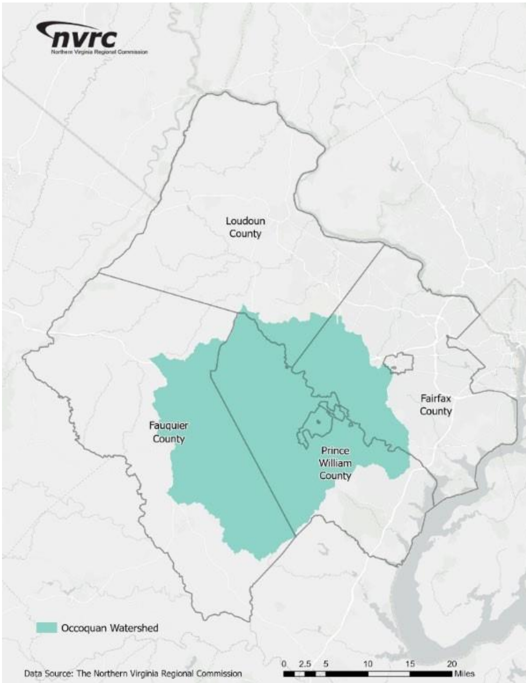
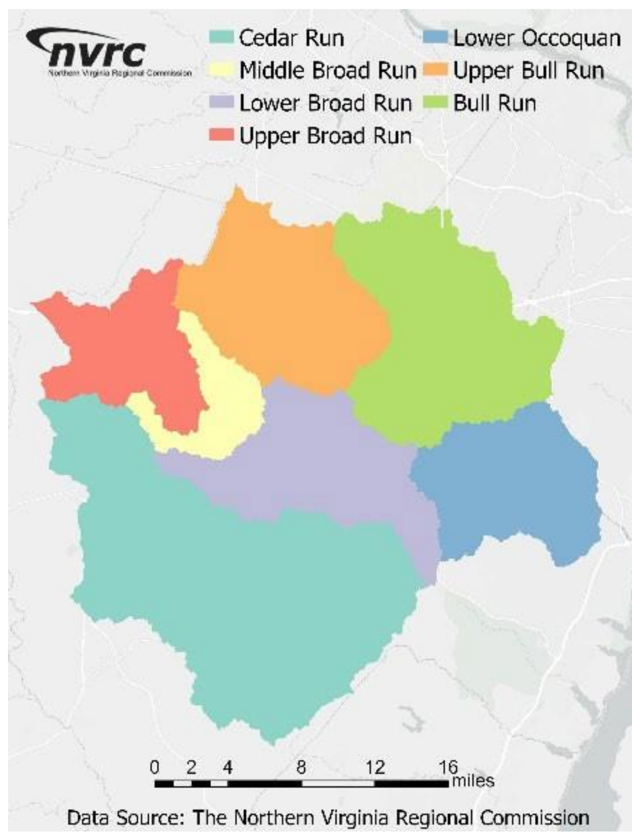
Abbreviated History of the Occoquan Watershed



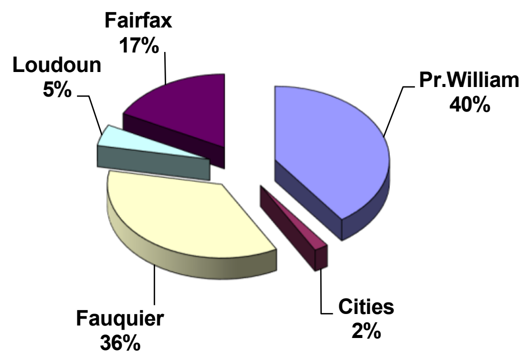
The Occoquan Reservoir serves as one of only two primary drinking water supplies for over 800,000 northern Virginians. The Occoquan Reservoir was developed when the Alexandria Water Company constructed a low head dam in the Occoquan River in 1950 (Ryan's Dam). In 1957, the Upper Occoquan Dam was constructed, increasing the holding capacity of the reservoir to 30,300 acre-feet in order to meet the needs of the burgeoning population of the service area. Ownership of the Occoquan Dam and its related water treatment facilities passed from the Alexandria Water Company to the Fairfax County Water Authority in 1967. In 1980 the dam elevation was increased by two feet, increasing the storage capacity of the reservoir to 33,700 acre-feet (11.2 BG) in order to meet increasing water demand in the Northern Virginia area. The increase in dam elevation increased the maximum reservoir depth to 72 feet and the mean depth to 10.1 feet with a surface area of 1,840 acres.



The basin upstream of the reservoir extends approximately 30 miles in a north-south direction and about 34 miles in an east-west direction encompassing a drainage area of approximately 375 thousand acres. The drainage basin occupies parts of four counties, Fairfax, Prince William, Fauquier, and Loudoun, and the entire land area of two independent cities (Manassas and Manassas Park). The drainage pattern is contained within three major tributaries, Bull Run, the largest tributary from the northwest, Broad Run from the west, and Cedar Run from the Southwest.

The Occoquan Reservoir is unique in several respects. First, it has an unusual configuration, being about 13 miles long with only an average width of less than 0.2 miles. Second it has a relatively small storage capacity for the drainage area served and third, it exists downstream of major urban areas. The northern Virginia area contains approximately 25 percent of the entire population of Virginia. Drinking water reservoirs are typically located in the headwaters of a watershed not downstream.

The relatively long and narrow conformation of the Reservoir tends to make it function as a plug flow system. That is, inflows tend to move through the impoundment in defined parcels with limited longitudinal dispersion, rather than mixing well with previously resident waters. This flow pattern, although generally intact longitudinally, is somewhat disrupted in the vertical dimension during the summer periods of density stratification, when warm waters of lower density overlie cooler, more dense bottom waters. Both these features have some rather important impacts on water quality responses to pollutant loads carried in the inflows.



Percent of Land Area of the Occoquan Watershed

HISTORIC WATER QUALITY ISSUES

Early in the decade of the 1960's, the urban growth began to reach into the upper Occoquan Watershed in unprecedented (and unanticipated) proportions. Coincident with the onset of accelerated population growth, a number of wastewater treatment plants were constructed and/or expanded in western Fairfax County and central Prince William County, resulting in substantial increases in the discharge of domestic wastes to the receiving waters of the Reservoir. By the latter part of the decade of the 1960's, eleven publicly owned treatment works (POTW's) of conventional secondary design were discharging an average of nearly three million gallons per day (MGD) of treated wastewater to the basin. The effluent quality was quite variable, and no provisions were made for the removal of nutrients from the discharges.

In addition, the percentage of urban land uses began to increase substantially, raising the input of urban stormwater into the system. Increased conventional agricultural activity in the western basin, along with the application of chemical fertilizers, resulted in greater soil erosion, and the accompanying loss of nutrients in surface runoff.

By the mid to late 1960's, with less than a decade of use as a raw water supply, the consequences of the changes in basin activity were readily apparent in the Occoquan Reservoir, resulting in:

- Massive algal blooms (including blue-greens) due to oversupply of nutrients
- Periodic episodes of taste and odor problems in the finished drinking water
- Shortened filter runs due to clogging during periods of high algal growth
- Periodic fish kills due to oxygen depletion during periods of algal respiration
- Rapid hypolimnetic deoxygenation due to the accumulation of organic material in the reservoir sediments.

Because the Occoquan Reservoir had already become an irreplaceable resource for the citizens of Northern Virginia, it was apparent that steps were required to insure the long-term viability of the reservoir as a public water supply. In 1968, the Virginia State Water Control Board (SWCB) commissioned a study of the Reservoir and its tributary streams (Metcalf and Eddy, 1969), with the goal of developing a management plan for the surface waters of the basin. That study, completed in 1970, stated that the reservoir was "highly eutrophic...", and further, that "the sewage plant effluents are mainly responsible for the advanced stage of eutrophication occurring..." The report concluded with the recommendation that three alternatives be considered for future management of water quality in the reservoir:

- Wastewaters from the basin be exported to another watershed.
- Advanced wastewater treatment practices be adopted; treated waters be exported for re-use, and basin population be limited.
- Advance wastewater treatment practices be adopted with effluents remaining in the watershed, and basin population be limited to 100,000.

THE *OCCOQUAN POLICY*

After considering the recommendations of the Metcalf and Eddy report, in July of 1971, the SWCB adopted "A Policy for Waste Treatment and Water Quality Management in the Occoquan Watershed" (VSWCB, 1971). Recognizing the practical limitations imposed by both the inter-basin transport of wastewaters and the imposition of population limitations, the *Occoquan Policy*, as it has come to be known, was based on a modification of the third option shown above. A milestone in water quality management in the Commonwealth of Virginia, the *Policy* included an implicit recognition that an indirect re-use of treated wastewater would become the operational norm in the Occoquan Basin. It also recognized that extraordinary measures would be required to protect the public health in a situation where a water body was to be subjected to the competing uses of wastewater disposal and public water supply. In addressing this, the document not only specified the type of waste treatment practice to be adopted on a basin-wide scale, but it provided for an ongoing program of water quality surveillance to quantify the success of the water quality protection effort.

NONPOINT SOURCE MANAGEMENT

In 1976 the then Northern Virginia Planning District Commission (NVPDC) conducted a Section 208 study for the Occoquan Watershed as part of a larger Washington Metropolitan Area '208' plan being conducted by the Washington Metropolitan Council of Governments. Further water quality research within the Occoquan Watershed, following the Metcalf and Eddy Report, indicated that in addition to the point source discharges impacting the reservoir, diffuse nonpoint source loads from urban development and agricultural development was also significantly impacting reservoir water quality. As a result of the '208' planning study, a Policy for Nonpoint Pollution Management in the Occoquan River Basin was included in the Washington Metropolitan Area '208' Plan adopted in 1978.

In accordance with this section of the '208' Plan, NVPDC coordinated the development of a multi-jurisdictional Nonpoint Pollution Management Program to supplement the benefits of the watershed's new advanced wastewater treatment plant. These efforts culminated in the establishment of the formalized interjurisdictional Occoquan Basin Nonpoint Pollution Management Program in February 1982. This regional Program formed a permanent vehicle for the necessary management of nonpoint source pollution in the Occoquan Watershed.

The Program is unique among watershed management cooperative agreements within the nation in that it is supported financially not only by the jurisdictions that use the reservoir as a water supply and recreational facility, but also by a major jurisdiction (Fauquier County) that drains into the reservoir but does not use it as a drinking water supply. Fifty percent of the program is additionally supported by two public drinking water Authorities and a private corporation that withdraws or wholesale purchases water from the Reservoir (Fairfax Water, Prince William Service Authority and Virginia American Water Corporation.

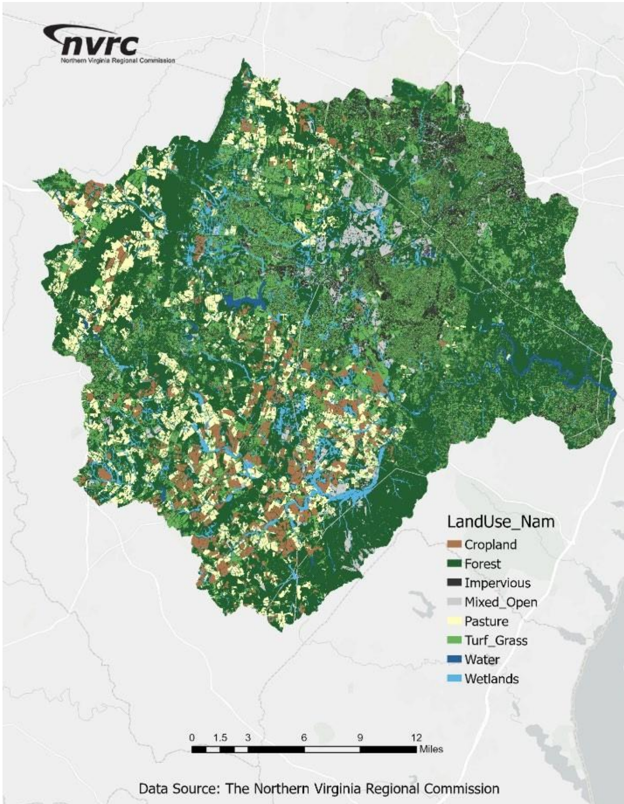
Local governments are kept abreast of regulatory changes and help shape through guidance and consensus building stormwater management policy and regulations at the federal, state and local levels through the Program support. Staff has served, and continues to serve, on many technical and policy advisory committees on behalf of the regions local governments. A couple of recent examples include a USEPA Advocacy Review Panel for a upcoming federal stormwater rulemaking, Chairman of the USEPA Chesapeake Bay Program's Urban Stormwater Workgroup, numerous Virginia DEQ Advisory Committees, and Virginia's Chesapeake Bay Watershed Implementation Plan Advisory Group.

Over the years the program has also supported or undertaken some of the nation's groundbreaking research in the area of urban stormwater management and continues the development and implementation of cost-effective nonpoint pollution mitigation techniques during the various stages of urbanization, so that the risk of irreversible water quality degradation and/or the need for costly remedial control measures at some later date is minimized.

Through the programs publications such as the Occoquan BMP Handbook, the Northern Virginia BMP Handbook, the Northern Virginia Nonstructural Urban BMP Handbook and the Northern Virginia Low Impact Development Handbook have been developed. The Handbook(s) have been adopted or referenced in all northern Virginia local government public facility manuals and are utilized by the development community. NVRC staff is also discussing the potential need to reconstitute some of these manuals in light of the proposed changes to the Virginia Runoff Reduction Method (VRRM) and other DEQ stormwater policy.

LAND USE DEVELOPMENT

The Occoquan Watershed is characterized by low, rolling hills interspaced by steep-sloped gorges within which lie Civil War battlefields, regional parks, rural farms, and urban concentrations. The topography is conducive to suburban development, thus, during the late 1950's and 1960's the land use evolved from one of an agricultural economy, based on beef and dairy cattle and cash crops of tobacco and corn, to one of primarily large tract developments of single and multiple family housing units.



Through the 1970s to present day, an unprecedented amount of urbanization and population growth occurred in Northern Virginia. Commercial and light industrial development has since followed. In areas where development occurs, much of the land becomes impervious surface. The amount of impervious surface contributes greatly to increasing the velocity and volume of runoff.

During storm events, water runs off impervious surfaces, picks up pollutants, and washes them directly into local streams. Additionally, uncontrolled urban runoff can lead to erosion of topsoil and undercutting of stream banks. Due to the relationship of land use and nonpoint source pollution, land use tracking has become a routine and important aspect of managing the Occoquan Watershed.

Land use tracking began in the late 1970's when a series of satellite images for the watershed were translated and transferred, by hand, to a mylar map. Subsequent map updates (1979, 1984, 1989) were obtained by revising the mylar map based upon visual interpretations of high altitude photographs (HAPs) Over time, more accurate data and updated technology has become available and NVRC's land use tracking methodology has changed along with it. For the 2015 land use update, NVRC utilized the Chesapeake Bay 2013/2014 1-meter Resolution Land Use Dataset (2013/2014 1m LU) which is composed of 17 land use classes in Virginia. To create the 2013/2014 1m LU dataset, the Chesapeake Conservancy High-Resolution Land Cover dataset was modified using 13 ancillary datasets including data on zoning, land use, parcel boundaries, landfills, floodplains, and wetlands. The Chesapeake Bay High-Resolution Land Cover Project was created for the Chesapeake Bay Program by the Chesapeake Conservancy's Conservation Innovation Center in partnership with the University of Vermont and WorldView Solutions, Inc and is currently utilized within the Chesapeake Bay Watershed Phase 6 Model framework.

RESULTS OF THE 2015 OCCOQUAN LAND USE UPDATE

The results of the 2015 update are presented in a number of different ways in Tables 5 through 8. The majority of the watershed, 84% is pervious and 93% of Upper Broad Run is pervious (Table 5). About 43% of the watershed is classified as forest (Table 7). And the two counties with the majority of forest in the watershed are Fauquier County with about 40% and Prince William with about 38% (Table 8). The average impervious surface for the watershed has increased to 10% with Bull Run leading the Basin at 24% imperviousness (Table 5). This is of particular concern given that water quality tends to decline as the percentage of impervious cover in a watershed increases and 10% impervious is considered to be the accepted threshold where watershed and water quality impacts begin to become significant.

Table 5. Acres and Percentages of Land Use Class in Watershed by Basin in 2015

		Impervious	Pervious	Wetland	Water
Upper Bull Run	**Acres**	3,741	43,362	3,266	351
	%	7	85	6	1
Bull Run	**Acres**	16,112	48,137	1,204	429
	%	24	73	2	1
Lower Occoquan	**Acres**	4,633	33,897	769	1,431
	%	11	83	2	4
Upper Broad Run	**Acres**	704	29,218	1,266	239
	%	2	93	4	1
Middle Broad Run	**Acres**	1,205	12,096	1,360	898
	%	8	78	9	6
Lower Broad Run	**Acres**	6,274	37,125	2,870	489
	%	13	79	6	1
Cedar Run	**Acres**	3,747	110,896	8,344	950
	%	3	89	7	1
Total	**Acres**	36,416	314,731	19,078	4,788
	%	10	84	5	1

Table 6. Acres of Land Use Classes in Watershed by Jurisdiction in 2015

Land Use	Fairfax	Loudoun	Fauquier	Manassas	Prince William	Manassas Park	Watershed Total
Impervious	11,347	2,933	4,386	2,394	14,781	581	36,421
Water	922	146	1,146	41	2,531	1	4,788
Wetlands	1,487	271	6,421	65	10,832	2	19,078
Forest	28,640	6,486	65,343	334	61,093	144	162,040
Turf Grass	17,740	4,375	18,629	3,359	36,239	814	81,156
Mixed Open	4,834	934	3,144	173	8,114	72	17,271
Cropland	0	794	12,263	0	6,165	0	19,221
Pasture	9	1,129	23,282	0	10,648	0	35,068
Total	64,980	17,068	134,613	6,366	150,404	1,613	375,043

Table 7. Percent of County Land in the Watershed in 2015

Land Use	Fairfax	Loudoun	Fauquier	Manassas	Prince William	Manassas Park	Watershed Total
Impervious	17.5%	17.2%	3.3%	37.6%	9.8%	36.0%	9.7%
Water	1.4%	0.9%	0.9%	0.6%	1.7%	0.1%	1.3%
Wetlands	2.3%	1.6%	4.8%	1.0%	7.2%	0.1%	5.1%
Forest	44.1%	38.0%	48.5%	5.2%	40.6%	8.9%	43.2%
Turf Grass	27.3%	25.6%	13.8%	52.8%	24.1%	50.4%	21.6%
Mixed Open	7.4%	5.5%	2.3%	2.7%	5.4%	4.5%	4.6%
Cropland	0.0%	4.7%	9.1%	0.0%	4.1%	0.0%	5.1%
Pasture	0.0%	6.6%	17.3%	0.0%	7.1%	0.0%	9.4%

Table 8. Percent of Watershed Land Use Class by Jurisdiction in 2015

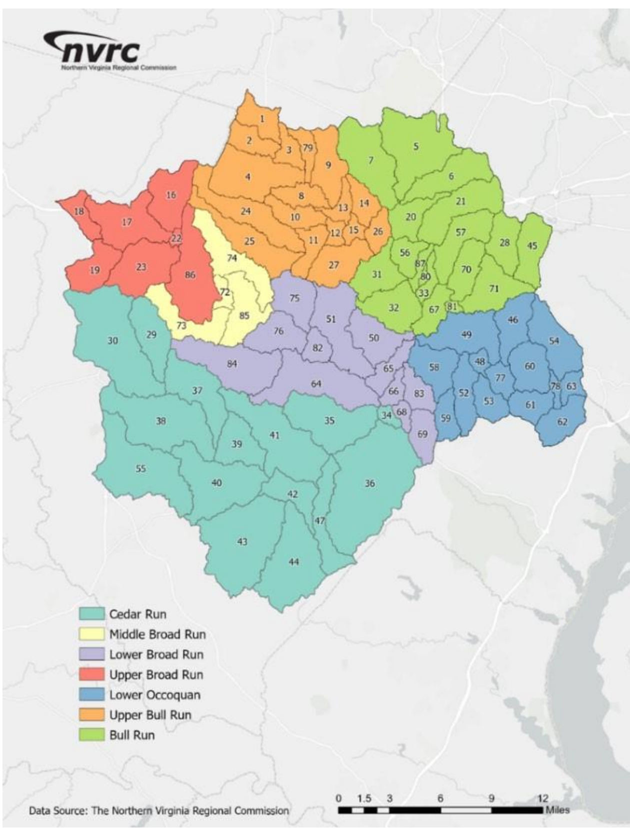
Land Use	Fairfax	Loudoun	Fauquier	Manassas	Prince William	Manassas Park
Impervious	31.2%	8.1%	12.0%	6.6%	40.6%	1.6%
Water	19.3%	3.1%	23.9%	0.9%	52.9%	0.0%
Wetlands	7.8%	1.4%	33.7%	0.3%	56.8%	0.0%
Forest	17.7%	4.0%	40.3%	0.2%	37.7%P	0.1%
Turf Grass	21.9%	5.4%	23.0%	4.1%	44.7%	1.0%
Mixed Open	28.0%	5.4%	18.2%	1.0%	47.0%	0.4%
Cropland	0.0%	4.1%	63.8%	0.0%	32.1%	0.0%
Pasture	0.0%	3.2%	66.4%	0.0%	30.4%	0.0%

OCCOQUAN WATERSHED AND RESERVOIR MODEL

Modeling refers to the application of an analytical tool that applies mathematical equations to represent and predict the natural processes within watersheds and waterbodies. Rainfall-runoff models intend to depict the hydrological processes within a watershed. They depict how the precipitation is transferred into surface flow, interflow and groundwater flow. Receiving water quality models describe the transport and fate of water quality constituents in the receiving waterbodies, such as rivers, streams and reservoirs. They simulate the phenomena such as lake stratification, dissolved oxygen (DO) sag and eutrophication. Hybrid models on the other hand integrate the rainfall-runoff model and the receiving water quality model into one package and reflect the integral nature by describing a watershed and downstream receiving waterbodies as a complete unit. Both point source and nonpoint source pollution are considered.

The Occoquan Modeling efforts can be traced back to the late 1970s when the digital revolution made mathematical simulation possible for a complex natural system. In 1978, the mainframe model, named Occoquan Basin Computer Model, was developed from Hydrocomp Simulation Programming (HSP) and Nonpoint Source Model (NPS). The modified HSP simulated hydrological processes while NPS estimated sediment erosion and other nonpoint source loads. Later, receiving water sub-models were added to represent Lake Manassas and Occoquan Reservoir as two-layer lakes. After the UOSA Advanced Wastewater Treatment plant went into operation, the model was further modified in 1982 to account for the impact of UOSA. The discharge from UOSA was represented as a point source in the model. The model had several successful applications including the landmark Fairfax County court case "Occoquan Basin Downzoning" in 1985.

In 1994, a PC (personal computer) version of the Occoquan model was proposed to replace the mainframe model to provide an up-to-date defensible tool to review future conditions and the consequent requirements that may be indicated. The improvement included two parts. First, after a review of watershed models available in the public domain, HSPF was proposed to replace NPS/HSP as the pollutant loading and transport model. Second, a more complex hydrodynamic reservoir model, CE-QUAL-W2 (W2), was proposed to replace the simple two-layer single-segment reservoir model for the Reservoir. The applications of these models were linked in a serial manner. The overall objective was to improve mathematical representation of the watershed and thus to enhance the accuracy of reservoir responses to alternative control strategies. This modeling effort was completed in 2003.



Starting in 2004, more improvements were implemented into the framework. Firstly, W2 was applied to fully represent the characteristics of Lake Manassas. As a further improvement, the watershed and waterbodies have been represented at finer scales. The Occoquan Reservoir is now modeled using four branches and 69 longitudinal segments in CE-QUAL-W2. Branch-1 is the mainstream of the reservoir, starting from Occoquan River close to Lake Jackson and extends all the way up to the dam. Branch-2 is the Bull Run Arm, discharging Bull Run watershed and UOSA-WRF to the mainstream of the reservoir. Branch-3 and Branch-4 are Sandy and Hooes Run, respectively, which are small tributaries.

Finer watershed and waterbody segmentations were adopted to allow better representation of the hydrologic and hydrodynamic activities. With the 2010 Land Use update the number of segments for the watershed increased from 56 (2005) to the current 87 segments. This additional segmentation was facilitated by an increase in the number of rainfall monitoring sites distributed throughout the watershed and the higher resolution digital elevation models (DEMs).

Besides the Fairfax County Downzoning, the Occoquan Model has been used to support many other notable policies including:

- UOSA Facility Expansions
- UOSA Nitrification/Denitrification Reservoir Operational Rules
- Waiver of ChesBay Wastewater Requirements for UOSA
- Reservoir Safe-Yield Determinations for DEQ and Fairfax Water
- Lake Manassas Golf Courses
- Cedar Run Bacterial Total Maximum Daily Load (TMDL)
- Micron Expansion – Salinization Impacts
- Simple Climate Change Assessment and other various Watershed Scenarios

While the current Occoquan Model framework is extremely robust, history does repeat itself. The current model framework was developed after support for the Mainframe NPS/HSP version ended. NVRC along with the consulting firm of GKY, Inc. performed a rigorous "state of the art" model review in 1994 prior to the development of the current model framework. A subset of Occoquan Policy Board recommendations regarding the model framework include:

- It is important that the model be continuously validated, updated and improved.
- The parameters required for the model must be applicable to the watershed, current condition and concerns and represent it accurately.
- The model should be easily adaptable to future technological advances.

Unfortunately support and continued development of HSPF by USEPA/USACE has ended as Version 12.4 (pre-release April 2014) was never publicly released despite continuous statements that it would be. Portions of HSPF were migrated to "EPA BASINS" however the latest release of that software package itself dates back to 2019. Therefore, in order to continue to fulfill the Programs directives from the Policy Board, the Occoquan Program will need to select and develop a new modeling framework.

Recent policy and monitoring developments within the sphere of emerging contaminants will also require the development of a new framework. The current HSPF model has limited support at best for salinity and no support for contaminants such as PFOA/PFOS. Both salinity and PFOA/PFOS have been identified as a significant concern with respect to the Occoquan as a drinking water reservoir.

Much of the modeling limitations have been noted lately as a result of the change in leadership at the Occoquan Monitoring Laboratory with the passing of Dr. Adil Godrej and assumption of duties by Dr. Stanley Grant and the request by Prince William County to evaluate several development projects. In October 2022, the Occoquan TAC met to review the Prince William County's Board of County Supervisor's request that the Occoquan Model be run to examine a number of land use changes within Prince William County for possible impacts to the Occoquan Reservoir in the near future. By unanimous consent the Occoquan TAC agreed that in order to get a more accurate picture as to the Reservoir's water quality condition in the near future, the land use analysis <u>should be expanded to the entirety of the reservoir</u> and not focus solely on

Prince William County. The Commission, Virginia Tech and the Modeling Subcommittee were charged with developing a work plan and budget to undertake this effort.

On May 30, 2023 the Modeling Subcommittee to the Occoquan TAC met to review and to receive a presentation on the Work Plan and Budget for this future land use analysis by Virginia Tech. The Modeling Subcommittee subsequently approved the Work Plan and Budget unanimously and recommended that it be presented to the Occoquan Policy Board Members (the CAOs) for approval and funding. This land use analysis will need to be funded separately from the FY24 Occoquan Program contributions as it greatly exceeds the available resources that the Program has budgeted. Virginia Tech's budget for the effort is a request for an additional $176,000. The Modeling Subcommittee further recommended that the cost for this effort be split by the Program Partnership utilizing the same formula that the annual fiscal year budget is developed with: 50% by the watershed jurisdictions and 50% by the three water purveyors.