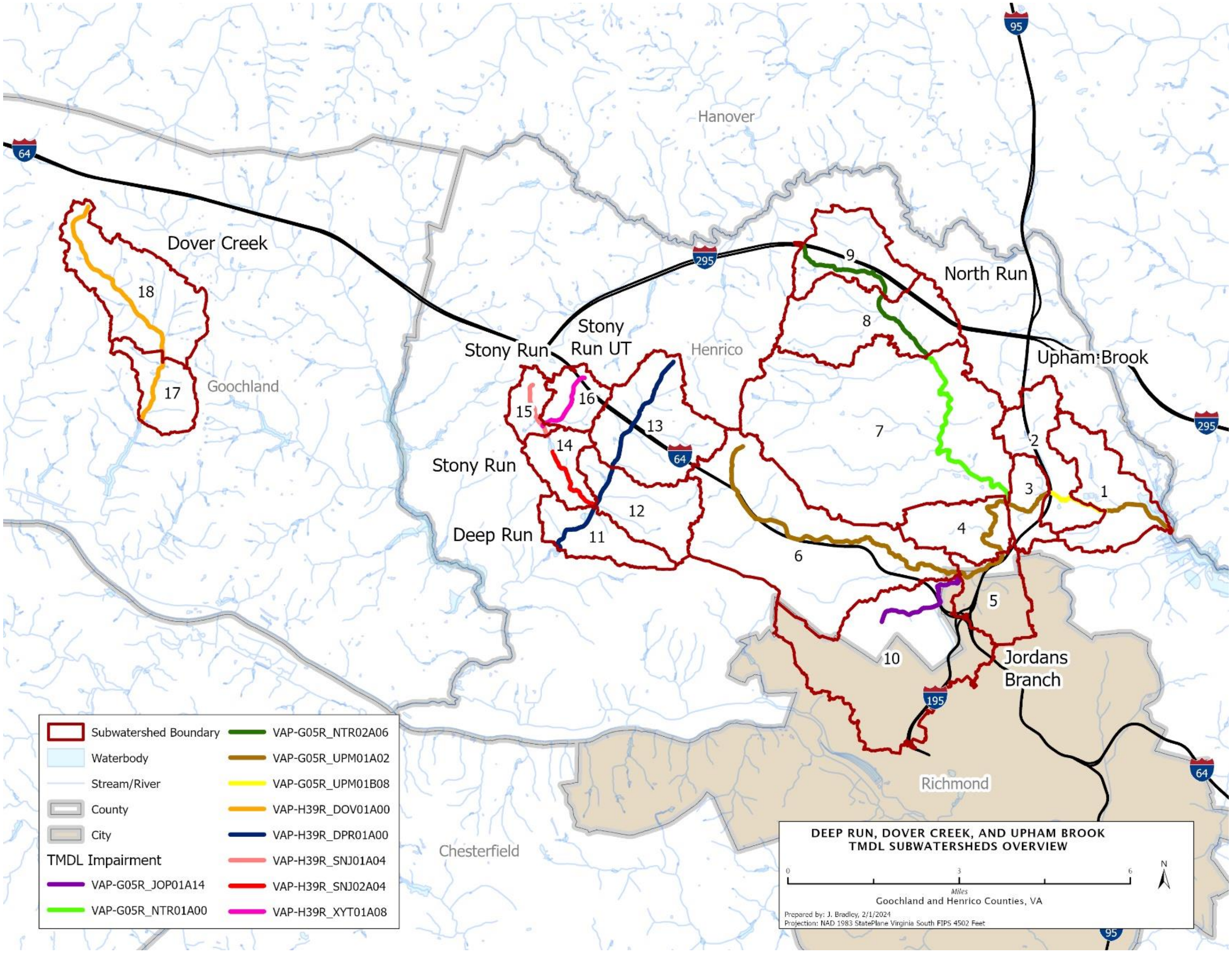

Figure 14. Henrico and Goochland County Stream TMDL study subwatersheds.

Hydrologic Calibration

While GWLF was originally developed as a planning tool for estimating nutrient and sediment loadings in ungauged watersheds and was designed to be implemented without calibration, hydrologic calibration was still performed as a preliminary modeling step. This is a process used to make sure that the model is accurately representing how stream flow changes in response to precipitation events. Capturing the hydrology of these watersheds correctly is key in simulating the path of sediment and phosphorus from the land to the stream. WSSI used the USGS flow gauge on Fine Creek to calibrate the Henrico and Goochland County watershed models. Fine Creek is located in Powhatan County and was selected based on its proximity to the study watersheds. Daily rainfall and temperature data for the watershed were obtained from Oregon Stations PRISM model. Streamflow, rainfall, and temperature data from 2012 through 2021 were used to calibrate the model. During the calibration process, different parameters characterizing the watersheds were adjusted so that actual flow recorded at the Fine Creek gauge matched modeled flow estimates. Examples of these parameters include recession and seepage coefficients, and an evapotranspiration cover coefficient. The typical target range for GWLF calibration efforts is to achieve ±5% of the observed total flow. This target was achieved for the TMDL study watersheds, with a difference of 3.26% between modeled and observed cumulative discharge during the calibration period. The calibration results are shown below in **Figure 15** and **Figure 16**.

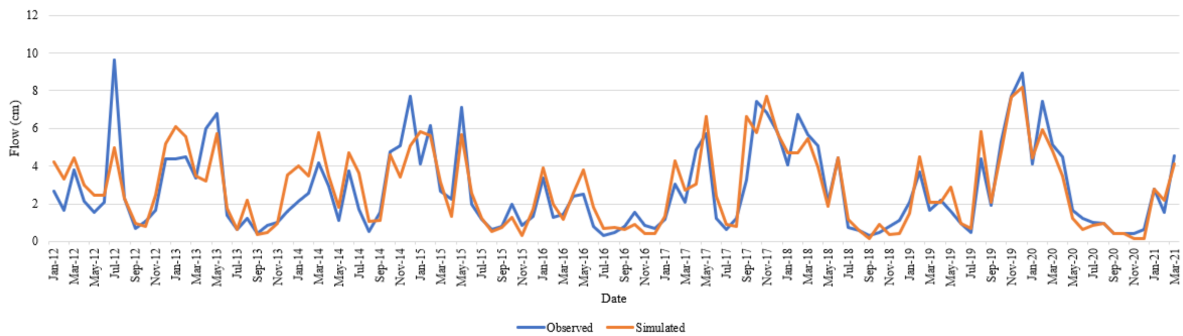

Figure 15. Calibration Data Set of Simulated Stream Flow Compared to Observed Flow at USGS Gauge 02036500.

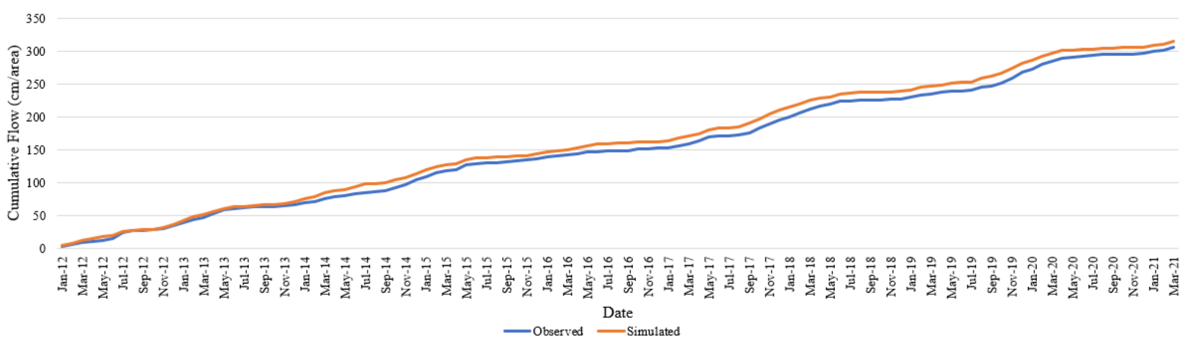

Figure 16. Cumulative Calibration Data Set of Simulated Stream Flow Compared to Observed Flow at USGS Gauge 02036500.

Hydrologic Validation

To ensure that the model was not just capturing stream flows during the calibration period (2012-2020), the model was validated for another time frame (2003-2011) following calibration. The results are shown below in **Figure 17** and **Figure 18**. Results for the validation period indicated that the model performed well even outside of the calibration window for which watershed parameters were adjusted, with a difference of -3.81% between modeled and observed flows during the validation time frame. See **Table 16** for a full comparison of the modeled and observed discharges.

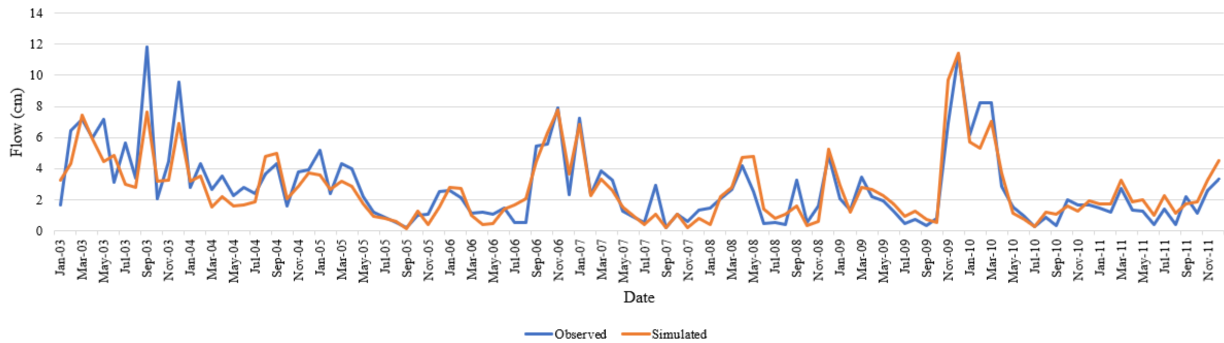

Figure 17. Validation Data Set of Simulated Stream Flow Compared to Observed Flow at USGS Gauge 02036500.

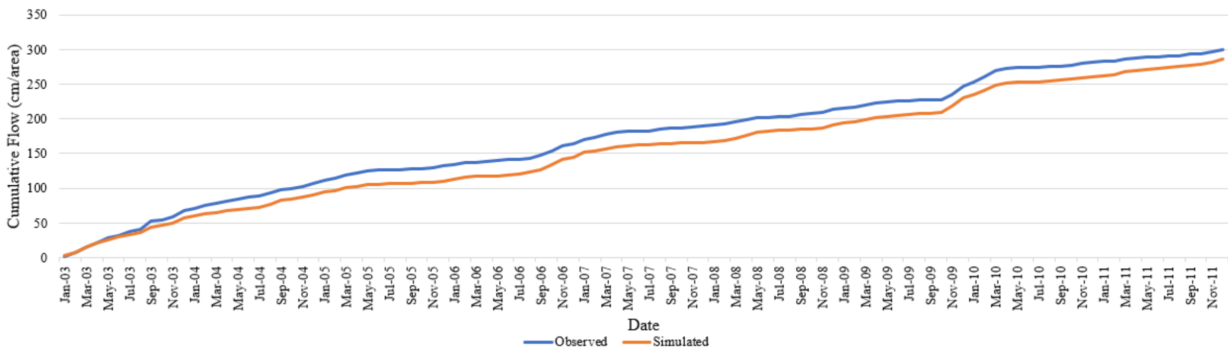

Figure 18. Cumulative Validation Data Set of Simulated Stream Flow Compared to Observed Flow at USGS Gauge 02036500.

Table 16. Results of the hydrology calibration

Criteria	Calibration Range Percent Difference (%)	Validation Range Percent Difference (%)	Entire Modelled Range (%)
Total Cumulative Discharge	3.26	-3.81	-0.39
Spring Discharge	-0.47	0.18	-0.20
Summer Discharge	10.08	-4.03	2.19
Fall Discharge	-8.80	-1.18	-5.01
Winter Discharge	13.88	-8.38	2.77
R^2	0.77	0.82	0.80

Setting Sediment and Phosphorus Reduction Targets

A key component of the TMDL study is the establishment of pollutant reduction goals. While Virginia has water quality criteria that regulate the concentration of some pollutants in our waterways, there are no such criteria for sediment or phosphorus. Therefore, an alternative method must be used to determine the water quality targets for sediment and phosphorus in the TMDL study.

The All Forest Load Multiplier (AllForX) Endpoint Approach

The AllForX approach has been used to establish sediment and nutrient reduction targets in many TMDL studies completed in Virginia since 2014. AllForX is the ratio of the simulated pollutant load under existing conditions to the pollutant load from an all-forested simulated condition for the same watershed (see illustration in **Figure 19**). In other words, AllForX is an indication of how much higher current sediment or phosphorus loads are above an undeveloped condition.

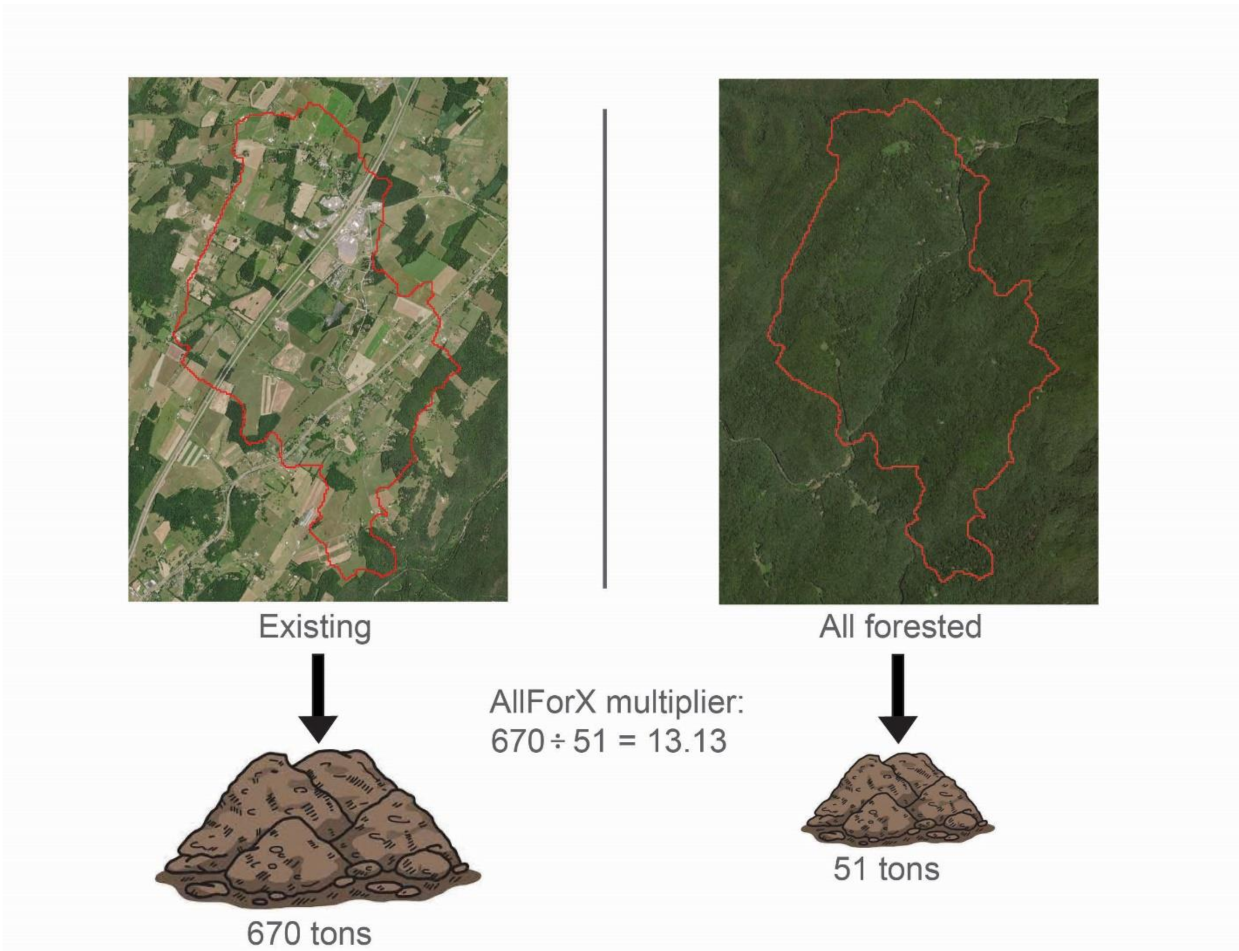

Figure 19. Illustration of Establishment of AllForX Multiplier for an example watershed

These multipliers are calculated for the TMDL watersheds as well as a group of unimpaired and impaired comparison watersheds. A regression is then developed between the average Virginia Stream Condition Index (VSCI) scores at each TMDL or comparison monitoring station and the corresponding AllForX ratio for the watersheds contributing to that monitoring site. This regression can be used to quantify the value of AllForX threshold that corresponds to the benthic health threshold (VSCI < 60 indicates impaired benthic community) as shown in the preliminary regression in **Figure 20**. The pollutant TMDL load can then be calculated by applying the AllForX threshold ratio to the all-forested simulated pollutant load of the TMDL study watershed.

Comparison watersheds used in developing the VSCI and AllForX regression should be similar in size and located near the study watershed to minimize differences in flow regime, soils, and other physiographic properties. Additionally, there must be adequate and recent VSCI data for a watershed to be a useful data point. Likewise, several of the impaired watersheds in this TMDL project are not present in the AllForX regression development as they did not meet the threshold of a minimum of three VSCI scores recorded, which was the same threshold used in selecting comparison watersheds. Though not included in the AllForX regression, the use of the AllForX method to determine the target loading rates of these locations still applies to these unused impaired watersheds.

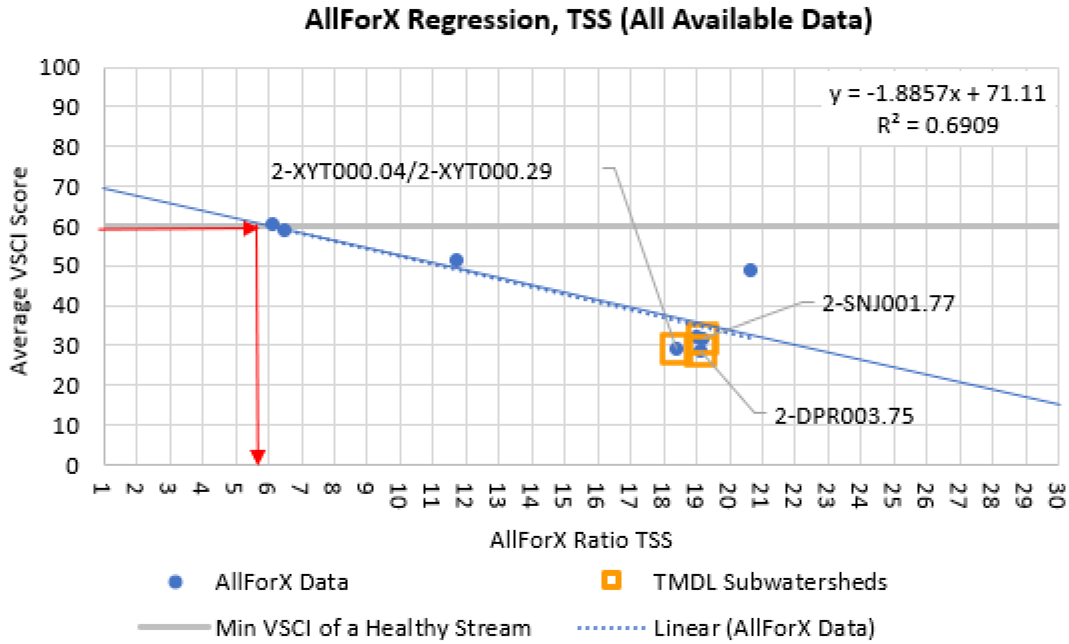

Figure 20. Preliminary TSS AllForX Regression Resulting in a TSS AllForX Target Ratio of 5.9.

Interpreting the AllForX Regression

The Stony Run UT watershed (2-XYT000.04/2-XYT000.29) has an existing sediment load of about 222,237 lb/yr, not including permitted sources. If the entire watershed were forested, this load would only be about 12,099 lb/yr. 222,237 lb/yr divided by 12,099 lb/yr yields an AllForX Ratio of about 18.4. This can be seen by matching the data point labeled "2-XYT000.04/2-XYT000.29" with the x-axis of the regression. The AllForX regression indicates that a VSCI score of 60, which is the expected minimum score of a healthy stream, would equate to the target ratio of 5.9. To achieve this, sediment load would need to be reduced to 71,338 lb/yr, which is a reduction of approximately 67.9%. See **Table 17** for the required reductions of the remaining streams.

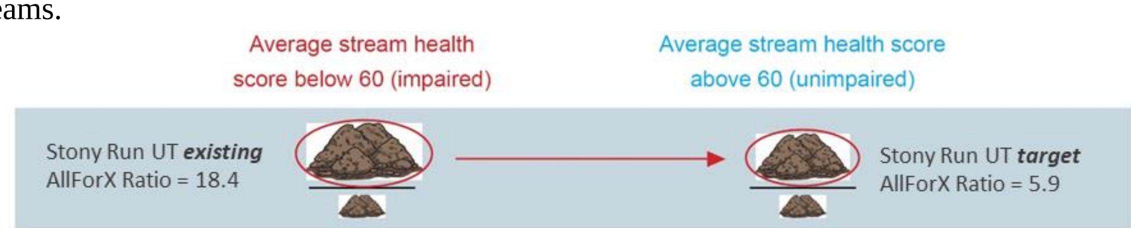

Table 17. Preliminary Target Sediment Reductions.

Impaired Stream	TSS Existing (lb/yr)	TSS AllForest (lb/yr)	TSS Target (lb/yr)	Estimated % Reduction
Upham Brook	13,659,964	372,764	2,196,212	83.9%
North Run	3,723,019	130,428	768,444	79.4%
Jordans Branch	1,686,773	19,991	117,780	93.0%
Deep Run	2,220,451	95,443	562,319	74.7%
Stony Run	537,712	25,262	148,837	72.3%
Stony Run UT	222,237	12,099	71,285	67.9%
Dover Creek	548,999	64,751	381,491	30.5%

A separate regression was developed for phosphorus loads, using the same methodology as the TSS regression, using the average VSCI scores while substituting the AllForX ratios of existing to all-forested phosphorus estimates. The target TP AllForX ratio was determined to be 5.0. Preliminary phosphorus reductions for each TMDL are presented in **Table 18**. The data that was used to create both of the AllForX regressions can be found in **Table 19**.

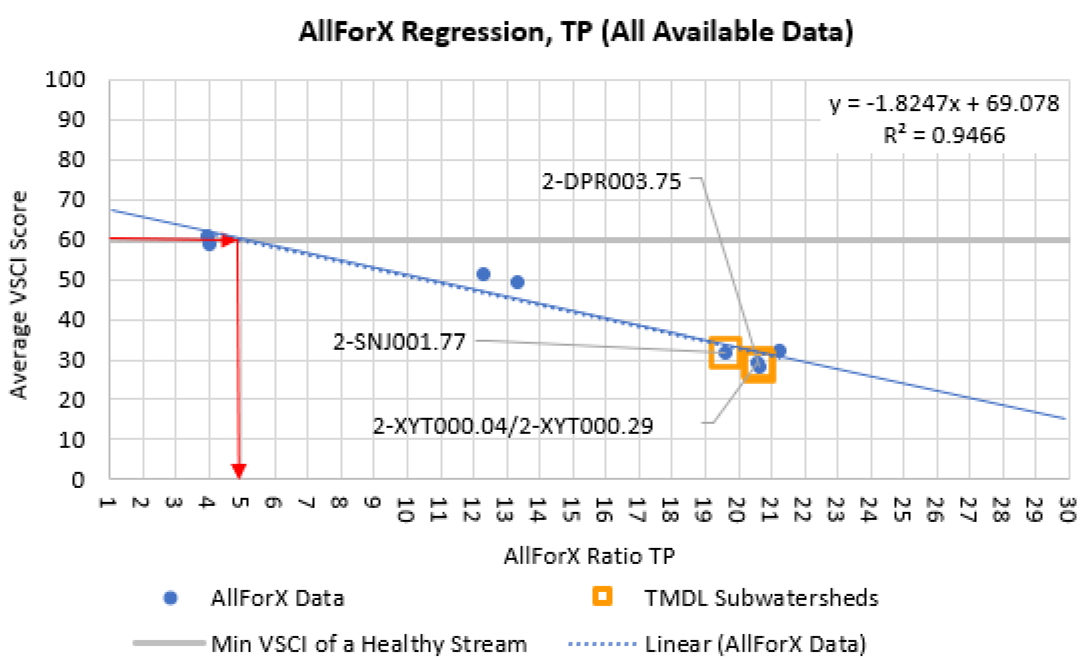

Figure 21. Preliminary TP AllForX Regression Resulting in a TP AllForX Target Ratio of 5.0.

Table 18. Preliminary Target Phosphorus Reductions.

Impaired Stream	TP Existing (lb/yr)	TP AllForest (lb/yr)	TP Target (lb/yr)	Estimated % Reduction
Upham Brook	18,604	904	4,498	75.8%
Stony Run	1,124	63	312	72.3%
Dover Creek	556	110	548	1.4%

Table 19. Summary of VSCI data and Model Data Used in AllForX Regression Development.

Station ID	Average VSCI	TSS (t/yr)	TSS All-Forested (t/yr)	TSS AllForX Ratio	TP (t/yr)	TP All-Forested (t/yr)	TP AllForX Ratio
2-DPR003.75	28.48	345.47	18.07	19.12	1,582.37	76.76	20.62
2-SNJ001.77	31.61	159.52	8.32	19.16	763.63	38.93	19.62
2-XYT000.04/ 2-XYT000.29	29.45	100.81	5.49	18.37	473.08	22.98	20.59
2-PSK006.68	32.03	275.30	14.50	18.99	1,302.03	61.23	21.26
2-PCT002.46	49.09	1,034.32	50.16	20.62	3,929.60	294.87	13.33
2-NUT000.62	51.42	353.07	30.23	11.68	1,453.97	118.52	12.27
2-JOH004.23	60.65	168.64	27.42	6.15	521.98	131.36	3.97
2-FIN000.81	58.81	615.26	95.09	6.47	1,967.94	489.37	4.02

What's next?

Developing Allocation Scenarios

A series of allocation scenarios for sediment and phosphorus in the watersheds will be developed. The scenarios will identify reductions in sediment and phosphorus needed from different sources (e.g. pasture, turfgrass, urban/suburban land) and assign wasteload allocations for the appropriate permitted discharges. Community members will be offered an opportunity to review these scenarios and select an option that makes sense for the community.

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