Commonwealth of Virginia

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January 13, 2022

It is with great pleasure that I present the 2020 State Water Resources Plan ("2020 State Plan"). The 2020 State Plan builds upon the foundation of the 2015 State Plan, the first comprehensive water resources plan developed in Virginia. The State Plan is developed based on information provided by Virginia's counties, cities, and towns in response to the Water Supply Planning Regulation (9 VAC 25-280). Local and regional water supply plans covering every locality in the Commonwealth were developed through the efforts of planning districts, localities, water utilities, industries, agriculture, state agencies and interested citizens. The water supply plans include information about their existing water use and sources of supply, future projections of population and water demand, anticipated water supply deficits, potential sources of future water supply, and current efforts to use water efficiently.

The 2020 State Plan makes several significant advances in data management and analysis, modeling, scope, and presentation. It includes several new surface water cumulative impact analysis model scenarios including an evaluation of impacts to streamflow from climate change. It also includes new metrics and 20 distinct regional analyses based on the river basins in Virginia (see Appendix A). The goal of this analysis is to provide Virginians more information about how current and future water demands, and a changing climate, may impact future water supply, aquatic life, and other beneficial uses. It offers the opportunity for all stakeholders to reinvest in the discussion on how Virginia's water resources can best be managed.

The 2020 State Plan was advertised for public comment from June 28, 2021 to September 13, 2021 and 14 comments were received. DEQ appreciates the time and effort it took to provide comments. Several changes were made to the State Plan itself based on the feedback received. A summary of the comments received and agency responses are included as Appendix D to the Plan. The Plan is available on the DEQ web site under DEQ State Water Resources Plan.

DEQ has begun planning a process to actively communicate the 2020 State Plan's findings across the Commonwealth. DEQ will provide more information on efforts to meet with local and regional planning partners as soon as possible. Meetings will be prioritized based upon areas where 2040 projected water needs are clustered, multiple potential risks are anticipated, and a deficit in water supply is predicted by 2040. Planning partners that believe they might benefit from a more

detailed discussion of their Cumulative Impact Analysis or in the evaluation of water supply alternatives are encouraged to contact DEQ to express their interest in being included in the prioritization.

The Plan will be subject to incremental revision at five-year intervals as DEQ, localities, and other stakeholders provide input through ongoing water supply planning efforts. Changes to the Local and Regional Water Supply Planning Regulation may have some bearing on this timeline and process going forward however. Legislation enacted following the 2020 General Assembly Session (2020 Va. Acts Ch. 1105) requires the State Water Control Board (SWCB), among other things, to adopt regulations designating regional planning areas based primarily on river basins, and requires localities to participate in cross-jurisdictional, coordinated water resource planning through the development of a single water supply plan for each regional planning area. This significant change to the Local and Regional Water Supply Planning Regulation may impact localities and water users, but also offers an opportunity to strengthen water supply planning in Virginia. A regulatory advisory panel has been convened and is in the process of working with DEQ to develop proposed amendments to address the changes to the statute.

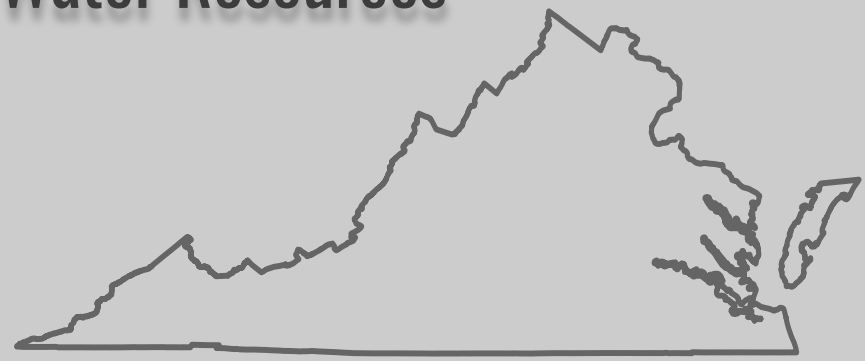
DEQ would like to thank everyone who participated in the development of the local and regional water supply plans, and other state agency staff from the Department of Health, Department of Conservation and Recreation, Marine Resources Commission, Department of Historic Resources, and Department of Wildlife Resources (formerly Department of Game and Inland Fisheries).

Sincerely,

David K. Paylor
Director

Virginia State Water Resources Plan

A Report of Virginia's Water Resources



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⋆ Preface

The 2020 State Water Resources Plan (State Plan) builds upon the foundation of the 2015 State Plan, the first comprehensive water resources plan developed in Virginia. However, this effort makes several significant advances in data management and analysis, modeling, scope, and presentation. Virginia has a history of water resources planning and the State Plan in many respects is a synthesis of those efforts. It is a comprehensive plan that incorporates information from 48 local and regional water supply plans, water withdrawal reporting and more into a single document. This information is used to conduct a cumulative impact analysis of surface water and groundwater use in Virginia. The goal of this analysis is to provide Virginians more information about how current and future water demands, and a changing climate, may impact future water supply, aquatic life, and other beneficial uses. It offers the opportunity for all stakeholders to reinvest in the discussion on how Virginia's water resources can best be managed.

The main text of the State Plan focuses on state wide analysis but water resources planning also requires a regional perspective. Appendix A provides 20 distinct regional analyses based around Virginia's river basins. In each, the reader will find localized water source and demand information, modeling results, and a summary of the key trends identified by DEQ. The State Plan also outlines DEQ's major management efforts since 2015, and identifies some potential priorities for the coming years. The State Plan is updated every five years following the review and update of local and regional plans.

Claytor Dam, Pulaski County VA.
Photograph by Joseph Kleiner, DEQ.

⋆ Acknowledgements

The State Plan is possible because of the time, effort, and expertise of many people and organizations throughout the Commonwealth of Virginia. The Virginia Department of Environmental Quality (DEQ) would like to thank everyone who participated in the development of the Local and Regional Water Supply Plans, Annual Water Withdrawal Reporting, and the 2020 State Plan update.

DEQ would also like to acknowledge the assistance from the Water Supply Plan Advisory Committee, which provided a final report that included guidance relevant to drafting both the 2015 and 2020 State Plan. Also, DEQ would like to thank the members of the original Water Policy Technical Advisory Committee (WP-TAC) that assisted in writing the Water Supply Planning Regulation in 2005.

Further appreciation goes to the following Virginia state agencies, which provided review and evaluation of the Local and Regional Water Supply Plans: Department of Health, Department of Conservation and Recreation, Marine Resources Commission, Department of Historic Resources, and Department of Wildlife Resources. DEQ also thanks the many individuals and organizations that have assisted in developing the science and tools that make the State Plan possible, particularly the United States Geological Survey and Virginia Polytechnic Institute and State University (Virginia Tech).

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⋆ Executive Summary

Virginia is commonly described as a water rich state, but it also has a large and growing population with significant water needs. Virginia has a long history of water resources planning and that history includes evidence that proactive management is necessary to ensure the long-term sustainability of water resources for water supply, as well as for other beneficial uses such as aquatic life and recreation.

Many Virginians remember the 2001-2002 drought, which in no small part led to the creation of the Water Supply Planning Program. This event made clear that even in a state with significant water resources, a severe drought can put at risk one of the basic services on which the public depends. The decline in groundwater levels in the Coastal Plain Aquifer System likewise shows that even one of the most significant and productive aquifer systems in the country has a limit beyond which withdrawals will impact the long-term sustainability of the source.

These two lessons alone encourage a proactive approach to water resources management and the State Water Resources Plan (State Plan) is in many respects a product of that. The 2020 State Plan builds upon the foundation of the 2015 State Plan, the first comprehensive water resources plan developed in Virginia. However, this effort makes several significant advances in data management and analysis, modeling, scope, and presentation. It incorporates information from 48 local and regional water supply plans, water withdrawal reporting, and more into a single document.

This information allows the Department of Environmental Quality (DEQ) to complete a cumulative impact analysis (CIA) of surface water and groundwater use in Virginia. The goal of this analysis is to provide Virginians more information about how current and future water demands, a changing climate, and other factors may impact future water supply, aquatic life, and other beneficial uses. It addresses not only the existing challenges for Virginia in terms of water resources, but also those that may be coming in the near future. Perhaps most importantly, it offers an opportunity for all stakeholders to reinvest in the critical discussion on how Virginia's water resources can best be managed.

The 2020 State Plan consists of five main chapters and several appendices that will be described briefly here.

Chapter 1 provides an overview of water resources management policy in Virginia. This chapter covers major legislation and regulations that pertain to the programs managed by DEQ as well as other state agencies involved in water supply management in Virginia.

Chapter 2 provides a brief overview of Virginia's natural resources. It is intended to provide basic information on Virginia's climate, geology, hydrology, and hydrogeology that may be helpful in understanding the CIA completed for the State Plan.

Chapter 3 collates and synthesizes key data from local and regional water supply plans and water withdrawal reporting to describe in broad strokes the current and future estimated water demands within the Commonwealth, as well as trends in the numbers and types of sources and demands.

Chapter 4 provides a CIA of current and future demands for surface water (statewide) and groundwater (within the Eastern Virginia and Eastern Shore Groundwater Management Areas) based on the information provided in water supply plans and otherwise.

Chapter 5 provides an overview of the major initiatives and accomplishments in water resources management achieved within the last five years, concluding with a discussion on upcoming priorities and challenges.

The 2020 State Plan includes statewide analysis of both demands and impacts to surface water and groundwater resources. However, water resource planning is not most effective when approached from a statewide scale, or even a major river basin scale. Water resources are shared and often many users within a river basin use the same source. Their needs impact one another. One of the major intentions of the Local and Regional Water Supply Planning regulation is to drive increased regional planning that is focused around shared sources.

The 2020 State Plan also includes Appendix A, which provides 20 distinct regional analyses completed at the minor basin scale.[1] This critical appendix will be useful to localities that want a finer resolution analysis on the regional demands and impacts that are

[1] Virginia is divided along hydrologic boundaries into 20 sub-basin units, referred to as "Minor Basins." Minor Basins vary in size from around 900 mi^2 to 6,000 mi^2 and roughly contain 1-3 HUC 8 units each.

most relevant to them. Each of these twenty analyses are intended as a starting point for a larger conversation with localities to assist them in making use of the results of these evaluations.

The following sections summarize the key findings from the State Plan and provide links to relevant sections to allow a more detailed review to those interested.

Current and Future Statewide Water Demands:

Water demand information used in the State Plan was submitted by localities through water supply plans and collected through annual water withdrawal reporting, and water withdrawal permit reporting. Virginia's estimated 2020 (current) daily demand is approximately 1,582 million gallons per day (MGD) or 1.58 billion gallons per day, when excluding power generation. Including power generation, total current demand is approximately 6,229 MGD. A comparison of these two numbers makes clear that power generation facilities are by far the largest withdrawals in Virginia. However, most of these power generation facilities return the vast majority of their demand to the source; meaning much of the demand is non-consumptive. Virginia's two nuclear power plants, North Anna Nuclear Power Plant and Surry Nuclear Power Plant, are good examples of this. All demands in water supply plans and thus the State Plan are organized into one of four categories:

- A Community Water System (CWS) is a municipal or non-municipal water system that serves at least 15 service connections year round or regularly serve 25 year round residents, and is regulated by the Virginia Department of Health's Waterworks Regulation (12VAC5-590).
- A Large Self-Supplied User (Large SSU) is a self-supplied user of more than 300,000 gallons per month of surface water or groundwater for non-agricultural uses, including but not limited to commercial, manufacturing, mining, and hydropower.
- A Small Self-Supplied User (Small SSU) is a residence or business that is self-supplied by individual wells withdrawing less than 300,000 gallons of groundwater per month. These demands are provided as locality-wide estimates of use.
- An Agricultural Self-Supplied User (AG) is an agricultural operation that uses more than 300,000 gallons of surface water or groundwater per month for irrigation or non-irrigation purposes. These demands can represent individual facilities or locality-wide estimates.

CWS facilities make up 59% of current (2020) estimated demands when excluding power generation. In addition, Small SSU demands from domestic or private wells make up an additional 9%; in other words, 68% of non-power demands are for domestic or municipal water purposes.

Community Water Systems make up nearly 60% of current water demands statewide when excluding power generation.

Large SSU demand, which includes industrial/commercial use not met by a CWS, among other types of users, makes up around 26% of current demands. Only around 5% of current demand is estimated for AG use. Virginia has a long history as a significant agricultural producer, although AG demand in the state has fallen as land-use and demographics have changed. Virginia also enjoys a climate where irrigation is not required for all types of crops so the necessity of irrigation is site and region dependent. Nevertheless, AG demand may actually be higher than estimated here, as many planning programs noted challenges in identifying, requesting, and receiving information about current and future water use from agricultural facilities.

Table 1: Summary of Virginia Water Demand by Source Type and System Type (excluding Power Generation)

System Type	Source Count	2020 Demand (MGD)	2030 Demand (MGD)	2040 Demand (MGD)	20 Year Percent Change
Surface Water					
Agriculture	456	75.73	77.94	80.15	5.83
CWS	208	884.22	991.25	1098.28	24.21
Large SSU	328	343.47	356.76	370.05	7.74
Small SSU	N/A	0.00	0.00	0.00	0.00
Total SW	**992**	**1303.42**	**1425.95**	**1548.48**	**18.80**
Groundwater					
Agriculture	500	9.52	9.96	10.41	9.32
CWS	1387	56.57	80.11	103.65	83.23
Large SSU	657	75.51	76.72	77.92	3.19
Small SSU	N/A	137.82	156.25	174.69	26.75
Total GW	**2544**	**279.42**	**323.04**	**366.67**	**31.23**
Total (SW + GW)					
Agriculture	956	85.25	87.91	90.56	6.22
CWS	1595	940.78	1071.35	1201.93	27.76
Large SSU	985	418.98	433.47	447.97	6.92
Small SSU	N/A	137.82	156.25	174.69	26.75
Virginia	**3536**	**1582.83**	**1748.98**	**1915.15**	**21.00**

* Small SSU demands are county-wide estimates of private well usage below 300,000 gallons a month. The number of private wells is not known.

Table 1 summarizes current (2020) and future (2040) water use by use category and by source type (surface water or groundwater) while excluding largely non-consumptive power generation withdrawals. In Virginia, surface water continues to meet the majority of the Commonwealth's needs, with 82% of total demands coming from surface water sources. The proportion of demands for each use category differs between surface water and groundwater sources.

For instance, Small SSUs (estimated private/domestic groundwater), make up 49% of total groundwater demands, while the remainder of total groundwater demand is made up largely of CWS and Large SSU demands. This is indicative of the significant impact that individual homeowner wells can have cumulatively on groundwater resources in particular. In comparison, CWS demands make up more than 65% of total surface water demands, and over 90% of all CWS demand is met by surface water. Some sizeable municipal systems in the Eastern Virginia Groundwater Management Area rely on groundwater due to limited surface water availability. However, in general, major CWS systems rely on surface water, while smaller systems and domestic users generally rely on groundwater. In many cases this is because groundwater in general is a less costly source type due to different treatment and infrastructure needs. Large SSU and AG demands make up the remainder of surface water demand.

When excluding power generation, **total water demand in Virginia** is projected to increase 21% from 1,582 MGD to 1,915 MGD between 2020 and 2040.

The vast majority of the projected demand increases in Virginia are from CWS facilities, which alone make up more than 260 MGD of the projected increase. Increasing population drives increasing water demands, and it is primarily in the urban/suburban areas of Virginia where most population growth is expected. As noted previously, larger CWS users are primarily surface water supplied, so it is also true that increasing surface water demands will supply the majority of these CWS-related increases.

Small SSU demand from private well and residential users is entirely groundwater supplied, but also driven by increasing population. These can be found in both rural and suburban areas. Therefore, increases in Small SSU demand are more widespread. In total, Small SSU demand is projected to increase by 37 MGD between 2020 and 2040, or more than 25%. AG and Large SSU demands are not projected to increase significantly. Large SSU facilities such as factories, or commercial operations, often are already at full build-out and do not necessarily increase in water demand as population does. Some Large SSU facilities did provide estimates of increased growth, with most of those projected increases coming from surface water. Some localities also projected increasing Large SSU demands based on the expectation of new facilities being developed by 2040. As with the current AG use estimates, it is unclear if the insignificant projected increases in AG demands are indicative of actual trends, or the challenge of collecting information on how agricultural use is expected to change over the next twenty years. Detailed information on current and future demands statewide can be found in Chapter 3.

Executive Summary Continues on Next Page

Cumulative Impact Analysis Results - Surface Water:

One of the major purposes of the State Plan is to use Virginia's water demands to help answer questions about the long-term sustainability of water resources, both in terms of future water supply and maintaining sufficient flow to protect other beneficial uses. A CIA of surface water impacts was completed statewide for all non-tidal rivers using both current (2020) and future (2040) demands as reported in local and regional water supply plans. The State Plan is intended to be a tool for proactive planning, so this effort also includes new scenarios that look at the potential for future climate impacts, as well as the potential for impacts from surface water users that are exempt from the requirement for a VWP permit according to Va. Code § 62.1-44.15:22 B.[2] The State Plan also includes multiple streamflow metrics to evaluate each scenario. The executive summary will primarily focus on the 30 day low flow[3], which represents a short-term or acute drought. Each of the surface water CIA scenarios, metrics, and the results are discussed in detail in Chapter 4, but the following section summarizes key trends.

Demand Scenarios: Total water demand excluding power generation is projected to increase 21% statewide from around 1.58 billion gallons per day to 1.91 billion gallons per day between 2020 and 2040. About 245 MGD of the total 333 MGD projected increase in statewide demand is from surface water sources. Figure 1 compares the 30 day low flow between the 2020 and 2040 demand scenarios. The figure shows the percentage change between the 2020 and the 2040 demand scenarios in each river segment. Generally, only minor (<10%) reductions were simulated in the 30 day low flow in the majority of river basins compared to the 2020 demand scenario, although moderate to major reductions are simulated in some areas, particularly headwater watersheds and areas with large demands and limited reservoir storage. Examples include portions of the Shenandoah, Roanoke, Meherrin, and York basins.

The lack of widespread streamflow reductions when comparing 2020 to 2040 does not mean that short and long-term drought flows in the 2020 scenario in some parts of the state are not already sufficiently low enough to impact water supply and other beneficial uses. Rather, comparing streamflows between the 2020 scenario and the 2040 scenario does not suggest major reductions driven by demand increases for most of Virginia.

The **2040 Demand Scenario** does not suggest major reductions in streamflow driven by projected demand increases for most of Virginia. However, even in the 2020 demand scenario, drought flows suggest the potential for impacts to water supply and other beneficial uses in some parts of the state, particularly in headwater streams and regions that lack storage.

The limited impacts as a result of increasing demands is in some part due to the success of planning and resource management, particularly as it relates to developing storage and diverse sources. Areas with the most projected growth in demands also tend to be those areas that have taken a regional approach to planning and source development. Pump storage projects such as Henrico County's Cobb's Creek Reservoir, or interconnected networks of reservoirs operated by Rivanna Water and Sewer, demonstrate that increasing demands can be met through adequate storage while limiting impacts to streamflow. The 2018 water supply plan compliance process also resulted in revised projections for some localities, and in many cases projections were revised to a lower amount than originally submitted. Each year new VWP permits are issued, which increases the amount of water that is withdrawn in compliance with permits that include instream flow requirements.

However, it is important to acknowledge that streamflows during critical drought periods are already impacting beneficial uses, including water supply, in some parts of Virginia, particularly in headwaters of streams and rivers and in areas with limited storage. The 2020 State Plan includes a new metric called

[2] Va. Code § 62.1-44.15:22 B

[3] The 30 day low flow describes the lowest consecutive 30 day average daily streamflow over the simulation period. This metric is a representation of a short-term, or acute drought. To learn more about the flow metrics used in the State Plan, see Chapter 4, Section 4.2.7

[4] "Potential Unmet Demand" is the portion of surface water demand for a specific facility that is limited by available streamflow as simulated in a given model scenario, including any known operational limits such as flow-by requirements. This unmet

"Potential Unmet Demand"[4] that is calculated for each facility during a modeling scenario and is useful in identifying areas where this is the case. This metric is discussed in more detail in Chapter 4. In short, nearly 10% of facilities modeled statewide have unmet demand of some amount in the 2020 demand scenario. The total potential unmet demand is more than 160 MGD statewide in the 2020 demand scenario, increasing to 229 MGD in the 2040 demand scenario. It is critical to understand where demand is not being met in these simulations as this will be helpful in understanding where supply challenges may already be likely.

A summary of potential unmet demand is provided for each minor basin in Appendix A. However, the 2020 State Plan also includes an appendix of all data used for the CIA modeling and analysis, which allows for evaluation of the raw streamflow results for each metric and scenario for any non-tidal river segment in Virginia. These data will be useful for localities as they take the next steps in developing local and regional water supply plans. These data can also be used in project scale evaluations.

DEQ is planning to offer **outreach opportunities to interested stakeholders** that would like to use the State Plan and the results of the CIA to better understand and address their own local and regional planning challenges.

Detailed results on the surface water demand scenarios at statewide scale can be found in Chapter 4, Section 4.2.8.1, or in Appendix A at minor basin scale.

30 Day Low Flow (Percent Change 2020 to 2040)

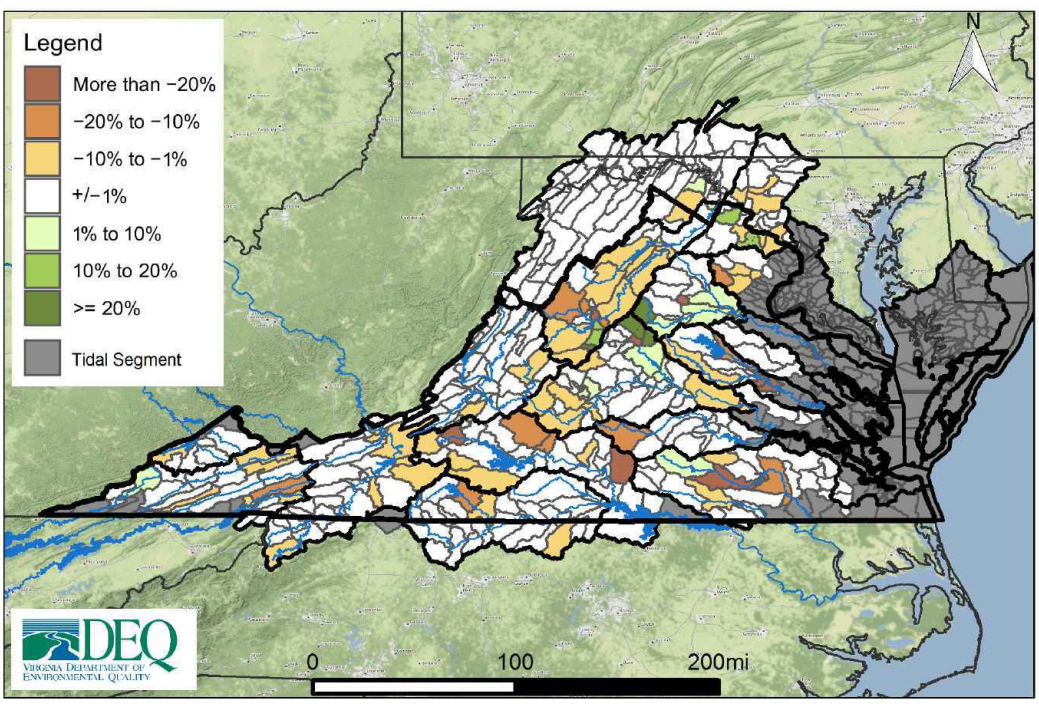


Figure 1: Change in 30 Day Low Flow between the 2020 and 2040 Demand Scenarios

demand, if realized, could be managed through water conservation, alternative sources, operational changes, or from available storage. Absent of these or other options, this portion of demand could remain unmet.

Climate Change Scenarios: The scientific consensus is that worldwide climate is changing in response to greenhouse gas emissions. Climate modeling has been completed by the United States Geological Survey (USGS) and the Chesapeake Bay Program to better understand how these changes may impact the Commonwealth of Virginia.[5] Global climate models nearly unanimously project Virginia to have continued increases in temperature over the next century; the extent of those increases depends primarily on the magnitude of greenhouse gas emissions.

Drought in Virginia is driven largely by the difference between annual rainfall and evaporation. Extreme droughts in most Virginia streams are the result of a combination of low rainfall during winter, which leads to depleted "base flows", combined with low summer rainfall and/or high summer evaporation.[6]

> Temperature increases observed over the last 30 years have already **increased evaporation throughout Virginia**. Although climate change will likely mean increased total rainfall, this additional evaporation means future droughts may be more severe than those experienced in the past.

While there is little uncertainty about the likelihood of increased evaporation, the effect of future temperature increases on future rainfall trends in Virginia is less clear. The three climate change scenarios included in the State Plan use precipitation and evaporation inputs drawn from a set of three different climate change models selected by the USGS and Chesapeake Bay Program modeling team. These scenarios vary from low to high in their total precipitation and evaporation changes, and are referred to as the "Dry", "Median", and "Wet" climate scenarios (more details can be found in section 4.2.3). Note that because climate data was only available for areas within the Chesapeake Bay Watershed, climate modeling could not be completed at this time in the "Southern Rivers" portion of Virginia that does not drain to the Chesapeake Bay.

The Dry climate scenario represents the greatest risk to instream and offstream beneficial uses, as it reflects a scenario where precipitation is reduced by an average of three inches per year compared to current conditions. It's important to recognize that the temperature and rainfall pattern changes that were simulated in the climate change scenarios are all within a reasonable bound based on the predictions of the best available global climate models of increasing atmospheric CO_2. These analyses show what may happen to streamflow should these meteorological conditions occur, particularly during drought periods. Because of the limits to climate model resolution, these results should not be viewed as predictions that a given river section or facility will be impacted as simulated; they are most useful as a basin level planning tool that can support the development of adaptive management strategies based on different combinations of future rainfall and temperature changes as predicted by the best available global climate models.

Figure 2 compares the 30 day low flow between the dry climate scenario (which includes 2040 demands) and the 2020 demand scenario which uses current meteorology. Streamflow reductions in this scenario are driven primarily by the meteorological inputs (precipitation, temperature, evapotranspiration), but do include projected 2040 demand. In contrast to the results for the 2040 demand scenario discussed earlier, reductions in short-term drought flows of at least 20% are simulated in nearly all non-tidal river segments in the James, Potomac, Rappahannock, and York river basins. When recalling the substantial impacts of the 2001-2002 drought in Virginia, any potential for more severe droughts must be taken seriously.

> In practical terms, under the meteorological conditions used in the Dry climate scenario, **streamflows could be 20% or more lower during a short-term drought** when compared to the same drought experienced under current temperatures and precipitation.

All stakeholders including state and local government, water authorities, and individual water users will need to take steps to incorporate these kinds of analyses into resource planning efforts. At minimum, climate change suggests that Virginia has the potential to experience droughts that are more severe than those experienced in the past. Even if such events are rare, it will become increasingly important that water supply planning occur at a scale that facilitates a regional evaluation of sources and demand, as well as evaluating regional opportunities for diversifying sources, developing storage, and building interconnections and redundancy where possible among neighboring systems. Detailed results on the three climate change scenarios can be found in Chapter 4, Section 4.2.8.2.

[5] See [Bhatt, 2019]
[6] See [Austin, 2014]

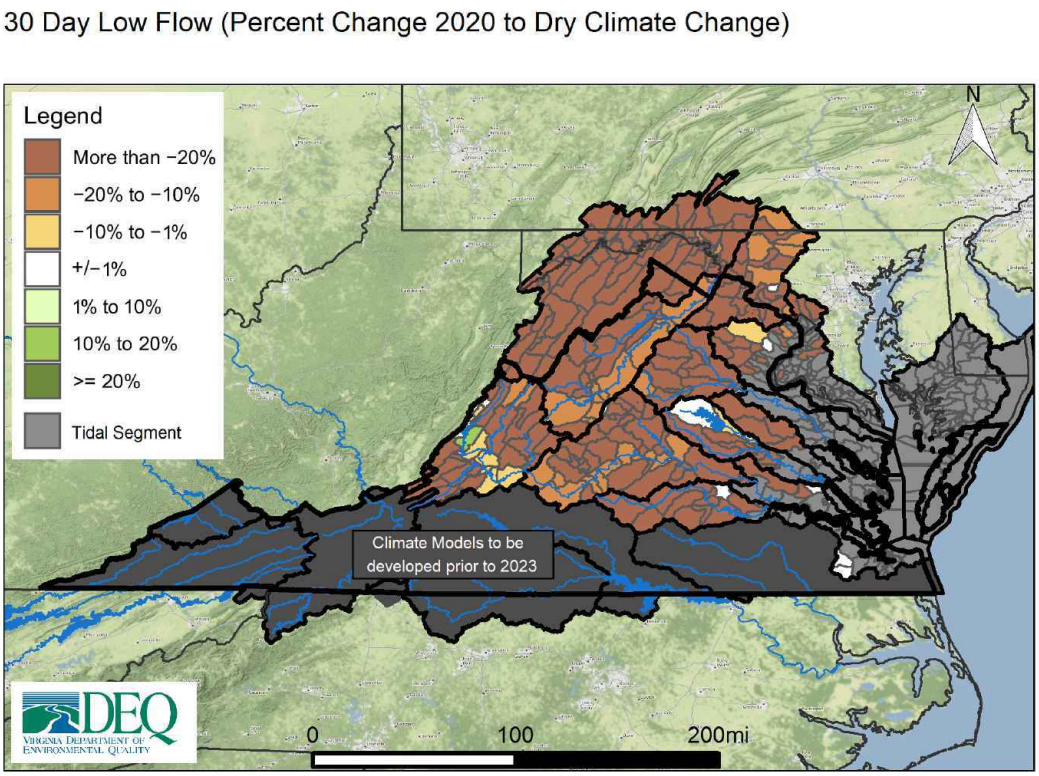


Figure 2: Change in 30 day low flow between current climate/demand scenario and the dry climate/2040 demand scenario

Exempt Surface Water User Scenario: Exempt and unpermitted surface water withdrawals made up approximately 75% of total reported surface water withdrawals in 2019.[7] Exempt in this context means a surface water facility meets one of the exemption criteria in Va. Code § 62.1-44.15:22 B.[8] or in 9VAC25-210-310 A. One of the challenges in evaluating impacts from exempt facilities is that multiple types of data are cited when asserting a claim to withdraw water without triggering the requirement for a VWP permit; claims are commonly based on values such as the capacity of the intake or the safe yield of the source. There is considerable variation across these values for any given facility, and this variation only increases when evaluating the cumulative impact of a stream with multiple exempt users.

One of the outcomes of the 2020 State Plan was an effort by DEQ to collect and compile potential exempt values for exempt surface water users.The scenario uses the largest value from: 1) VDH Waterworks Operations permits issued for the facility; 2) information supplied by the user with the estimated maximum capacity of the intake structure in place as of July 1, 1989; 3) the maximum annual water withdrawal reported prior to July 1, 1989; or 4) the maximum annual water withdrawal reported after July 1, 1989.

These data informed the exempt user scenario, which evaluates impacts to streamflows based on the cumulative maximum possible exempt demand for all such users in addition to any permitted demands within a basin. In order to effectively manage surface water resources and address the uncertainty related to these demands, DEQ determined the most conservative, or maximum possible, demand should be evaluated in this scenario. However, DEQ does not agree that the maximum values used in this scenario represent an allocation for, or the expectation of, a future withdrawal of that volume; nor does DEQ concede that any particular exempt user is necessarily entitled to withdraw any particular maximum value used in this scenario. The exempt user scenario is the first such effort to quantify potential cumulative impacts to beneficial uses from potential exempt demands.

Figure 3 compares the 30 day low flow (short-term drought) in the exempt user scenario with the 30 day low flow from the 2020 demand scenario. The simulated exempt demands reduce short-term drought flows in many river segments across Virginia by more than 20% compared to a short-term drought under current (2020) demands. Some streams or rivers that have particularly large or multiple exempt withdrawals in close vicinity experience simulated reductions in the 30 day low flow of 90% or more, including instances where simulated drought flows are reduced to zero in this scenario. More specific discussions of these simulated impacts can be found at the minor basin scale in Appendix A.

In summary, the results from the exempt user scenario suggest that the **cumulative maximum possible exempt demands** for exempt surface water users would exceed the available water budget in many of Virginia's streams and rivers.

The exempt user scenario does not suggest that any specific exempt user is proposing to operate at these maximum possible exempt demands, but provides a necessary reference point to understand the potential impacts should they do so. Were these demands to be realized, many surface water users, exempt or not, would be unable to meet their demand due to significant reductions in streamflow. Substantial impacts to other beneficial uses, such as aquatic life, waste assimilative capacity, and recreation, are also likely based on the simulated reductions in streamflow. As a whole, it underscores the importance of evaluating potential exempt demands cumulatively and in the context of the available regional water resources, particularly when these amounts exceed the available water budget for a source. More information on the exempt scenario can be found in Chapter 4, Section 4.2.5, while the full statewide results of the scenario can be found in Chapter 4, Section 4.2.8.3.

[7] "2019 Annual Report on the Status of Virginia's Water Resources."
[8] Va. Code § 62.1-44.15:22 B

30 Day Low Flow (Percent Change 2020 to Exempt Users)

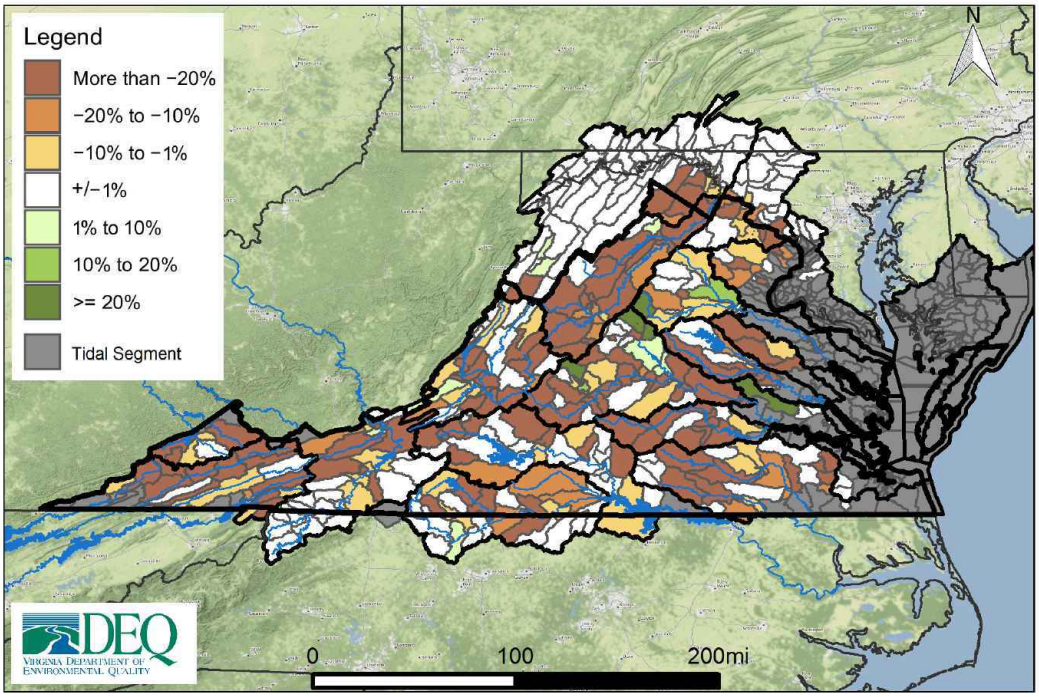


Figure 3: Change in 30 Day Low Flow between 2020 and Exempt Demand Scenarios

Impacts to Aquatic Life: The 2020 State Plan introduced two new components that will be important to evaluating impacts to aquatic life in the future: the overall change in flow (consumptive use) metric, and the elfgen framework[9], which together can be used to evaluate potential impacts to species richness as a result of flow reductions.

The overall change in flow metric describes how much water is removed from a stream or river by withdrawals and not returned. This is often described as consumptive use, but this metric evaluates this cumulatively in a watershed. Reduction of the overall flow in a stream can impact aquatic life through the loss of habitat and ultimately therefore reducing species richness.[10] The elfgen framework allows the quantification of potential species loss resulting from flow change, and may offer an improved understanding of the variability of risks to aquatic life due to geographic location, stream size and local scale.

Statewide evaluation using the elfgen framework showed that overall flow change in the 2040 demand scenario results in only a few areas with significant risks to species richness. In general, consumptive use in all scenarios was highest below impoundments which regulate releases downstream of the dam, particularly those that are unpermitted and have no minimum release requirement. Other areas of concern include smaller headwater streams which also showed an elevated risk of species loss.

The exempt user scenario results in higher consumptive use due to the higher total withdrawals in the scenario, and this increases the extent of the risk to species richness when applying the elfgen framework.

> This represents the first implementation of this framework for **evaluating the potential for impacts to aquatic life** from withdrawals. More work is needed to define and implement procedures for the use of this framework in a resource management context.

More details on the elfgen framework and the results from this new form of analysis can be found in Chapter 4, Section 4.2.8.4.

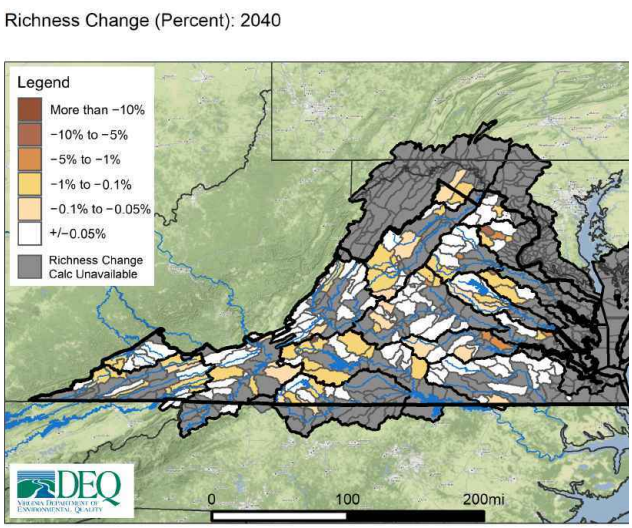


Figure 4: Richness Change as a Percent for 2040 Demand Scenario

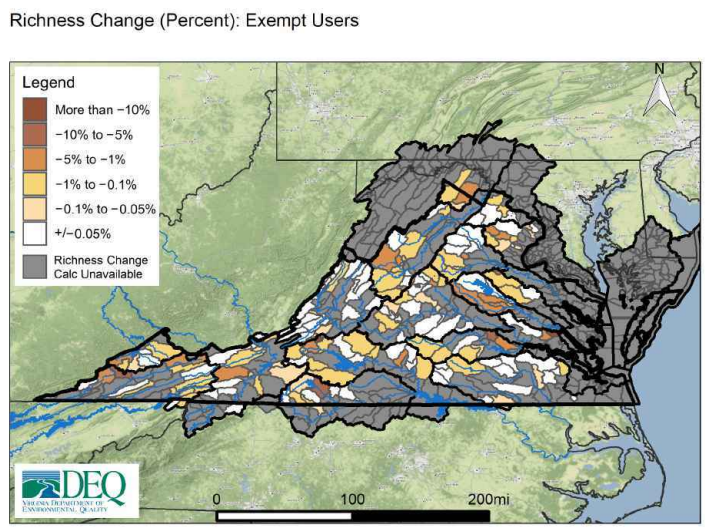


Figure 5: Richness Change as a Percent for Exempt User Scenario

[9]The elfgen framework is a new methodology and tool set for characterizing relations between streamflow and aquatic organism species richness. This methodology builds on existing minimum instream flow approaches and is part of an evolving approach to managing environmental flows for aquatic life. The elfgen framework was developed as a cooperative project between DEQ, the USGS, and Virginia Tech.

[10]Species richness is the number of different species represented in an ecological community, landscape or region.

Cumulative Impact Analysis - Groundwater:

Groundwater CIA modeling was also completed in the Eastern Virginia Groundwater Management Area (EVGMA) and Eastern Shore Groundwater Management Area (ESGMA). For each management area, 2020 and 2040 demand scenarios were developed based on demand projections submitted by localities in water supply plans. These scenarios also took a novel approach of estimating domestic groundwater use using Small SSU demand projections and existing information on the distribution of domestic wells. Simulation of chloride concentration changes were also completed for the ESGMA.

Eastern Virginia Groundwater Management Area: In the Virginia Coastal Plain, the 2040 demand scenario results in a widespread increase in the number of critical cells[11] in areas with existing critical cells, and therefore an increasing potential for challenges in meeting regulatory criteria for groundwater withdrawal permit issuance in these areas, and generally for large withdrawals (greater than 1-2 MGD) anywhere in the Coastal Plain.

The **number of critical cells in the Potomac Aquifer** at the end of the fifty year water supply plan demand simulation increased from 177 in the 2020 demand scenario to 608 in the 2040 demand scenario.

It's important to note that the increased number of critical cells in the 2040 scenario is not primarily driven by permitted use. Individual domestic well use is on the rise, and these scenarios simulate this increased demand on the aquifer based on the estimates for each locality in water supply plans. DEQ has worked with the largest permitted users in the EVGMA to reduce the total permitted withdrawals from the Potomac Aquifer, but groundwater withdrawals below 300,000 gallons in a month are not regulated by DEQ.

An additional scenario that simulated injections of treated water into the Potomac Aquifer from the Hampton Roads Sanitation District's Sustainable Water Initiative for Tomorrow (SWIFT) project shows promise in increasing water levels, but more data are needed to evaluate how the actual rate of recovery compares to the model. It remains crucial that groundwater users in the Coastal Plain continue to take a regional planning approach, evaluate and implement alternative sources, and continue to improve water conservation to reduce groundwater demand overall. Detailed results and figures for these scenarios for the Eastern Virginia Management Area can be found in Chapter 4, Section 4.3.3.

Eastern Shore Groundwater Management Area: The Eastern Shore is projected to see moderate increases in groundwater demand between 2020 and 2040. However, the majority of that demand is projected for CWS facilities. Accomack and Northampton counties are projected to decrease in population by 20% and 15% respectively. As a result, demand for Small SSU, or domestic groundwater use, is projected to decrease by around 10% by 2040, and this results in decreased domestic pumping rates in the 2040 demand scenario when compared to the 2020 demand scenario.

Groundwater demands are projected to increase around 1 MGD on the Eastern Shore, with those demands primarily associated with permitted facilities in areas of existing demand concentration rather than dispersed more generally through domestic demand increases. On the Eastern Shore, 2040 demand projections are not significantly higher than 2020 demands, and therefore the impacts to water levels in the 2040 scenario are not substantially different in comparison to current demands.

In the **Eastern Shore Groundwater Management Area**, water levels are not simulated to fall below the critical surface in either the 2020 or 2040 demand scenario in the Upper, Middle, or Lower Yorktown-Eastover Aquifers.

[11] Critical cells are model cells where simulated water levels are at or below the threshold set by the Groundwater Withdrawal Regulations. New or existing withdrawals that create new critical cells or whose impacts intersect existing critical cells may not be able to receive a permit.

[12] The "Total Permitted Scenario" is a groundwater CIA modeling scenario used in all groundwater withdrawal permit applications in a groundwater management area. It evaluates the cumulative permit limits for all permitted facilities in conjunction with estimates for unpermitted use including private wells.

Despite the minimal impacts seen in the 2040 Demand Scenario, the 2019 Total Permitted scenario[12] completed for groundwater withdrawal permit applications on the Eastern Shore has shown simulated water levels nearing the critical surface in the vicinity of two poultry processing plants, which are the largest withdrawals in the region. New or increasing groundwater demands in these areas may face challenges meeting the regulatory criteria for issuance of a groundwater withdrawal permit.

Simulations of chloride concentration changes in the 2040 scenario compared to the 2019 Total Permitted showed the potential for increasing chlorides in areas with existing elevated chloride concentrations, primarily near the Town of Cape Charles and Captain's Cove. This reflects the potential for increasing chloride concentrations in these areas if growth were to align with the projections in the regional water supply plan. Agricultural use is also growing, driven in part by an increase in the number of poultry farms. This growth is not fully captured in the water supply plans at this point and is therefore not fully captured in these scenarios.

These results as a whole suggest that developing alternative water supply sources is as important on the Eastern Shore as in the EVGMA, although the options are limited. Investigation of the surficial aquifer as a supplement to the Yorktown-Eastover aquifer system is a promising option, particularly for agricultural use. The surficial aquifer recharges from precipitation at much higher rates than the confined aquifers below it, and therefore any use that can be placed on the surficial will be more sustainable long-term. Desalinization may be a viable option for larger systems, although that would likely require a regional partnership due to the cost of desalinization. The location and extent of demand growth in the next twenty years will ultimately determine where these measures may be most necessary. Surface water from dug ponds and other types of surface water impoundments can be an effective alternative to groundwater for agricultural water use.

Detailed results of these scenarios for the Eastern Shore Management Area can be found in Chapter 4, Section 4.3.5.

Looking Forward:

The State Plan is intended to be an instrument to assist in proactive resource management; it is intended as a means to look forward. Another common theme throughout is that water resources management is at its best when it is collaborative, or when it involves a variety of stakeholders. The individual interests of those who work in and around Virginia's waters may not align entirely, but the goal of ensuring the long-term sustainability of these vital resources may well be unanimous, even if the rationale or means of getting there are not. Transparency is key to having a meaningful conversation among all these parties about the challenges facing Virginia.

Chapter 5 identifies the efforts DEQ has taken in recent years to address these challenges. The "Annual Report on the Status of Virginia's Water Resources" provides similar updates with additional detail on an annual basis. In Chapter 5, Section 5.2, DEQ identifies items that are expected to take priority, based on the information in this plan and elsewhere. By raising these priorities here, DEQ expects that they will become a larger part of the conversation in coming years.

It is beyond the scope of an executive summary to cover all of the priorities in detail, but a brief description of each is provided below with more information presented in Section 5.2.

Amendments to Local and Regional Water Supply Planning Regulations: One of the objectives of the Local and Regional Water Supply Planning program is to establish a process that facilitates cross-jurisdictional planning that takes into consideration a cumulative understanding of shared water resources within a given region. In practice, the extent to which cross-jurisdictional planning for water supply has been implemented has varied across the state and from locality to locality.

Legislation enacted following the 2020 General Assembly Session (2020 Va. Acts Ch. 1105) requires the State Water Control Board (SWCB), among other things, to adopt regulations designating regional planning areas based primarily on river basins, and requires localities to participate in cross-jurisdictional, coordinated water resource planning through the development of a single water supply plan for each regional planning area. This significant change to the Local and Regional Water Supply Planning Regulation may impact localities and water users, but also offers an opportunity to strengthen water supply planning in Virginia.

A Notice of Intended Regulatory Action (NOIRA) was published in June, 2021. A Regulatory Advisory Panel (RAP) made up of a variety of stakeholders will be used to develop recommended regulation amendments for SWCB consideration through the collaborative approach of regulatory negotiation and consensus.

Evaluating Impacts from Unpermitted Water Users: Evaluating and addressing impacts from water users that are exempt from the requirement to obtain a withdrawal permit, or otherwise unpermitted, continues to be a challenge in managing both surface water and groundwater.

The **exempt user surface water CIA scenario** shows that when evaluated cumulatively, and even in some cases individually, many exempt user demands are not sustainable during drought conditions regularly experienced in Virginia today.

A process for incorporating the evaluation of exempt user demands into the VWP withdrawal permit application review process needs to be developed.

The proportion of groundwater use that is exempt from permitting, or otherwise unpermitted, although smaller in absolute terms than exempt surface water demands, is more difficult to estimate since much of it comes from domestic wells with no requirement to report withdrawals. DEQ has worked with USGS to improve estimates of domestic groundwater use historically and these estimates contribute to the total pumping used for groundwater modeling. DEQ continues to make incremental progress on this need as resources and authority allow. The groundwater scenarios completed for the 2020 State Plan represent an additional approach in estimating domestic use based on water supply plan projections that account for the local expectations of growth (see Chapter 4, Section 4.3).

Climate Change and Resource Planning: The simulated meteorological conditions used in the climate change scenarios discussed previously are all

within the range of outcomes from climate ensemble models in Virginia. Simulated streamflow reductions during both short-term and long-term drought flows suggest the potential for droughts to become more severe, even if they remain uncommon. Planning at regional and local levels should begin to evaluate how that may impact water supply long-term. State level management must also consider the potential for impacts to other beneficial uses, aquatic life in particular. Developing a process for incorporating the evaluation of climate change into existing management actions including permitting and water supply plan development and review is increasingly necessary.

Expanding the coverage of climate change scenarios to include the **"Southern Rivers" portion of Virginia** located outside the Chesapeake Bay watershed is necessary to provide this important analysis statewide.

Evaluating Tidal Fresh Surface Water Withdrawals: Groundwater limitations in the Coastal Plain have led water users to consider alternatives that they previously considered to be cost prohibitive. Recently, several applications for the construction of tidal fresh surface water withdrawal intakes have been received and are under review by DEQ. Examples have been proposed in the Rappahannock, Pamunkey, Chickahominy, and Appomattox rivers. The water quality in a tidal system is dynamic and the amount of available freshwater can improve or reduce local water quality. Reducing freshwater inflows into a tidal system can shift the gradient where low salinity and high salinity water combine further upstream.

DEQ's non-tidal model was not designed to model water quality changes in a tidal system. Given the growing interest in tidal fresh withdrawals, developing an in-house model to evaluate water quality impacts from upstream withdrawals would allow evaluations comparable to those completed for non-tidal projects. Additional funding would be required to support this development. In addition, developing procedures for both modeling and evaluating tidal fresh withdrawal projects will be necessary to ensure a consistent and clear application review process.

Eastern Virginia Groundwater Management Area - Long-term Supply: One of the long running challenges that DEQ has worked to address is the historic over allocation of groundwater from the Coastal Plain aquifer system, particularly from the Potomac Aquifer. A long-term decline in water levels required DEQ to take several actions described in Chapter 5, including negotiating an average reduction of 52% in permit withdrawal limits for the largest groundwater users in the EVGMA. As actual use has dropped as well, water levels in the Potomac Aquifer have begun to stabilize in some areas of the Coastal Plain. However, despite reductions in permit limits, increasing domestic and other unpermitted groundwater use still results in areas of the Potomac Aquifer where water levels are simulated to fall below the critical surface, particularly along the fall-line and in the Southern Virginia Piedmont region.

DEQ expects continued challenges in issuing both new and existing groundwater withdrawal permits in some parts of the EVGMA.

This is a long-term issue that will require an adaptive approach that regularly reviews existing management strategies, incorporates new data, and where necessary revises and implements new strategies. No single strategy is likely to solve this issue. The reconvening of the Eastern Virginia Groundwater Management Advisory Committee[13] will provide a forum to continue investigating ways to improve management of groundwater in Eastern Virginia. Recent successes in reducing water use and the HRSD SWIFT pilot program offer good reasons for cautious optimism, but there is more work ahead for DEQ and the many stakeholders that are invested in solving this issue.

Funding Challenges: DEQ commits significant staffing and financial resources to ensure the programs discussed throughout the State Plan are supported by current data and science. Over time, these programs have grown more complex as regulations have changed and new responsibilities have been added. Often programs have had to find ways to manage new responsibilities without additional funding for staffing or technical services. Additional staffing and funding remains a critical need.

Conclusion: The State Water Resources Plan is intended to be a continual development and planning process. DEQ's goal is for it to be less a large document published at five year intervals, and more of a reflection of an ongoing process to ensure that the

[13] Eastern Virginia Groundwater Advisory Committee - DEQ Webpage

waters of the state continue to provide adequate water supply and other beneficial uses for all Virginians, even in the face of changing conditions. DEQ is working to develop new ways to share the results of the State Plan in ways that localities and the public can make efficient use of it to answer questions about Virginia's water resources.

DEQ has developed new ways to simulate the complex inputs and outputs in Virginia's surface and groundwater resource systems, visualize effects on these systems, make trade-offs among beneficial water uses more transparent, and provide the underlying data to those that want to build on the analysis. At the same time, greater local government use of VAHydro as a tool for planning can mean reduced overall costs to planning programs, and provides a means to keep data sets more current than in the past. Each of these aspects brings the State Plan closer to being the tool it is intended to be, and DEQ looks forward to continuing this work well after publication.

⋆ Acronyms and Abbreviations

AG: Agricultural Self-Supplied Users

ALF: August Low Flow

CBIC: Chesapeake Bay Impact Crater

CBP: Chesapeake Bay Program

CIA: Cumulative Impact Analysis

CU: Consumptive Use

CWA: Clean Water Act

CWS: Community Water System

DCR: Virginia Department of Conservation and Recreation

DEQ: Virginia Department of Environmental Quality

DHR: Virginia Department of Historic Resources

DMR: Discharge Monitoring Report

DMTF: Virginia Drought Monitoring Task Force

DWR: Virginia Department of Wildlife Resources

FERC: Federal Energy Regulatory Commission

EVGMA: Eastern Virginia Groundwater Management Area

ESGMA: Eastern Shore Groundwater Management Area

GWMA: Groundwater Management Area

GWPP: Groundwater Withdrawal Permitting Program

HSPF: Hydrologic Simulation Program FORTRAN

HUC: Hydrologic Unit Code

ICPRB: Interstate Commission on the Potomac River Basin

IFIM: Instream Flow Incremental Method
Large SSU: Large Self-Supplied User

MGD: Million Gallons per Day

MGY: Million Gallons per Year

NLCD: National Land Cover Database

NOAA: National Oceanic and Atmospheric Administration

NOIRA: Notice of Intended Regulatory Action

NPDES: National Pollutant Discharge Elimination System

NWS: National Weather Service

ORSANCO: Ohio River Valley Water Sanitation Commission

PET: Potential Evapotranspiration

RAP: Regulatory Advisory Panel

Rappahannock RBC: Rappahannock River Basin Commission

Rapidan RBC: Rapidan River Basin Commission

RRBBC: Roanoke River Bi-State Commission

RTR: Rainfall-Temperature-Runoff

SDWA: Safe Drinking Water Act

Small SSU: Small Self-Supplied User

SSU: Self-Supplied User

SWCB: State Water Control Board

SWMA: Surface Water Management Area

TMDL: Total Maximum Daily Load

USACE: United States Army Corp of Engineers

USDA: United States Department of Agriculture

USEPA: United States Environmental Protection Agency

USFWS: United States Fish and Wildlife Service

USGS: United States Geological Survey

VDH: Virginia Department of Health

VDH-ODW: Virginia Department of Health Office of Drinking Water

VGIN: Virginia Geographic Information Network

VMRC: Virginia Marine Resources Commission

VPA: Virginia Pollution Abatement Program

VWP: Virginia Water Protection

VWUDS: Virginia Water Use Database System

VWWR: Virginia Water Withdrawal Reporting

WSP: Water Supply Plan

WUDR: USGS Water-Use Data and Research Program

⋆ Glossary

7Q10 is the lowest seven-day average flow that occurs (on average) once every 10 years. 7Q10 is generally used in the evaluations of in-stream beneficial uses such as waste assimilative capacity.

Aquifer as defined by 9VAC20-50-40 means a "water-bearing geologic formation, group of formations, or part of a formation that is capable of yielding a significant amount of groundwater to wells or springs. An aquifer is unconfined (water table) or confined (artesian) according to whether the upper surface of the water is at atmospheric pressure or at greater than atmospheric pressure." Derived from the two Latin words aqua, or "water," and ferre, meaning "to bear" or "to carry," aquifers literally carry water underground. Aquifers may be comprised of a layer of sand or gravel, sandstone or cavernous limestone, a rubbly top or base of lava flows, or even a large body of massive rock such as fractured granite with sizable openings. Aquifers are replenished by the seepage or infiltration of precipitation falling on the land.

Assimilative capacity means the ability of a body of water to cleanse itself; its capacity to receive waste waters or toxic materials without harmful effects and without damage to aquatic life or humans.

Baseflow, or groundwater seepage into a stream channel, means the portion of streamflow that comes from the sum of deep subsurface flow and delayed shallow subsurface flow. During most of the year, streamflow is composed of both groundwater discharge and surface water runoff. When groundwater provides the entire flow of a stream, baseflow conditions are said to exist. Perennial streams flow year-round because groundwater remains above the streambed throughout the year. Intermittent streams, those that flow only part of the year, generally from spring to mid-summer or only during wet periods, occur when the water table rises above or falls below the base of a stream channel in response to wet or dry weather conditions. The amount of baseflow a stream receives is closely linked to the permeability of rock or soil in the watershed.

Baseline Flow Budget is a critical tool in water supply engineering. This budget is estimated by constructing a model of flows through a river system without including withdrawals, discharges, or detainment of water by lakes or reservoirs. This budget reveals the quantity, quality, and timing of flows through river systems and allows the determination of total capacity of the stream, assesses system stress due to water supply activities, and sets reasonable expectations for potential beneficial uses.

Beneficial use as defined by the State Water Control Law §62.1-44.3 means both instream and offstream uses. Instream beneficial uses include, but are not limited to, the protection of fish and wildlife resources and habitat, maintenance of waste assimilation, recreation, navigation, and cultural and aesthetic values. The preservation of instream flows for purposes of the protection of navigation, maintenance of waste assimilation capacity, the protection of fish and wildlife resources and habitat, recreation, cultural and aesthetic values is an instream beneficial use of Virginia's waters. Offstream beneficial uses include, but are not limited to, domestic (including public water supply), agricultural uses, electric power generation, commercial, and industrial uses. According to the Groundwater Management Act of 1992 § 62.1-255, beneficial use includes domestic (including public water supply), agricultural, commercial, and industrial uses.

Community water system (CWS) as defined by 9VAC25-780-30 means a waterworks that serves at least 15 service connections used by year-round residents or regularly serves at least 25 year-round residents, and is regulated by the Virginia Department of Health Waterworks Regulation (12VAC5-590). This definition for CWS is identical to that of "community waterworks," one of the three types of "waterworks" regulated by the VDH (12VAC5-590-10).

Consumptive use refers to water withdrawn that is evaporated, transpired, incorporated into products or crops, consumed by humans or livestock, or otherwise removed from the immediate water environment.

Cumulative impact analysis is a modeling and analysis approach that takes into account the varied hydrologic process occurring throughout a river network (including meteorology and human water use). By simulating a daily water balance for every individual river segment within a watershed, DEQ is able to

evaluate the potential "cumulative impact" of all streamflow changes occurring upstream of any location within the river network. CIA is an assessment of the environmental impacts resulting from the incremental actions when added to other past, present, and reasonably foreseeable future actions.

Dendritic drainage patterns are the most common form of drainage system. In a dendritic system there are many contributing streams similar in form to the twigs of a tree, which are then joined together into the tributaries of the main river (the branches and trunk of the tree). Dendritic drainage patterns develop where the river channel follows the slope of the terrain, typically in V-shaped valleys, in areas of impervious and non-porous rock such as in the Appalachian Plateau Physiographic Province.

Estuary means a partly enclosed coastal body of brackish water with one or more rivers or streams flowing into it, and with a free connection to the open sea.

Evaporation is the process by which water changes from a liquid to a gas or vapor, representing the water loss from open bodies of water, such as lakes and reservoirs, wetlands, bare soil, and snow cover. Evaporation is the primary pathway water moves from a liquid state back into the water cycle as an atmospheric water vapor. Studies have shown that the oceans, seas, lakes, and rivers provide nearly 90 percent of the moisture in the atmosphere via evaporation, with the remaining 10 percent being contributed by plant transpiration.

Evapotranspiration (ET) means the combined release of water from the earth's surface via evaporation plus transpiration from plants.

Groundwater as defined by 9VAC25-600-10 means "any water, except capillary moisture beneath the land surface in the zone of saturation or beneath the bed of any stream, lake, reservoir or other body of surface water within the boundaries of this state, whatever may be the subsurface geologic structure in which such water stands, flows, percolates or otherwise occurs."

Groundwater discharge means the movement of water out of an area of saturated soil. Groundwater discharges into streams when the water table, or the top of groundwater saturation, rises above the stream bed.

Groundwater recharge is a hydrologic process where water moves downward from surface water to groundwater. This process occurs both naturally and through artificial processes where rainwater and/or reclaimed water is routed to the subsurface. Groundwater is recharged naturally by the infiltration of rain and snow melt and to a smaller extent by surface water. Recharge may be impeded by human activities such as paving, land development, or logging, which can result in loss of topsoil and reduced water infiltration.

Groundwater management area means a geographically defined groundwater area in which the Virginia State Water Control Board has deemed the levels, supply, or quality of groundwater to be adverse to public welfare, health, and safety.

Human consumption as defined by 9VAC25-610-10 means the use of water to support human survival and health, including drinking, bathing, showering, cooking, dishwashing, and maintaining hygiene.

Hydrologic (or water) cycle means the natural sequence through which water is transferred across or beneath the earth's surface and between the earth and the atmosphere.

Hydrologic units are surface water drainage areas that are delineated so as to nest into a multi-level hierarchical drainage system. Aside from the surface waters that are collected within the boundary of a hydrologic unit, it may also accept water from one or more points outside of the unit's boundary. Hydrologic units may include associated surface areas whose drainages do not connect, thus resulting in multiple outlet points. This is usually the case with coastal units such as those containing multiple outlets to the Chesapeake Bay or Atlantic Ocean.

Hydrologic Unit Code (HUC) refers to a unique code assigned to hydrologic units in a hierarchical system initially created by the USGS to provide a standardized method of cataloging watersheds in the United States. In 2006, new hydrologic unit delineation standards officially expanded the hierarchy from four to six levels with HUCs 2 to 12 digits in length.

Hydrology means the study of the waters of the earth on and below the surface of the planet. Hydrology also involves the study of the various properties of water and their relationship with the living and nonliving environment.

Hydrogeology is the area of geology that deals with the distribution and movement of groundwater in and through the soil and rocks of the earth's crust. Infiltration means the process by which water on the surface enters the soil.

In-stream flow means the state in which water remains in its natural course (e.g., streams, creeks, or rivers) as opposed to water that has been diverted artificially for other purposes (e.g., irrigation, reservoirs, drinking water, etc.).

Instream use describes water that is used, but not withdrawn, from a surface water source for purposes such as as hydrolelectric-power generation, navigation, and recreation.

Karst topography as defined by 9VAC20-50-40 means a type of topography that may form over limestone, dolomite, or gypsum formations by dissolving or solution, and that is characterized by closed depressions or sinkholes, caves, and underground drainage.

Land-river segments are units in the VAHydro model that consist of an intersection between river segment and land segment layers. Land-river segments function to route flows, nutrient loads, and sediment sources from land segment model simulations to river segment models.

Land segments are land units in the VAHydro model based on political boundaries (around 150 total). These regions are delineated according to county and city designations, with some areas being further divided along physiographic boundaries. Land segments are the units used in the VAHydro model for simulating meteorological inputs including rainfall, temperature, snowfall, potential evapotranspiration (PET), dewpoint, wind, solar radiation and cloud cover.

Local government as defined by 9VAC25-780-30 means a city, incorporated town, or county.

Local program as defined by 9VAC25-780-30 means the combined water plan, resource conditions, and drought response and contingency plan developed in compliance with the Local and Regional Water Supply Planning Regulation. The term "local program" will be used to mean either local or regional programs.

Local water supply plan means a water supply plan developed by and pertaining to a single local government.

Lowest 30 day flow or l30 describes the lowest consecutive 30 day average daily streamflow over the simulation period. This metric is a representation of a short-term, or acute drought.

Lowest 90 day flow or l90 represents the lowest consecutive 90 day average daily streamflow over the simulation period. This would represent a prolonged drought.

Minimum in-stream flow means the amount of water flow necessary to preserve stream values.

Minor Basin Virginia is divided along hydrologic boundaries into 20 sub-basin units, referred to as "Minor Basins." Minor Basins vary in size from around 900 mi^2 to 6,000 mi^2 and roughly contain 1-3 HUC 8 units.

Non-consumptive use as defined by 9VAC25-220-10 means the use of water withdrawn from a stream in such a manner that it is returned to the stream without substantial diminution in quantity at or near the point from which it was taken and would not result in or exacerbate low flow conditions.

Nonpoint source pollution as defined by 9VAC25-870-10 means pollution such as sediment, nitrogen, phosphorous, hydrocarbons, heavy metals, and toxics whose sources cannot be pinpointed but rather are washed from the land surface in a diffuse manner by stormwater runoff.

Offstream use involves the withdrawal or diversion of water from a surface water source for residential, industrial, agricultural, energy development, or other purposes.

Overall change in flow describes the net loss of water from the riverine system as a result of off-stream use not otherwise returned through point source discharges, or losses due to evapotranspiration.

Percolating water means water which seeps or filters through the ground without any definite channel and is not a part of the flow of any waterway.

Permeable refers to a rock or membrane that can be permeated, or penetrated, especially by liquids or gases. Physiographic province means a region or area with similar landforms that are distinctly different from landforms found in adjacent areas. Virginia has five physiographic provinces: the Appalachian Plateau, Valley and Ridge, Blue Ridge, Piedmont, and the Coastal Plain.

Point source as defined by 9VAC25-31-10 means any discernible, confined, and discrete conveyance including, but not limited to, any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, concentrated animal feeding operation, landfill leachate collection system, vessel, or other floating craft from which pollutants are or may be discharged. This term does not include return flows from irrigated agriculture or agricultural stormwater runoff.

Potable water as defined by 9VAC25-740-10 means water fit for human consumption and domestic use that is sanitary and normally free of minerals, organic substances, and toxic agents in excess of reasonable amounts for domestic usage in the area served and normally adequate in quantity and quality for the minimum health requirements of the persons served.

Potential Evaporation (PET) describes the total evaporation that could occur on an un-covered water surface (such as a lake), or the amount of water that could be transpired by a plant given sufficient available soil moisture.

Potential unmet demand is the portion of surface water demand for a specific facility that is limited by available streamflow as simulated in a given model scenario, including any known operational limits such as flow-by requirements. This unmet demand, if realized, could be managed through water conservation,through alternative sources, operational changes, or from available storage. Absent of these or other options, this portion of demand could remain unmet. For the purpose of the State Plan, potential unmet demand is calculated based on the maximum average daily unmet demand in MGD over a 30 day period.

Precipitation is water released from clouds in the form of rain, freezing rain, sleet, snow, or hail. Precipitation is the primary connection in the water cycle providing for the delivery of atmospheric water to the earth.

Planning period as defined by 9VAC25-780-30 means the 30- to 50-year time frame used by the locality or region to project future water demand in accordance with 9VAC 25-780-100 B.

Reclaimed water as defined by 9VAC25-740-10 means water resulting from the treatment of domestic, municipal, or industrial wastewater that is suitable for water reuse that would not otherwise occur.

Regional water plan as defined by 9VAC25-780-30 means a water plan developed and submitted by two or more cities or counties or both. A town and an adjacent county may develop a regional water plan. Two or more towns may develop and submit a regional plan where the plan results in the proposed development of future water supply projects that supply the water supply demands of the affected towns. Such plans developed by two or more towns may be included in regional water plans developed and submitted by counties or cities. Regional water plans shall be developed and submitted in conjunction with all public service authorities operating community water systems within the regional planning unit, if applicable.

Reuse or water reuse as defined by 9VAC25-740-10 means the use of reclaimed water for a direct beneficial use, an indirect potable reuse, an indirect non-potable reuse, or a controlled use.

Riparian area or zone is that area of land immediately adjacent to streams, lakes, or other surface waters. Riparian land as defined by §62.1-104 means land which is contiguous to and touches a watercourse. Riparian owner or landowner as defined by §62.1-104 means an owner of riparian land.

Riparian (water) rights refer to a system for allocating water among those who possess land adjacent to a body of water. Having its origins in English common law, under the riparian principle, landowners whose property adjoins a body of water such as a navigable river, bay, creek, or ocean, have the right to make reasonable use of it as it flows through or over their property.

River segments are high-resolution hydrologic subsections used for modeling and analysis. Over 600 river segments in VAHydro, roughly the size of HUC 10 hydrologic units.

Safe yield of public water supply means the highest volumetric rate of water that can be withdrawn by a surface water withdrawal during the Drought of Record since 1930, including specific operational conditions established in a Virginia Water Protection permit, when applicable.

Self supplied user (SSU) as defined by 9VAC25-780-30 means any person making a withdrawal of surface water or groundwater from an original source (e.g., a river, stream, lake, aquifer, or reservoir fed by any such water body) for his own use. Self-supplied users do not receive water from a community water system. Self-supplied users are further described in Section 9VAC25-780-70 of the Water Supply Plan Regulation as follows:

- **Agricultural Self-Supplied User** (AG) is an agricultural operation that uses more than 300,000 gallons of surface water or groundwater per month for irrigation or non-irrigation purposes. These demands can represent individual facilities or locality-wide estimates.
- **Large Self-Supplied User** (Large SSU) is a self-supplied user of more than 300,000 gallons per month of surface water or groundwater for nonagricultural uses, including but not limited to commercial, manufacturing, mining, and hydropower.
- **Small Self-Supplied User** (Small SSU) is a residence or business that is self-supplied by individual wells withdrawing less than 300,000 gallons of groundwater per month. These demands are provided as locality-wide estimates of use.

Service area as defined by 9VAC25-780-30 means the geographical area served by a community water system.

Springs are water resources formed when the side of a hill, valley bottom, or other excavation intersects a flowing body of groundwater at or below the water table. Although they can be formed in any type of rock, springs are more prevalent in limestone and dolomite formations because of their fractal nature and their propensity to dissolve in rainfall that is weakly acidic. As the rock dissolves and fractures, spaces can form that allow water to flow. If the water flow is horizontal, it can reach the land surface and result in a spring.

Stormwater as defined by §62.1-44.15 means precipitation that is discharged across the land surface or through conveyances to one or more waterways and that may include stormwater runoff, snow melt runoff, and surface runoff and drainage. Stormwater runoff is generated when precipitation from rain and snow melt flows over land or impervious surfaces (sidewalks, parking lots, rooftops) and does not percolate into the ground. Traditional definitions of stormwater have characterized it as non-point source runoff; however, a great deal of urban and industrial stormwater is discharged into surface waters through storm sewers, ditches, channels, or other conveyances which are considered point sources. As stormwater runoff flows overland, it accumulates debris, chemicals, sediment, or other pollutants that could adversely affect water quality if it is discharged into surface water bodies untreated.

Streamflow refers to the amount of water flowing in a river. Streamflow and the water quality of a river are affected by whatever is happening in the land area "above" the point where a river flows out of a watershed. Natural mechanisms that cause changes in streamflow include runoff from rainfall and snowmelt, evaporation from soil and surface water bodies, transpiration, groundwater discharge, and sedimentation of lakes and wetlands. Human-induced mechanisms include surface water withdrawals and inter- or intra-basin diversions; river flow regulation for hydropower and navigation, construction, removal, and sedimentation of reservoirs and stormwater detention ponds; stream channelization and levee construction; drainage or restoration of wetlands; land use changes such as urbanization that alter erosion, infiltration, overland flow, or evapotranspiration rates; wastewater outfalls; irrigation wastewater return flow, etc.

Surface water as defined by 9VAC25-210-10 means any water in the Commonwealth, except groundwater as defined in §62.1-254 of the Code of Virginia, which wholly or partially are within the Commonwealth or bordering the Commonwealth.

Surface water withdrawal as defined by 9VAC25-210-10 means a removal or diversion of surface water from a stream, spring, and/or lake/pond in Virginia or from the Potomac River.

Sustainability means using, developing, and protecting resources in a manner that enables people to meet current needs, and provides the ability for future generations to also meet future needs. Additionally, sustainability is defined in terms of maintaining the "beneficial uses" that are considered to be essential to the wellbeing of the Commonwealth's human and natural resources. These beneficial uses are protected by law and include the protection of fish and wildlife habitat, maintenance of waste assimilation, recreation, navigation, cultural and aesthetic values, public water supply, agricultural uses, electric power generation, and commercial and industrial uses.

Topography means the arrangement of the natural and artificial physical features of an area.

Transpiration is the release of water from living plant surfaces. Transpiration rates can vary widely depending upon weather conditions such as temperature, humidity, sunlight availability and intensity, precipitation, soil type and saturation, root depth, wind speed, density and type of vegetative cover, land slope, reflective land-surface characteristics, and the season of the year. During dry periods, transpiration can contribute to the loss of moisture in the upper soil zone which can effect vegetation and crops.

VAHydro is a web-based platform used by DEQ for water resource management in Virginia. VAHydro is an integrated platform for data management/modeling/analysis, designed to link information and data associated with water withdrawal permitting and compliance, water supply planning, water withdrawal reporting, groundwater well registration, drought monitoring, and surface water and groundwater resource modeling. A primary component of the VAHydro system is the VAHydro surface water model, which is used to perform all CIA modeling.

Water budget is an accounting of the flow of water into and out of a system. The water budget of a place or system, whether it is an agricultural field, a watershed, or a continent, can be determined by calculating the input, output, and storage changes of water at the earth's surface over a period of time.

Water demand management as defined by 9VAC25-780-30 means plans for water conservation, reuse, and reducing unaccounted for water losses contained in a local or regional water supply planning program.

Water resource management means the activity of planning, developing, distributing, and managing the optimum use of water resources.

Water sources as defined by 9VAC25-780-30 means wells, stream intakes, and reservoirs that serve as sources of water supplies.

Water supply planning area means the geographical area as defined by local government boundaries that is included in a local or regional water supply plan.

Watershed as defined by 4VAC5-15-10 means a drainage area or basin in which all land and water areas drain or flow toward a central collector such as a stream, river, or lake at a lower elevation.

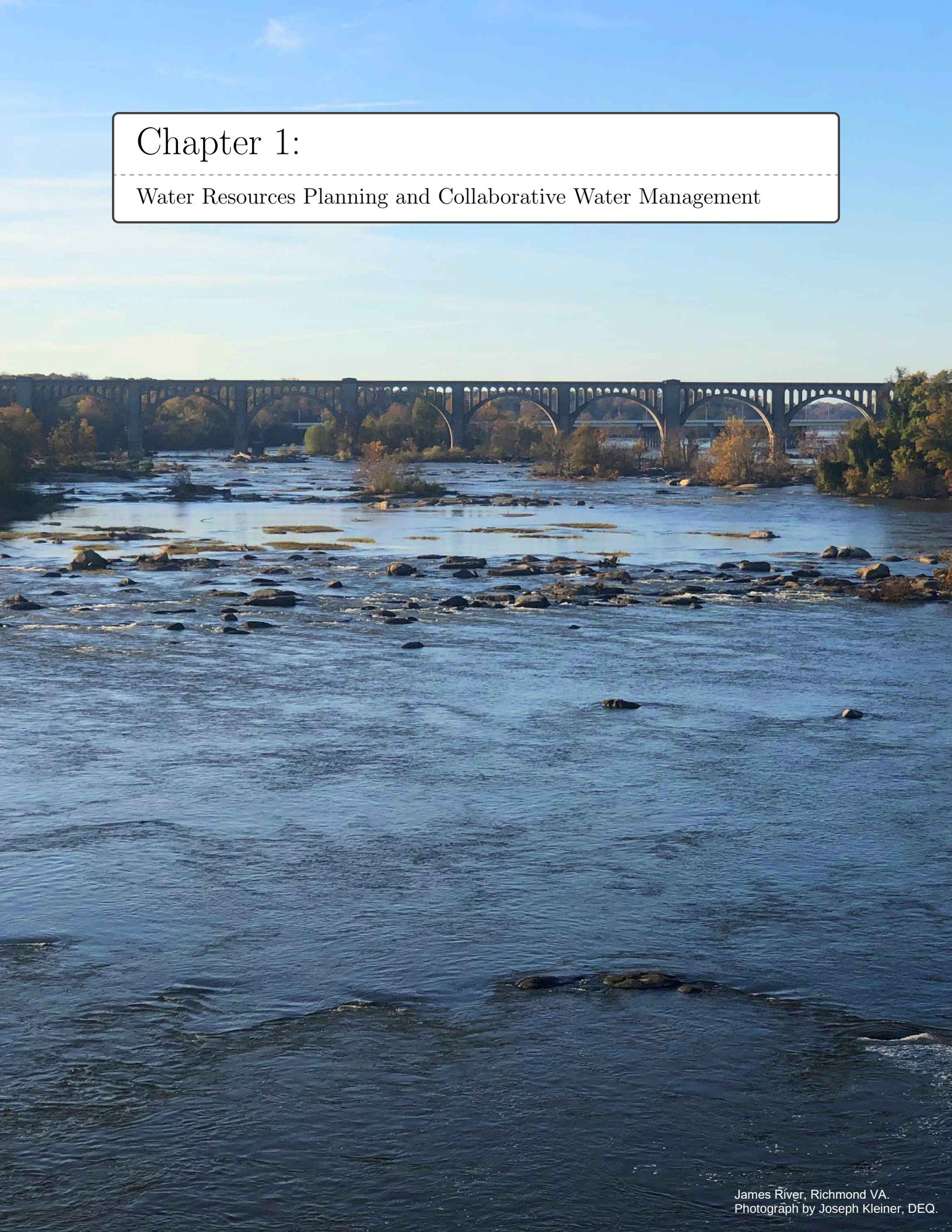
Waterworks as defined by 12VAC5-590-10 means a system that serves piped water for drinking or domestic use to (i)the public, (ii) at least 15 connections, or (iii) an average of 25 individuals for at least 60 days out of the year. The term "waterworks" shall include all structures, equipment and appurtenances used in the storage, collection, purification, treatment and distribution of pure water except the piping and fixtures inside the building where such water is delivered (see Article 2 (§ 32.1-167 et seq.) of Chapter 6 of Title 32.1 of the Code of Virginia).

Well as defined by 9VAC25-610-10 means any artificial opening or artificially altered natural opening, however made, by which groundwater is sought or through which groundwater flows under natural pressure or is intended to be withdrawn.

Wetland means a transitional area on the landscape between dry land and open water or streams, often exhibiting characteristics of both terrestrial and aquatic habitats. State Water Control Law (§ 62.1-44.3) and Virginia Water Protection Permit (VWP) Program regulations (9VAC25-210-10) define "State waters" as "all water, on the surface and under the ground, wholly or partially within or bordering the Commonwealth or within its jurisdiction, including wetlands." Further, "wetlands" are defined as "those areas that are inundated or saturated by surface or groundwater at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas." The definition of "wetlands" in state law mirrors the definition in the federal Clean Water Act.

Chapter 1:

Water Resources Planning and Collaborative Water Management



James River, Richmond VA.
Photograph by Joseph Kleiner, DEQ.

1 Water Resources Planning and Collaborative Water Management

1.1 Planning and Water Resources Management in Virginia

Water resources management involves the planning, developing, distributing, and managing of water resources for their optimum use. Water Supply Planning is one of several pillars through which this overarching task is supported. Planning works in tandem and is supportive of surface and groundwater withdrawal permitting. Both permitting and planning are supported by and support the ongoing collection and analysis of data, and the advancement of primary science that informs resource management decisions as a whole. Collaborative integration of these pillars is necessary to meet the primary objective of any water resource management program: allocating water resources on an equitable basis. The Water Supply Planning Program in Virginia is designed, among other goals, to encourage, promote, and protect all beneficial uses of the Commonwealth's water resources, as defined by § 62.1-44.3 of the Code of Virginia:

> "Beneficial use" means both in-stream and off-stream uses. In-stream beneficial uses include, but are not limited to, the protection of fish and wildlife resources and habitat, maintenance of waste assimilation, recreation, navigation, and cultural and aesthetic values. The preservation of in-stream flows for purposes of the protection of navigation, maintenance of waste assimilation capacity, the protection of fish and wildlife resources and habitat, recreation, cultural and aesthetic values is an in-stream beneficial use of Virginia's waters. Off-stream beneficial uses include, but are not limited to, domestic (including public water supply), agricultural uses, electric power generation, commercial, and industrial uses.

This chapter is intended to provide a brief overview of the evolution of the Water Supply Planning Program, and to describe many of the other actors and activities that are part of collaborative water resources management in Virginia.

1.2 Virginia's Water Supply Planning Evolution

Formal water resources management began in Virginia in 1927. Major river basin bulletins were the first product, periodically developed until the late 1960s with a focus on surface water resources. An extended multi-year drought spurred an expanded planning effort between 1968 and 1972. During this time frame major river basin reports were created, containing the first local water use inventories. Section 62.1-44.36 of the Code of Virginia outlines the principles and policies for these early reports - which continue to inform water resources management today.

Amended in 1981, Section 62.1-44.38 of the Code of Virginia required preparation and submission of a plan and programs for the management of the Commonwealth's water resources "to encourage, promote and secure the maximum beneficial use and control thereof." Plans were required for each major river basin of the Commonwealth, specifically naming the Potomac-Shenandoah, Rappahannock, York, James, Chowan, Roanoke, New, and the Tennessee-Big Sandy River Basins, and for those areas in the Tidewater region or otherwise not located within these major river basins. Major river basin plans were created between 1985 and 1988, inventorying local water systems to include their current use and estimates of future water demand. Alternative water management strategies were developed which included possible solutions to identified water management problems. For the first time, safe yield[14] was assessed within each major river basin.

During the extended drought of 1999 to 2002, public water supply systems experienced shortages and interruptions of service across Virginia. Many systems were unprepared for the severity of the drought, and a number of large municipal systems had less than 60 days of water supply capacity remaining in reservoirs. The Virginia General Assembly responded, amending

[14] see "safe yield" in the glossary
[15] Va. Code §62.1-44.38:1 (2003)

the Code of Virginia[15] to require the establishment of a comprehensive water supply planning process to develop local, regional, and state water supply plans "... designed to (i) ensure that adequate and safe drinking water is available to all Citizens of the Commonwealth, (ii) encourage, promote, and protect all beneficial uses of the Commonwealth's water resources, and (iii) encourage, promote, and develop incentives for alternative water sources, including, but not limited to desalination."

Water supply planning in Virginia is now a continuous, comprehensive, long-range planning process. Local governments must adopt a local program, including any revisions to comprehensive plans, water supply plans, water and sewer plans, and other local authorities necessary to implement such plans.[16] A local program is defined in 9VAC25-780-30 as follows:

> "Local program" means the combined water plan, resource conditions and drought response and contingency plan developed in compliance with this regulation. The term "local program" will be used in this regulation to mean either local or regional programs. The term "program" implies the institution of a continuous planning process for maintenance of these documents.

Water supply plans include evaluations of current water sources and use, local environmental resources, future water demand and possible water source alternatives to meet future demands. Unlike the earlier planning efforts, today's comprehensive water supply planning process incorporates locally led planning by individual localities. The first set of local and regional comprehensive water supply plans, described below, were submitted between 2008 and 2011. The data from these local and regional plans is essential for understanding the possible impacts of future demands on water resources. Water supply plan information is also considered in the permitting process for future water supply withdrawals.

1.2.1 Initial Local and Regional Plan Submission 2008-2011

Virginia's water supply planning program is designed to be a statewide partnership, enabling local and regional partners, such as planning district commissions, water authorities, and other stakeholders, to take the lead in identifying their future water needs with the technical support and oversight of the state. The Local and Regional Water Supply Planning Regulation[17] (WSP Regulation) requires that all counties, cities, and towns in the Commonwealth of Virginia participate in the development of, and formally adopt, a local or regional water supply plan.

Ten local (individual locality) and 38 regional (two or more localities) water supply plans were developed and submitted to the Virginia Department of Environmental Quality (DEQ) between 2008 and 2011. The ten local plans were submitted by the Towns of Chincoteague, Hillsboro, Port Royal, and Warrenton, the City of Richmond, and the Counties of Amelia, Charles City, King George, New Kent, and Stafford. Regional plan boundaries are depicted in Figure 6.

DEQ provided technical and financial assistance to facilitate development of the plans and aided localities and regions in acquiring the necessary information. As required by the WSP Regulation, all localities in the Commonwealth held public hearings during the development of the water supply plans and formally adopted the plans. All 48 plans were submitted to DEQ by the regulatory deadlines. DEQ carefully reviewed each plan for compliance with the WSP Regulation, coordinated with local governments to ensure that plans were as complete and accurate as possible, and entered submitted information into VAHydro, DEQ's web-based platform for water resource management.

[16] 9VAC25-780-50.A
[17] 9VAC25-780

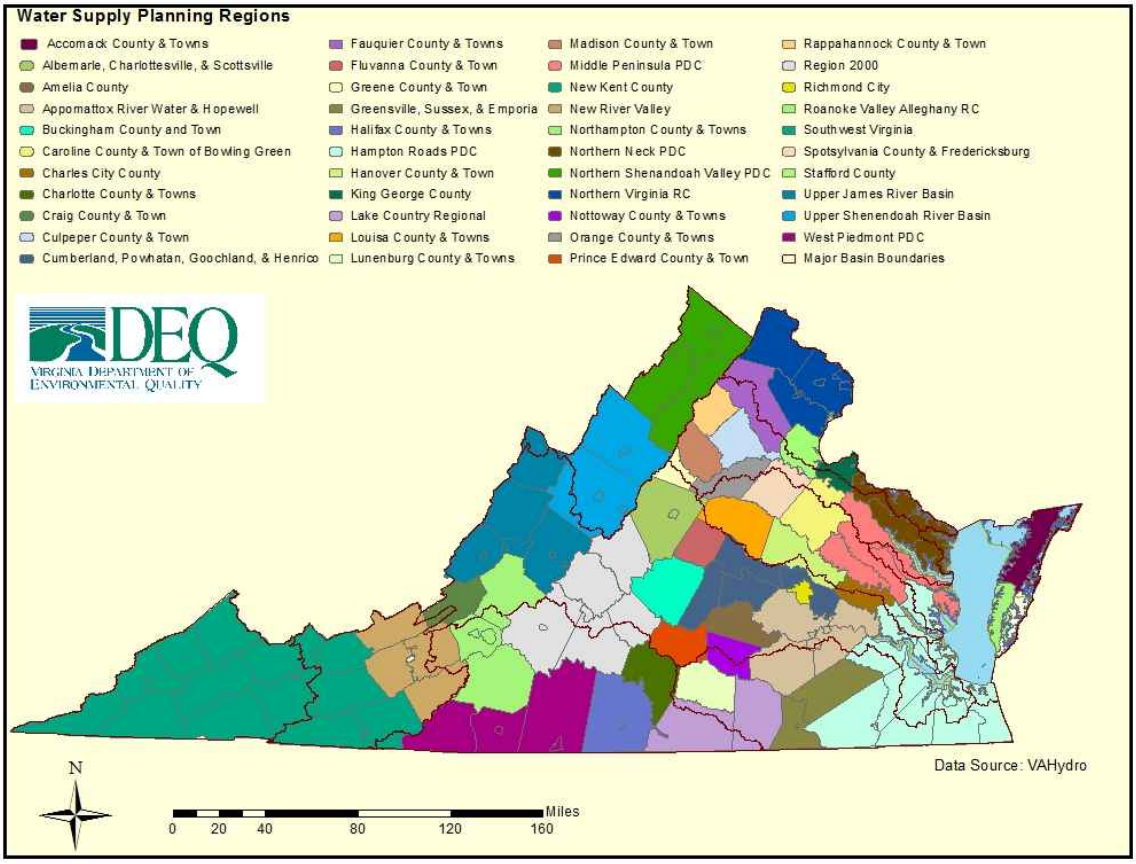


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Figure 6: Water Supply Planning Regions for Plans Submitted 2008-2011

1.2.2 VAHydro

In 2015 DEQ began development of VAHydro, a web-based platform for water resource management in Virginia. VAHydro is an integrated platform designed to link information and data associated with water withdrawal permitting and compliance, water supply planning, water withdrawal reporting, groundwater well registration, drought monitoring, and surface water and groundwater resource modeling.

The VAHydro platform is interactive and dynamic depending on what modules a user may need. For example, a well driller may use VAHydro to complete the groundwater well registration of a newly drilled well. A golf course superintendent may access VAHydro to report the course's monthly water withdrawals in compliance with the withdrawal reporting regulation .[18] Likewise, localities across the state are registered to use VAHydro to revise and update their water supply plan data. While regulation requires all local and regional water supply plans to be reviewed and resubmitted periodically,[19] one goal of VAHydro is to promote a more continuous planning process by allowing localities to update water supply planning information at anytime. To date, over 120 users representing local governments and planning programs have been granted access to VAHydro to enter new or revised information related to their water supply plans.

VAHydro provides the basis of the efficient data collection and analysis that DEQ relies on to make resource management decisions. It is critical to improving DEQ's understanding of the Commonwealth's wa-

[18] 9VAC25-200
[19] 9VAC25-780-50.D and E

ter resources and beneficial uses. VAHydro remains in active development with each year bringing updates and additional refinement to the platform.

1.2.3 Five-Year Water Supply Plan Review 2016-2019

In 2018, Virginia localities reviewed water supply plans in accordance with the Water Supply Planning Regulation 9VAC25-780. This process began in 2016 with DEQ conducting outreach with localities to identify compliance needs. The process continued through 2018 with final compliance determinations issued in 2019. The WSP Regulation requires plan revisions if the review of a local program indicates that circumstances have changed or new information has been made available that will result in water demands that will not be met by supply alternatives contained in the water plan. These circumstances may be caused by changes in water demands, the availability of the anticipated source, cumulative impacts, in-stream beneficial uses, or other factors. In addition to the review, localities addressed conditions specified in each plan's 2013 compliance determination. All localities in Virginia: 38 cities, 95 counties, and 190 towns (323 in total), reviewed their plans and addressed compliance conditions by the required five-year review deadline.

Localities also provided new or updated water supply information if such information was available. Localities largely completed the revisions using VAHydro to enter and revise water supply planning information. Information added or revised during the five-year review included: new groundwater or surface water sources, water use and demand projection updates, drought response and contingency plans/ordinances, mapping of community water system service areas, and more. This information provides the basis of water supply planning throughout the Commonwealth and feeds directly into this document. Further analysis of this information can be found in Chapter 3 for a statewide overview and in Appendix A for overviews based on minor basins.

1.2.4 Local and Regional Water Supply Plan Re-submission Expected 2023

According to 9VAC25-780-50.E, all local programs shall be reviewed, revised, and resubmitted to DEQ every ten years after the date of last approval. The local and regional water supply plans were approved in 2013. Therefore updated plans will be due from all localities in 2023. Similar to the five-year review period, updates will largely be completed by registered users through the use of VAHydro. Registered users hcan update and edit their water supply planning data in VAHydro at any time. It is anticipated and encouraged that localities will begin the review and revisions process before the 2023 deadline, however upcoming changes to the regulation (discussed further in following section) are expected to have some bearing on this timeline.

Legislation enacted following the 2018 General Assembly Session (2018 Va. Acts Ch. 420) amended §15.2-2223 of the Code of Virginia. These amendments authorize a locality to include long-range recommendations for groundwater and surface water availability, quality, and sustainability in their comprehensive plans. The bill requires the local planning commission to survey and study groundwater and surface water availability, quality, and sustainability in the preparation of a comprehensive plan. Local governments are contacting DEQ regarding water supply program components in order to meet the comprehensive planning requirements.

1.2.5 Upcoming Changes to the Water Supply Planning Regulation

Legislation enacted following the 2020 General Assembly Session (2020 Va. Acts Ch. 1105) directs the State Water Control Board to estimate the risk that each locality and region in the Commonwealth will experience water supply shortfalls, to encourage the development of cross-jurisdictional water supply projects, and to adopt regulations designating regional planning areas based primarily on river basins. The bill also directs localities to participate in cross-jurisdictional, coordinated water resource planning, and to develop a single water supply plan for each regional planning area. The regulatory process required by this legislation is expected to begin in early 2021. This is discussed more in Chapter 5.

1.2.6 Development of the State Water Resources Plan

Through participation in the water supply planning process, localities collect a large amount of data related to sources, current and future demands, and alternatives. DEQ's role is to collate and analyze the data provided by all planning programs to evaluate the current and future status of Virginia's water resources. The State Water Resources Plan (State

Plan) is the vehicle for this data collection and analysis, and is intended to be a tool that stakeholders can use to inform future planning efforts. The Virginia General Assembly established the State Water Supply Plan Advisory Committee during the 2010 General Assembly Session to assist DEQ in developing, revising, and implementing the State Plan.

The committee's final report, submitted in December 2012, provided recommendations to DEQ for the development of the State Plan. The first rendition of the plan was developed with consideration of these recommendations and published in October 2015.

The 2015 State Plan provided a statewide view of the information submitted by localities as well as the results of the cumulative impact analysis completed using this information. The analysis factored in both the future water demand estimates provided in the plans and the water withdrawal data submitted by users under the Water Withdrawal Reporting Regulation.[20] Major water supply challenges facing the Commonwealth and recommendations for addressing those challenges were also outlined in the 2015 State Plan.

The 2020 State Plan expands on the 2015 State Plan in many areas including: updated demand projections, more precise spatial information for withdrawals, more robust handling of discharges, and a far higher resolution in both the simulation and the presentation of the analysis. Where as the 2015 State Plan broke the state into 9 major basins, the State Plan now provides highly localized information on sources, demands, and results of cumulative impact analysis (where applicable) for 20 minor basins. As a result, stakeholders engaged in cross jurisdictional planning will enjoy a reference that focuses on basin level analysis at a scope that supports a better understanding of the state of their shared water resources.

[20] 9VAC25-200

1.3 Collaborative Water Management

The Commonwealth of Virginia implements a variety of laws and regulations pertaining to water quality and water supply. Meeting Virginia's environmental challenges is a cooperative effort that involves communities, businesses, educators, government agencies, and many other stakeholders. This section contains descriptions of programs implemented by state and federal agencies that impact water resources management and water supply planning. The programs implemented at DEQ do not address riparian rights, but seek to balance reasonable water use for all defined beneficial uses.[21]

1.3.1 State Natural Resource and Water Resource Policies

Article XI, Section 1 of the Virginia Constitution states the following:

> To the end that the people have clean air, pure water, and the use and enjoyment for recreation of adequate public lands, waters, and other natural resources, it shall be the policy of the Commonwealth to conserve, develop, and utilize its natural resources, its public lands, and its historical sites and buildings. Further, it shall be the Commonwealth's policy to protect its atmosphere, lands, and waters from pollution, impairment, or destruction, for the benefit, enjoyment, and general welfare of the people of the Commonwealth.

Virginia's State Water Control Board (SWCB) adopted a Water Resources Policy[22] on May 7, 1974. The creation of this policy supports the SWCB in fulfilling its statutory responsibilities under § 62.1-44.36 of the Code of Virginia. The policy begins with precepts or agreed upon statements which acknowledge the need to balance natural resource protection and economic growth. The document includes a number of policies that the SWCB observes when preparing Water Resource Management Plans, when advising on the adequacy and desirability of water resource projects, and in authorizing specific water resource projects or in commenting on projects which affect water resources. The policies are, generally, to:

- Acknowledge and protect natural water sources
- Understand and protect all beneficial uses and ensure the public benefits from water resources projects
- Consider long-term protection of the environment as a guiding criterion in decisions relating to water and related land resources
- Minimize pollution and the inefficient water use
- Support water supply planning and encourage storage
- Promote awareness of flood plains and flood control
- Understand the financial factors associated with water resource projects
- Preserve wetland ecosystems

1.3.2 Virginia's Statutory and Regulatory Controls Concerning Water Use and Water Quality

Water quantity and quality management as it relates to water supply is the shared responsibility of a number of programs within DEQ. These programs aim to improve and protect Virginia's streams, rivers, bays, wetlands, and groundwater for aquatic life, human health and other beneficial water uses. A brief description of each DEQ program follows.

Local and Regional Water Supply Planning Regulation

The WSP Regulation, discussed in Section 1.2 of this chapter, requires the DEQ to review local programs for compliance with the regulation. Local and regional water supply programs are also reviewed by the Virginia Department of Health (VDH), the Department of Conservation and Recreation (DCR), the Department of Historic Resources (DHR), the Virginia Marine Resources Commission (VMRC), and the Department of Wildife Resources (DWR), as part of the determination of compliance.[23]

[21] see "beneficial use" in Glossary
[22] 9VAC25-390
[23] 9VAC25-780-140 and 150

Virginia Water Withdrawal Reporting Regulation

The Virginia Water Withdrawal Reporting (VWWR) Regulation[24] requires reporting of total monthly and maximum daily withdrawal amounts for any withdrawal whose daily average withdrawal meets or exceeds 10,000 gallons per day, with the exception of crop irrigation. Reporting of crop irrigation is required for withdrawals meeting or exceeding one million gallons in any single month. Withdrawal reports for the previous calendar year are due annually on January 31. If a withdrawal meets the reporting threshold, reporting under the VWWR Regulation is required, regardless of whether or not a withdrawal permit is held and regardless of whether or not the withdrawal is within a groundwater management area. Reporting is a statewide requirement, with over 90% of all reporters using VAHydro to enter their information.

Water withdrawals reported under this regulation provide a foundation for comprehensive watershed water budgets, as well for evaluating possible impacts to beneficial uses associated with withdrawals. Users report the amount of water withdrawn, the purpose of the withdrawal, and the water source (surface water, groundwater, or water transferred among users). DEQ relies on these data to inform resource management as they are a critical input in the cumulative impact analysis of surface water and groundwater resources, and are therefore instrumental in the evaluation of water withdrawal permit applications and the State Plan.

Water withdrawal data is primarily reported to and stored within VAHydro, and organized by the water source, location, and the owner of the withdrawal. Water withdrawals are also categorized by the use of the water withdrawn. These categories include: agriculture (including but not limited to livestock watering), commercial (includes golf course irrigation), power production (including nuclear, fossil, and hydro), irrigation (including but not limited to agricultural crop, sod, and nursery production), manufacturing, mining, and public water supply. Each year the data is compiled and summarized by DEQ in the "Annual Report on the Status of Virginia's Water Resources" which is submitted to the General Assembly on October 1st of each year. The Annual Report provides an overview of current water use in Virginia and how that use is changing.

[24] 9VAC25-200

Virginia Water Protection Permit Regulation

Pursuant to Article 2.2 of the State Water Control Law[25], projects involving permanent and temporary impacts to surface waters are permitted under the Virginia Water Protection (VWP) Permit Program Regulation to protect water quality and manage instream flows, balancing on-stream and off-stream beneficial uses. Surface waters are defined in the VWP Regulation as all state waters that are not groundwater as groundwater is defined in §62.1-255 of the Code of Virginia. Wetlands, stream channels, lakes, springs, and ponds are all surface waters and fall under the VWP Regulation's jurisdiction. Surface water activities regulated under the VWP Program include surface water withdrawals, non-agricultural impoundments, impacts to surface waters such as land clearing, dredging, filling, excavating, draining, flooding, or ditching in open water, streams, and wetlands. A surface water withdrawal, as defined in 9VAC25-210-300, means "a removal or diversion of surface water in Virginia or from the Potomac River for consumptive or nonconsumptive use thereby altering the instream flow or hydrologic regime of the surface water". All surface water withdrawals, unless excluded according to 9VAC25-210-310, require a VWP permit.

According to the 2019 Annual Report, 75% of the total reported surface water withdrawals in 2019 were excluded, or exempt, from VWP permit requirements. Unlike permitted withdrawals, most excluded withdrawals are not subject to permit conditions that require conservation during times of low flow or require a certain volume of water to flow by the intake or release from a reservoir. Such permit conditions help to ensure the existing beneficial uses of the water resource, including the permitted withdrawal and those uses downstream, are sustained at all times, even during dry periods. Excluded surface water withdrawals are also not subject to periodic review as is the case for permitted withdrawals, which are reviewed throughout the 15-year permit term. The 2020 State Plan includes additional analysis intended to assist in evaluating potential impacts and uncertainty to water resources from excluded users (also referred to as exempt users) in Chapter 4 and Appendix A.

DEQ issues VWP Individual permits through the Joint Permit Application (JPA) process. The JPA review for a VWP permit requires an evaluation of the proposed surface water withdrawal's cumulative

[25] Va. Code §§ 62.1-44.15:20 through 62.1-44.15:23.1 (2007)

impacts on beneficial uses. DEQ developed and maintains an operational hydrologic model covering all streams and impoundments in the Commonwealth for this purpose. For each surface water withdrawal application, whether for a new project or renewal, DEQ evaluates both the potential for impacts to downstream beneficial uses as well as the potential for the withdrawal itself to be impacted by water users located upstream. DEQ uses the output of these analyses to inform the permit decision and to develop appropriate limits on withdrawal volumes and minimum in-stream flow conditions if a permit is issued. DEQ's review of a JPA includes formal coordination with the U.S. Army Corps of Engineers (USACE), VMRC, VDH, DWR, and DCR.

The VWP Program also serves as the Commonwealth's issuing authority for Section 401 Certifications for Federal Energy Regulatory Commission (FERC) licenses as established by the VWP Regulation.[26] Ten of the twenty-two regulated hydroelectric facilities in Virginia are currently undergoing or will be initiating the relicensing process with FERC and DEQ within the next five years, resulting in an increase in VWP permit applications overall. The VWP permitting process for these facilities will incorporate current scientific framework and regulatory requirements, which are more robust than those in place during the original 401 Certification issuance processes. Previous certifications generally required only a minimum release from the facility downstream. Once issued, VWP permits provide enhanced data collection, instream flow management during droughts or low flow events, and better protections for instream beneficial uses, especially in regions where multiple hydroelectric facilities are located on the same river. Figure 7 illustrates VWP surface water withdrawal permitting activities as of July 2020. Currently, DEQ administers 111 VWP permits for surface water withdrawals. These permits are authorized to withdraw a combined total of 785 MGD.

[26] 9VAC25-210-340

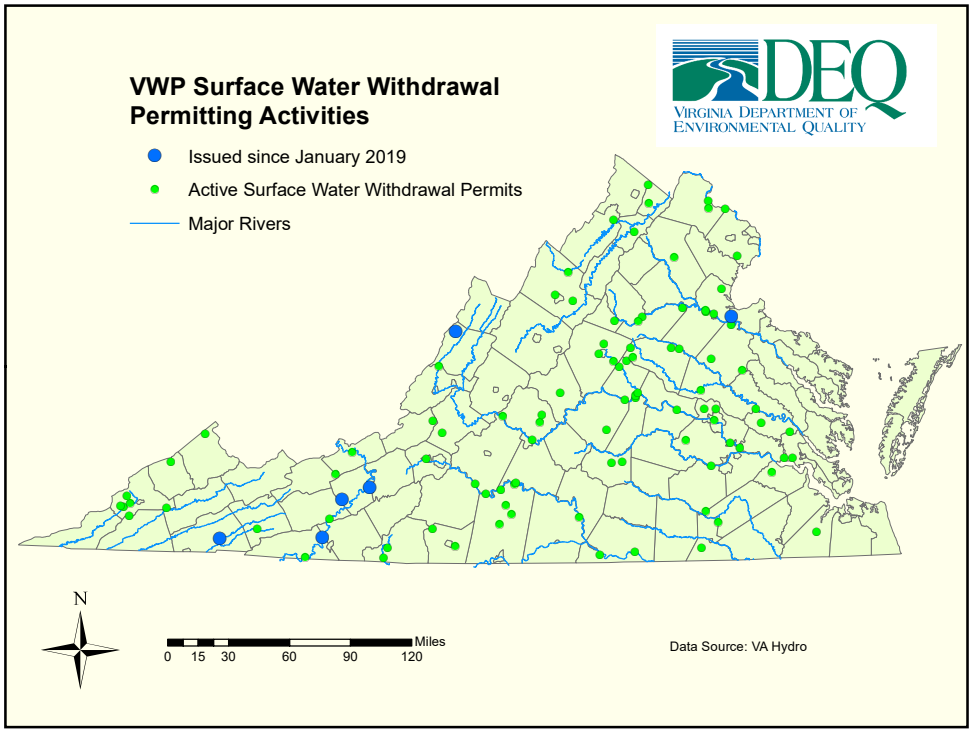

Figure 7: Surface Water Withdrawal Permitting Activities

Surface Water Management Areas

In 1989, the Virginia General Assembly enacted legislation providing for the creation of a Surface Water Management Area (SWMA) [27] for the purpose of protecting in-stream uses from excessive surface water withdrawals. The legislation and resulting regulation [28] authorizes the SWCB to establish a SWMA when there is evidence that: 1) a stream has substantial instream values as indicated by evidence of fishery, recreation, habitat, cultural or aesthetic properties, 2) historic records or current conditions indicate that a low flow condition could occur which would threaten important instream uses, and 3) current or potential offstream uses contribute to or are likely to exacerbate natural low flow conditions to the detriment of instream values. The legislation also encourages the SWCB to promote voluntary agreements among surface water users within the same designated SWMA. The SWCB would, after sufficient public notice, approve and be a party to any such voluntary agreement, and the agreement would act in lieu of a permit issued by the SWCB to withdraw surface water. The cumulative impact analyses completed by DEQ may form the basis for a SWMA designation. To date, no surface water management areas have been designated within the Commonwealth.

Ground Water Management Areas

The Ground Water Management Act[29] of 1992 was adopted in order to conserve, protect, and beneficially utilize the groundwater of the Commonwealth and to ensure the public's welfare, safety, and health. The Virginia General Assembly determined that the continued and unrestricted usage of groundwater is causing and will continue to contribute to the degradation of groundwater quality and shortage of groundwater. The legislation authorizes the SWCB to establish a Groundwater Management Area (GWMA) when there is evidence that 1) ground water levels

[27] Va. Code §§ 62.1-242 through 62.1-253 (1989)
[28] 9VAC25-220
[29] Va. Code §§ 62.1-254 through 62.1-270 (1992)

in the area are declining or are expected to decline excessively, 2) the wells of two or more ground water users within the area are interfering or may reasonably be expected to interfere substantially with one another, 3) the available ground water supply has been or may be overdrawn, or 4) the ground water in the area has been or may become polluted. Pollution includes any alteration of the physical, chemical or biological properties of ground water which has a harmful or detrimental effect on the quality or quantity of such waters. Currently, there are two GWMAs designated in the Commonwealth (Figure 8), the Eastern Virginia Groundwater Management Area, which includes all areas east of interstate 95, and the Eastern Shore Groundwater Management Area, which covers Accomack and Northampton Counties.

Groundwater Withdrawal Regulations

The Groundwater Withdrawal Regulations[30] regulate groundwater withdrawals in the two designated GWMAs, defined by the regulation as "a geographically defined groundwater area in which the [State Water Control Board] has deemed the levels, supply or quality of groundwater to be adverse to public welfare, health and safety." Any person or entity located within a declared GWMA must obtain a groundwater withdrawal permit to withdraw 300,000 gallons or more of groundwater in any month.

Groundwater withdrawal permit applications for new or expanded withdrawals in a GWMA are evaluated to determine impacts of the proposed permit on the groundwater resource. The evaluation determines the area of impact, the potential for a proposed withdrawal to cause salt water intrusion, and assesses the impact of the combined draw down from all existing lawful withdrawals. Existing lawful withdrawals include those permits issued under historic use conditions and current new or expanded use permits, as well as users that withdraw less than 300,000 gallons per month.

As of July 2020, DEQ administers a total of 370 groundwater withdrawal permits. These users are authorized to withdraw a combined total of approximately 46.3 BGY, which equates to an annual average withdrawal rate of 127 MGD. Figure 8 provides an overview of groundwater withdrawal permit activity within the Commonwealth.

[30] 9VAC25-610

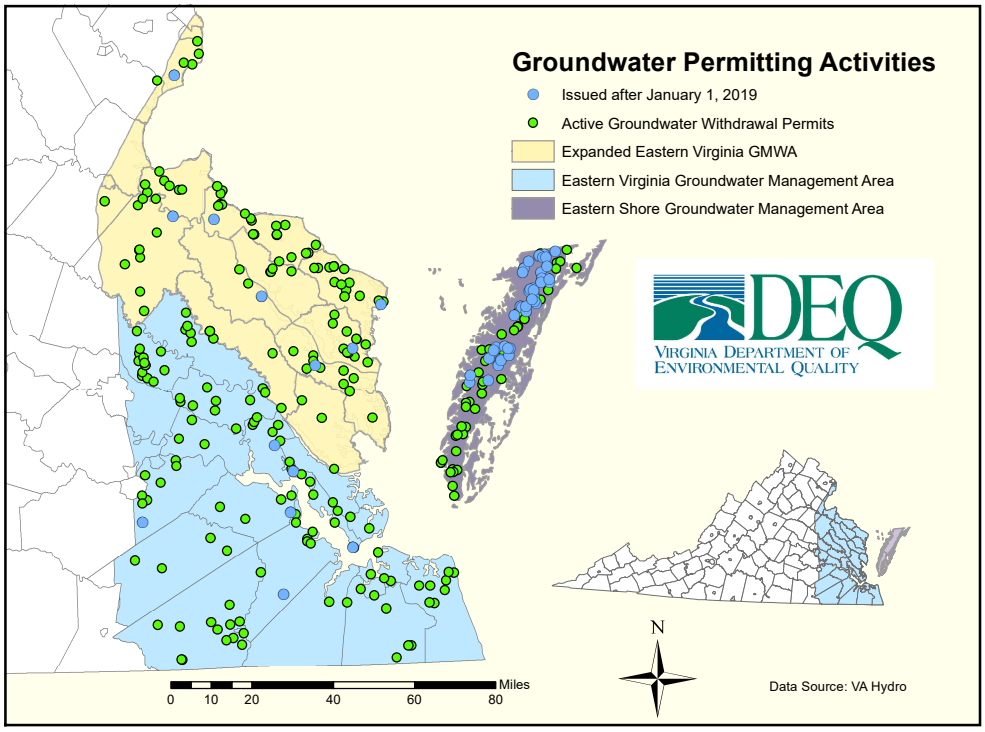

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Figure 8: Groundwater Withdrawal Permitting Activities: January 2020

Water Reclamation and Reuse Regulation

Water reuse is a nontraditional water alternative listed as one consideration for water supply planning programs to address in the Statement of Need and Alternatives section of the WSP Regulation.[31] The reclamation and reuse of either municipal or industrial wastewater is regulated in accordance with the Water Reclamation and Reuse Regulation.[32] Reclaimed water includes wastewater, stormwater, or gray water that is treated to remove pollutants and pathogens which are potentially harmful to the environment or human health. Reclaimed water can be reused in a variety of ways for non-potable purposes. The greater the potential for public contact with reclaimed water for a particular reuse, the more treatment and disinfection the water will require to protect public health.

Facilities that typically require a permit for water reclamation and reuse include reclamation systems, satellite reclamation systems, and reclaimed water distributions systems. End users of the reclaimed water are rarely required to obtain a permit. A reclamation system associated with a wastewater treatment facility (WWTF) that has or will have a surface water discharge is covered under the Virginia Pollutant Discharge Elimination System Permit Program (VPDES). A reclamation system associated with a WWTF that does not or will not have a surface water discharge is covered under the Virginia Pollution Abatement Permit Regulation (VPA). Water reclamation systems independent of treatment facilities and reclaimed water distribution systems require a VPA individual permit.

A cumulative impact analysis is considered for all new or expanding water reclamation and reuse projects that have the potential to reduce the discharge of a VPDES permitted WWTF to surface waters. This applies to WWTFs that divert a portion or all of their discharge to a reclamation system, and to sewage collection systems that divert a portion of the sewage that they convey to a satellite reclamation system to produce reclaimed water for reuse. CIAs for proposed water reclamation and reuse projects are performed

[31] 9VAC25-780-130.C
[32] 9VAC25-740

by DEQ based on the information provided by the owner of each project. DEQ will, in consultation with an applicant, determine the need for completion of a CIA based upon the scale of the reduction in the VPDES permitted discharge in relation to the receiving stream(s).

In Virginia there are a number successful water reclamation and reuse programs. New Kent County has treated and provided millions of gallons of non-potable wastewater effluent to customers since 2002. In 2011, renovations to the County's WWTF at Parham included the construction of a new reclaimed water system. Reclaimed water is provided to two golf courses for irrigation use and a horse racing track for dust suppression and irrigation. New Kent County is located within the Eastern Virginia GWMA and their water reclamation and reuse program conserves potable groundwater while also putting fewer nutrients back into surface waters.

The only indirect potable resuse (IPR) project in Virginia is implemented by the Upper Occoquan Service Authority (UOSA) in northern Virginia. The UOSA is permitted to discharge up to 54 MGD of treated reclaimed water into a tributary of the Occoquan Reservoir. The UOSA project is the longest running potable reuse project in the United States. It predates Virginia's Water Reclamation and Reuse Regulation, therefore it is not subject to the requirements of the regulation. Nonetheless, this project is still subject to equally protective environmental and human health requirements, as detailed in the Occoquan Policy.[33]

Water reclamation and reuse can have a positive effect on water supply by reducing the amount of water needed to meet demand, as the reclaimed water is used to supplant other sources. On the other hand, water reuse can impact downstream users who previously benefited from the discharge of treated wastewater, as such discharges supplement surface water flow. When wastewater is reused, it is removed from the source and may affect beneficial uses downstream. This underscores the importance of completing a cumulative impact analysis to evaluate the potential benefits and/or impacts.

Drought Assessment and Response

The Virginia Drought Monitoring Task Force (DMTF) is an interagency group of technical representatives from state and federal agencies responsible for monitoring natural resource conditions and the effects of drought on various segments of society. The Virginia Drought Assessment and Response Plan directs the DMTF, which is coordinated by the DEQ, to meet to assess hydrologic conditions and make recommendations to the Virginia Drought Coordinator. Meetings are held regularly when moderate drought conditions occur. There are 13 drought evaluation regions (Figure 9) designated by the Virginia Drought Plan. Since the Virginia Drought Plan's adoption in 2003, drought watch declarations have been issued for various regions nearly every year, but drought warning declarations have occurred less frequently. A Drought Emergency declaration has not been issued since the 2002 drought.

Drought monitoring is an important component of water resources management. Careful observation and analysis of groundwater levels and surface water flow is paramount to thoughtful and fair resource decisions. Planning for conservation during water shortages allows all users to share the responsibility. To view daily drought conditions, DEQ provides a drought indicator map on the agency's website, which can be viewed online at Current Drought Conditions in Virginia.

[33] 9VAC25-410

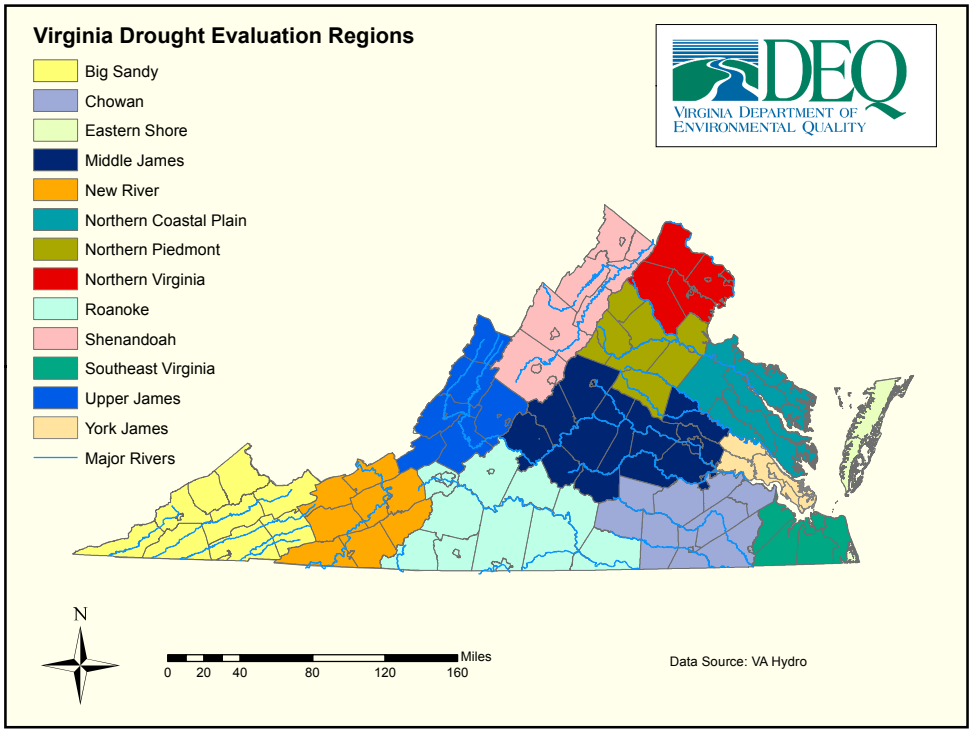


Figure 9: Virginia Drought Evaluation Regions

Source Water Protection

In Virginia, the VDH's role in public water supply is to ensure that all people in Virginia have access to an adequate supply of affordable, safe drinking water that meets federal and state drinking water standards. The VDH enforces drinking water regulations and standards of the Virginia Public Water Supply Law[34] and the federal Safe Drinking Water Act[35] (SDWA). The VDH monitors drinking water quality, provides technical assistance and training with respect to all drinking water issues, and provides financial assistance to improve drinking water systems. VDH also supports voluntary source water protection efforts.

In 1986, amendments to the SDWA established a federal Wellhead Protection Program to protect groundwater that supplies wells and wellfields contributing to public water supply systems. The legislation called on states to develop programs that would protect groundwater-based public water supplies from contaminants that may adversely affect human health. Ten years later, the SDWA Amendments of 1996 established a Drinking Water State Revolving Fund (DWSRF) Program and expanded the protection concept to include surface waters. As a part of the DWSRF Program, funds have been set aside to enhance the ability of waterworks owners to ensure long-term capacity to produce safe drinking water and to protect source waters, including groundwater that supplies wells, wellfields, and surface-based systems. Protecting source water can benefit the environment, waterworks owners, and the public. The environment benefits from a reduced risk of contamination and impacts to ecosystems, the owner benefits from lower and/or sustainable operational costs in treating the water, and the public benefits from safer drinking water and a cleaner environment.

The 1996 Amendments to the SDWA also required states to develop a Source Water Protection Program (SWAP) and complete assessments and susceptibility evaluations on all public water supply sys-

[34] Va. Code §§ 32.1-167 through 32.1-176 (1950)
[35] 42 U.S. Code § 300f et seq. (1974)

tems. In Virginia, this effort was completed in 2003. The objective of the SWAP is to facilitate and promote the implementation of source water protection measures among water supply systems. To achieve the objective, VDH delineates an assessment area for each drinking water source and creates an inventory of potential sources. This information is used to make a susceptibility determination of the drinking water source in relation to the potential source of contaminants found in the assessment area.

VDH and DEQ encourage and provide support, both financial and technical, towards the development of source water protection plans. These plans are voluntary. Virginia's Source Water Protection Program focuses on the reduction of contamination to water sources to ensure the sustainability of Virginia's drinking water supply. Since 2005, DEQ and VDH have collaborated to offer grants for local wellhead protection implementation projects. In 2014, VDH became the lead agency responsible for funding and managing the grants. Both agencies continue to collaborate in offering this grants program. Past grant awards have included projects for well abandonment, educational outreach, developing zoning ordinances, wellhead fencing, and wellhead protection area delineation.

Virginia River Commissions

Virginia River Commissions are established in federal and state codes to provide guidance and make recommendations to local, state, and federal legislative and administrative bodies regarding the use, stewardship, and enhancement of a river basin's water and other natural resources. The commissions promote communication, coordination, and education and can undertake basin studies and prepare, publish, and disseminate basin reports related to water quantity, quality, and other natural resources. Virginia has five river basin commissions with legislative representation.

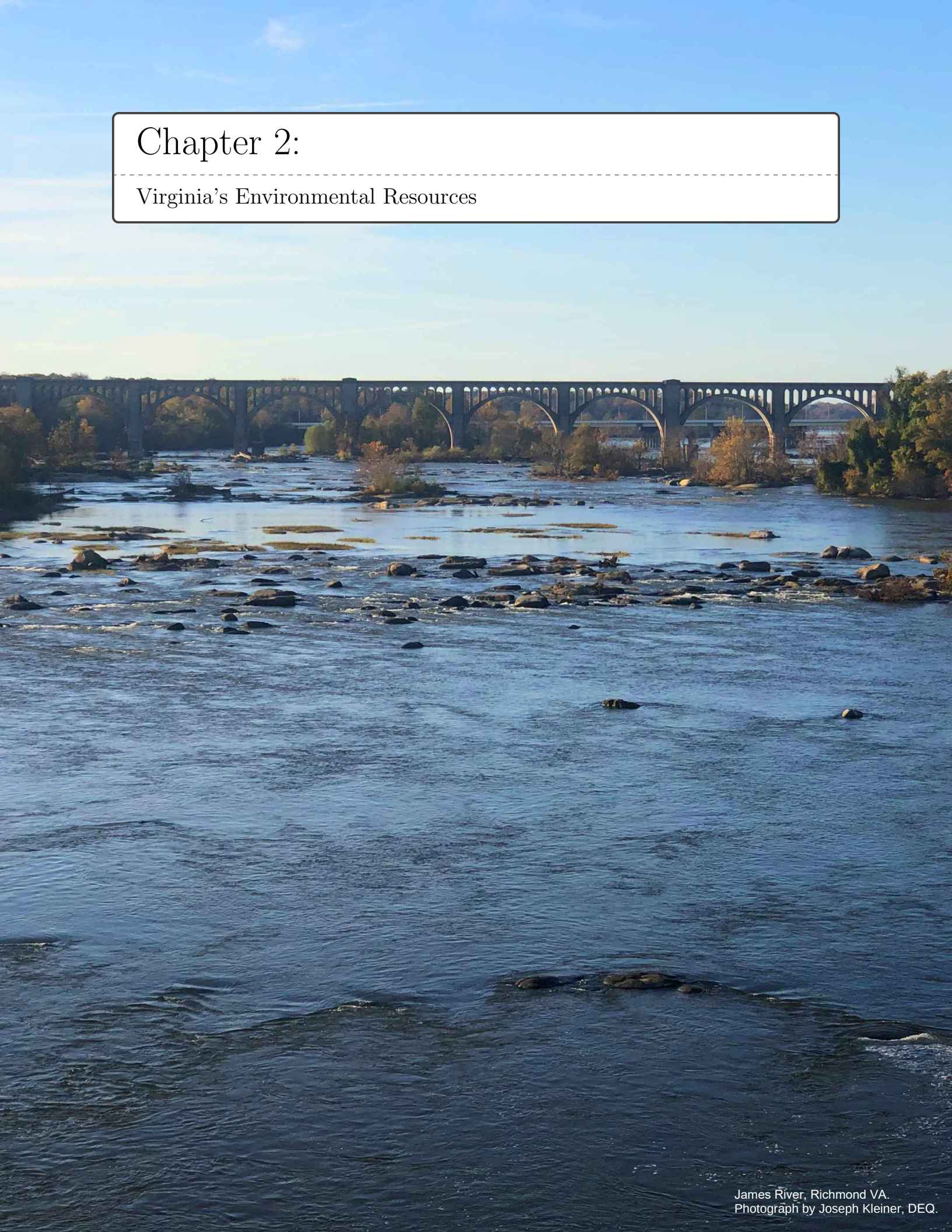
Virginia's River Commissions:

- Interstate Commission on the Potomac River Basin (ICPRB)
- Ohio River Valley Water Sanitation Commission (ORSANCO)
- Rappahannock River Basin Commission
- Rivanna River Basin Commission (Rivanna RBC)
- Roanoke River Basin Bi-State Commission

The watersheds covered by these river commissions range in size from the Rivanna RBC at 760 square miles to the ORSANCO watershed which covers 205,000 square miles within eight states. The larger commissions employ many staff and tackle projects such as water quality studies, drought monitoring, source water protection, and emergency response. The Commissioners of the ICPRB adopted the Potomac Basin Comprehensive Water Resources Plan in June 2018. The plan is the culmination of a multi-year, collaborative stakeholder driven process. The fifteen-year plan describes a shared vision for the basin, identifies water resources issues of interstate and/or basin wide significance, and recommends actions for achieving the shared vision. Plan review will occur every five years to evaluate implementation progress and identify actions for the next five-year period.

Chapter 2:

Virginia's Environmental Resources



James River, Richmond VA.
Photograph by Joseph Kleiner, DEQ.

2 Virginia's Environmental Resources

This chapter provides a general overview of Virginia's climate, surface water, and groundwater resources.

2.1 Virginia's Climate

Virginia has five climate regions according to the University of Virginia Climatology Office.[36] These are the Tidewater, Piedmont, Northern Virginia, Western Mountain, and Southwestern Mountain regions. Virginia's climate is driven from global-scale weather drivers including the Atlantic Ocean, the gulf stream, latitude, as well as by regional topographic characteristics that differ between physiographic provinces. Virginia's annual average precipitation between 1895-1998 was 42.7 inches, but that can vary significantly across the state. Thirty-three inches is typical of the Shenandoah Valley; sixty inches or more is not uncommon in the mountains of southwestern Virginia. East of the Blue Ridge Mountains Virginia is considered to have a humid sub-tropical climate. Climate west of the Blue Ridge in the southern part of the Shenandoah and Roanoke Valleys, is considered humid continental and maritime temperate, and experiences lower humidity and is 5 to 10 degrees Fahrenheit cooler on average across all seasons compared to areas east of the Blue Ridge.

2.1.1 Influences of Geography and Water Bodies on Climate

Geography and water features across Virginia influence and drive regional climactic conditions in three primary ways. First, proximity to the Atlantic Ocean and the warm waters of the Gulf Stream directly influence weather patterns. As westward winds push storms east across the state, there is a tendency for storms to shift northeastward and parallel to the coast and Gulf Stream. The shift is the result in part from the tendency of storms to follow the boundary between the cooler land surface and the warmer waters of the Gulf Stream. Increased moisture and energy along the coast allows storms to grow rapidly, with the eastern foothills of the Blue Ridge Mountains as the prime recipients of this moisture.

Secondly, the increase in elevation and topographic relief in the Appalachian and Blue Ridge Mountains is a major driver of precipitation patterns in Virginia. The mountains create a well defined rainfall pattern driven by the interactions of moisture rich air moving along the mountains. As a result, a rain shadow effect occurs as moisture rich air is blocked by the mountains on the windward side resulting in a "shadow" or area of little precipitation on the leeward side. The highest amounts of rainfall occur in far southwest Virginia and along the eastern edge of the Blue Ridge Mountains.

The final regional driver of climate in Virginia is the complex pattern of streams, rivers, and other surface water bodies across the state. In southwestern Virginia, the Clinch and Holston rivers flow south into Tennessee. Moving east across the state, the New River drains northwestward into the Ohio River, while the Shenandoah River flows north into the Potomac. Finally, the Chowan, James, Rappahannock, Roanoke, and York Rivers flow east through the Piedmont into the Coastal Plain. Each major river influences the movement of air across the State, generally air currents follow the major river valleys or mountains. For example, flow of moist air from the south would move up the Holston River Basin, with precipitation amounts increasing as the air cools and falls in the higher elevations near the headwaters. In contrast, the same southerly airflow would track downriver (North) in the New River Basin and into the Ohio Basin.

Rainfall in Virginia is primarily associated with the movement of warm and cold fronts across the state. As previously discussed, storms generally move from west to east, and northeast when in the vicinity of the coast. Storms are most frequently observed moving parallel to the Appalachian and Blue Ridge Mountains, the coast, and Gulf Stream.

2.2 Hydrology of Virginia

[36] https://climate.Virginia.edu/Virginia$_c$*limate.htm*

Hydrology is the study of water on Earth both above and below ground. This includes the movement of water, its physical and chemical properties, along with its relations with living and non-living components of the environment. Virginia has an abundance of hydrologic features across the state. With over 50,000 stream and river miles within nine major river basins. Each of those nine major river basins can be broken down into smaller river basins, which the State Plan does for several parts of the upcoming analysis.

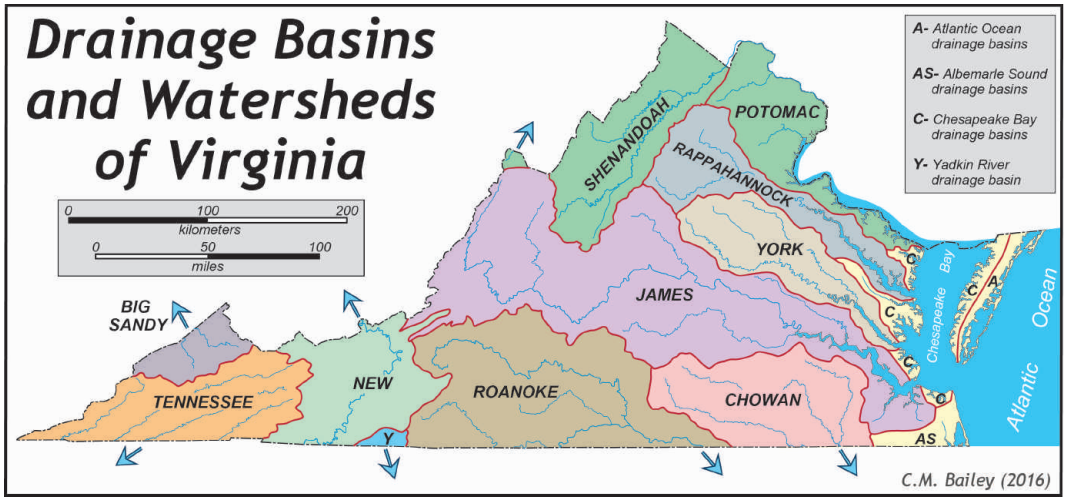


Figure 10: Major River Basins of Virginia

Characteristics of each river basin are directly related to the geography and physiographic provinces they flow through. Streams of the Valley and Ridge flow down linear valleys between parallel ridges. Streams of the Blue Ridge descend rapidly from sharp ridges and mountain slopes to channeled valley floors. In the Piedmont, moderate and lower gradients lead to sharp relief along the Fall Zone into the Coastal Plain. As gradients flatten throughout the Coastal Plain, stream flow slows and channels widen into broad estuaries entering the Chesapeake Bay.

In addition the network of river basins, Virginia contains a significant number of reservoirs formed from construction of dams and impoundments within stream channels. In total, 248 publicly-owned lakes are spread across the state and have a combined area of approximately 130,344 acres. Of the 248 publicly owned lakes, only two are naturally occurring: Lake Drummond in Great Dismal Swamp and Mountain Lake in Giles County. The three largest impoundments (Lake Gaston, Kerr, and Smith Mountain) account for two-thirds of the total impounded area in Virginia.

Other significant hydrologic features of Virginia include approximately 236,900 acres of tidal and coastal wetlands, 808,000 acres of freshwater wetlands, 120 miles of Atlantic Ocean coastline, and over 2,300 miles of estuaries. Virginia's total shoreline including the Chesapeake Bay and estuaries is approximately 3,315 miles long. Detailed maps of rivers, lakes, and hydrologic features are provided in individual watershed sections in Appendix A.

2.2.1 Hydrologic Cycle and Virginia's Water Budget

The hydrologic cycle is a complex series of processes through which water is continuously transported. Water vapor from evaporation and transpiration collects and condenses forming clouds. As air currents circle the globe, land surfaces and water bodies receive precipitation. In Virginia, much of it ends up in the Chesapeake Bay, and then the Atlantic Ocean. But along the way this precipitation generates runoff, snow pack, groundwater recharge, or is utilized by plants and animals. The question of a water budget, or how much water is available in total, and how do current uses impact that total, is one of the core questions that the State Plan seeks to address in the following chapters.

2.3 Geology and Groundwater of Virginia

Spanning over 400 miles along its southern boundary, Virginia reaches from the Atlantic Ocean in the east, to the eastern continental divide to the west. The characteristics of geology vary across the state. With unique geomorphology and relief distinguishing five physiographic provinces: the Appalachian Plateau, Valley and Ridge, Blue Ridge, Piedmont, and Coastal Plain.

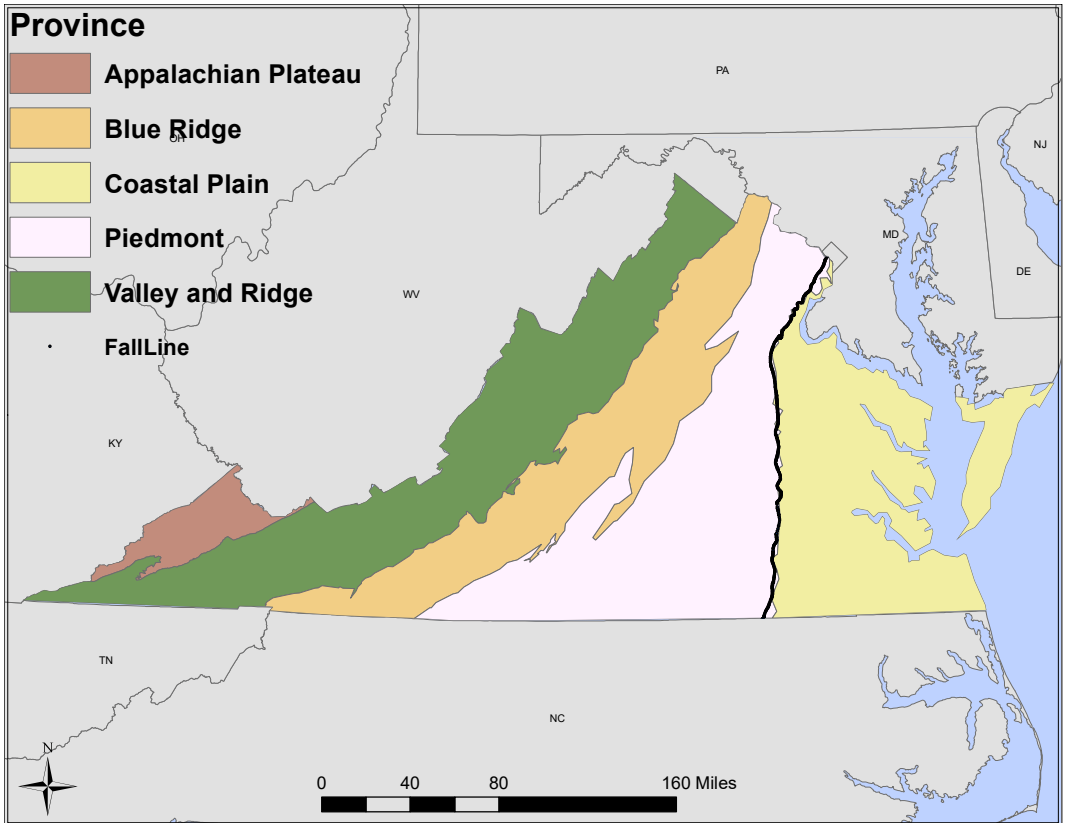


Figure 11: Physiographic Provinces of Virginia

2.3.1 Appalachian Plateau

Located in far southwest Virginia, the Appalachian Plateau is characterized by a well-dissected rugged landscape with dendritic drainage patterns. Elevations in the province range from 1,000-4,000ft and average between 2,000-2,500ft above sea level. The highest elevation occurs at High Knob near Norton, VA at 4,223ft above sea level. Two sub-provinces, the Allegheny Plateau and the Cumberland Plateau are divided by an area of transition between upturned edges of the Appalachian Plateau, where the horizontal beds of the Plateau give way to the folded beds of the Valley and Ridge. This area is known as the Allegheny Fold and is along the New River through West Virginia.

Rocks in the province are primarily horizontally lying or broadly and gently folded sedimentary. The largely homogeneous subsurface geology is responsible for the dendritic drainage pattern. As streamflow or runoff encounters rocks of similar weathering rates, tributaries struggle to control the direction of flow. Older Cambrian rocks lie underneath the top-most, and younger Pennsylvanian rocks. Composed of primarily hard sandstone, Pennsylvanian rocks form the mountain tops of the province and often contain reserves of coal. With steep faces throughout the region, rivers have eroded and carved deep valleys into the sandstone to expose the softer underlying rocks.

Only a small portion of Virginia lies in the Appalachian plateau Province, and that portion is lo-

cated entirely within the Cumberland Plateau subprovince. This area is Underlain by the same Paleozoic sedimentary rocks as the Valley and Ridge-primarily sandstone, shale, and coal. While the sedimentary rocks are similar, in the Cumberland Plateau they have not yet been deformed and still occur in horizontal formations.

The consolidated geology of the Cumberland Plateau generally produces poor quantity and quality of groundwater due to high acidity, concentrations of iron, manganese, sulfates, and dissolved solids. Quality also varies with depth, with the first 100ft of rock below stream level often being of the lowest quality. Additionally, naturally occurring saline waters occur at depths greater than 300ft. Portions of the province have acceptable quality groundwater between 150-300ft below surface; however in areas where coal mining operations have occurred, mine drainage has impacted quality and is predominately not suitable for most uses. Due to these issues, constructing or maintaining a well with dependable water quality and quantity is difficult and can become a significant investment.

Sandstone cemented throughout the Plateau rock formation has secondary permeability features such as bedding-plane separation, open fractures, and cleats; these features found in coal seams account for the majority of groundwater movement in the region. Groundwater flow across gradients exploits stress-relief fractures along valley walls forming localized discharges. Regional groundwater movement is likely dominated by permeability along coal bed cleats as transmissivity along coal seams is of much higher magnitude than all other rock types in the plateau. Due to groundwater concerns and challenges, the region is largely supplied by surface water sources.

2.3.2 Valley and Ridge

Geology of the Valley and Ridge Physiographic Province consists of Cambrian to Mississippian sedimentary rocks that were faulted, tilted, and folded during the Pennsylvanian and Permian periods. Consolidated sedimentary rocks underlie the Valley and Ridge including limestone, sandstone, and dolomite blocks. The blocks lay in parallel layers of sandstone and shale ridges. The valleys are primarily carbonate. The harder sedimentary ridges and softer carbonate valleys pushes water to drain parallel to ridges, creating a trellis drainage pattern as the carbonate is eroded.

The western boundary of the Valley and Ridge is formed by the Allegheny Front, an abrupt change from the horizontal rocks of the Plateau to the folded and faulted rocks in the Valley and Ridge. Groundwater across the region varies as sandstone and shale ridges often supply limited yield sufficient for only rural or domestic uses. In the low lying portions of the province such as the Shenandoah Valley, limestone and dolomite formations provide one of the highest producing aquifer systems in Virginia. Karst topography including sinkholes, caves, and underground streams characterize the region and are an extremely important source of water supply. Springs in the region are especially important as discharges from large springs commonly exceed hundreds or thousands of GPM.

Groundwater and surface water interaction in the province is a major influence and driver of stream discharge and groundwater recharge. Aquifers are often recharged when streams cross fault zones; wells intersecting these fault zones produce the highest yields along the Valley and Ridge. Additionally, limestone sinkholes and underground networks allow water to bypass prolonged infiltration through soil and directly enter groundwater systems. Due to the complexities of karst geology formations, delineation and development of source water protection areas is challenging, as underground limestone conduits act as hidden streams capable of rapid pollution transport.

2.3.3 Blue Ridge

Ranging from 4-26 miles at its widest, the Blue Ridge Physiographic Province is a narrow region including the Blue Ridge Mountains and the area eastward including Galax, Charlottesville, and Warrenton. Geologically defined by underlying course-grained igneous and metamorphic Grenville basement rocks, with some intrusive and sedimentary rocks present, the region is largely impervious with shallow soils. The Blue Ridge also contains the oldest rocks in the Commonwealth dating back to 1.1-1.9 billion years and provides some of the lowest producing groundwater withdrawals in the state.

Groundwater is primarily transmitted and stored in fractured rock and faults due to impervious bedrock. Compared to the Appalachian Plateau the Blue Ridge has higher-quality groundwater, insoluble rocks, with elevated concentrations of iron and radon spread through the province. This region's ability to transmit and store groundwater is highly variable and dependent on factors including orientation of the fracture network, source of recharge, and others. As a result, minimal residential and industrial development has occurred in the Blue Ridge, with groundwa-

ter withdrawals primarily used to supply private domestic wells rather than larger public supplies. With sporadic well yields. Springs occurring at lower elevations are also used as private water sources.

Developing a consistent yielding well in the Blue Ridge for uses other than residential often requires site specific studies incorporating geophysical and geological mapping to maximize water yield. Larger regional groundwater sources are often found in structurally complex zones of the Vinton/Roanoke area. Transverse faulting is believed to have created the high transmissivity sources compared to the largely impervious bedrock found in the region.

2.3.4 Piedmont

The largest of Virginia's physiographic provinces, the Piedmont spans from the Blue Ridge mountains in the west to the fall zone in the east. The principal differences between the Blue Ridge and Piedmont are relief, altitude, and geographic position. The Piedmont is characterized by broad rolling hills, thicker soil profiles, and further weathered bedrock.

Hard crystalline igneous and metamorphic formation dominate the region, with sporadic sedimentary and saprolite (clay/silt) deposits overlying bedrock. With weathered bedrock overlying more impervious rock underneath, groundwater supplies are primarily found within a few hundred feet of the surface with transmissivity decreasing with depth.

Extensive fracture and fault systems occurring throughout the western edge of the Piedmont, at the base of the Blue Ridge often yield large groundwater supplies. Diversity of subsurface geology across the Piedmont leads to wide variations of groundwater quality and well yields, and areas where groundwater use is less viable. High iron concentrations, acidity, and dry holes are not uncommon and usually limit wells within 300ft of the land surface. Similar to the Blue Ridge, well locations and site evaluations are critical, including evaluation of wellhead protection zones. Assumptions of porosity and permeability of overlying saprolite are often made to determine estimates of wellhead protection areas.

2.3.5 Coastal Plain

As the easternmost province, the Coastal Plain is a highly unique and diverse province. With the fall zone marking the western boundary with the Piedmont and the Chesapeake Bay and Atlantic Ocean to the east, the broad low relief slopes widen into large easy to navigate waterways. The youngest of all provinces, rocks were deposited after the Atlantic Ocean began to form in the early Mesozoic Period. Several low wave cut terraces define the landscape where softer sedimentary rocks of the Coastal Plain abut resistant metamorphic rocks of the Piedmont. The formations create a low escarpment visible on the landscape known as the fall line. Passing through Fairfax, Fredericksburg, Richmond, Petersburg, and Emporia, the fall line provides easy access to the major rivers of Virginia, and serves as a geologic barrier to ships traveling upstream. The impasse of ships during initial European colonization resulted in the settlement of major cities as shipment points including Richmond.

Topography of the province is defined by a terraced landscape gradually stepping down to broad flat land to the coast. Major rivers including the James, Potomac, Rappahannock, and York flow southeastward across the region into the Chesapeake Bay, and eventually into the Atlantic Ocean. Three primary peninsulas were dissected from the flow of the major rivers and were named by Virginia's European settlers. The Northern Neck, Middle Peninsula, and Virginia Peninsula are primarily composed of layered unconsolidated deposits of sand, silt, and clay.

The Northern Neck is the northern most of the three peninsulas, bounded by the Potomac River in the north and the Rappahannock River to the south the area includes: Lancaster, Northumberland, Richmond, and Westmoreland Counties. The Middle Peninsula is the second of the three peninsulas with the Rappahannock River to its north and the York River to the south including: Essex, Gloucester, King and Queen, King William, Mathews and Middlesex Counties. The Virginia Peninsula is the southernmost peninsula and was the primary area of development during initial European settlement. Today the peninsula includes James City and York Counties, and the Cities of Hampton, Newport News, Poquoson, and Williamsburg.

Primarily composed of unconsolidated deposits of sand, silt, and clay, the Coastal Plain groundwater system is drastically different from all other provinces in Virginia. Highly permeable deposits store more groundwater than any other province, with shallow unconfined aquifer systems often overlying relatively impermeable clay beds. These aquifer systems are the source for hundreds of residential, industrial, and other wells. However, pollution potential of uppermost aquifers is high due to the permeability and high population and agricultural activities in the region.

Groundwater quality is generally high, except in

areas of elevated iron, hydrogen sulfide, or in areas that experience saltwater intrusion. Increased withdrawals from the system can impact the salt-freshwater interface gradually. The result is that water quality in some areas of the lower York-James and Norfolk-Virginia Beach peninsulas is not fit for domestic use without treatment. As a result, deeper confined aquifers are the principal source of major groundwater withdrawals in the region.

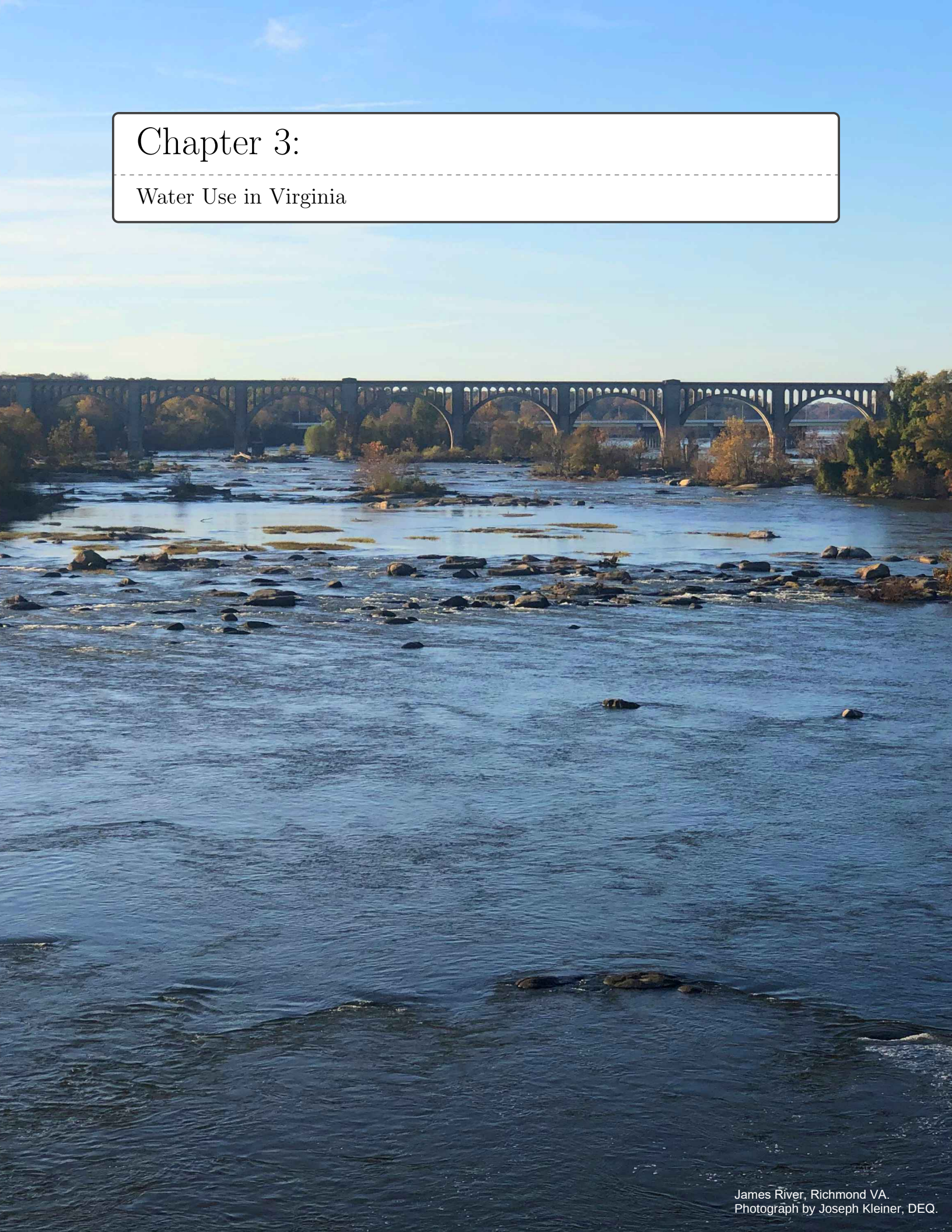
The Virginia Coastal Plain Aquifer system is part of a larger aquifer system spanning from New Jersey to Alabama, which is bounded by the fall line in the west and a saline dense boundary to the east. It is comprised of 19 units which include one unconfined aquifer, seven confined aquifers, and 11 confining units. The Potomac, Virginia Beach, Peedee, and surficial aquifers are composed of quartz/feldspathic sand and gravels; the Aquia, Piney Point, St. Marys, and Yorktown-Eastover aquifers are primarily fossil shell material. Historically, the Potomac aquifers have the highest withdrawal demand. It is the dominant hydrologic unit in the Coastal Plain and supplies most major agricultural, commercial, domestic, industrial, and public water supply wells.

While numerous confining layers are present throughout the Coastal Plain, they restrict, but do not prevent infiltration or vertical flow between aquifers. The recharge area of the aquifers can occur miles from the formation outcrop, however infiltration from the shallow confined aquifer to deeper aquifers can also occur. This type of infiltration can be extremely slow, but does serve as a path for pollutants to reach deeper aquifer systems, and wells that are drilled through the aquifers only increase the likelihood of this occurring. With large numbers of wells present in the Coastal Plain, wellhead protection is critical to ensure deep confined aquifers are not contaminated. In contrast, the surficial aquifer has a more direct interaction with the surface and groundwater nexus with pollutant pathways much easier to identify.

About 35 million years ago in the late Eocene Epoch, a bolide (comet or asteroid-like object from space) hit the earth, leaving behind a crater in the continental shelf near the Town of Cape Charles on Virginia's Eastern Shore. The bolide created what geologists call the "Exmore Crater," or the Chesapeake Bay Impact Crater. Geologists believe the bolide was as large as Rhode Island and as deep as the Grand Canyon. Although the bolide did not create the Chesapeake Bay, it helped determine that a bay would eventually be located there. The inner rim of the CBIC is 23 miles in diameter and the outer rim is 56 miles in diameter. The outer disruption boundary is approximately 80 miles in diameter. The crater impacts groundwater availability and quality in the Middle Peninsula and other parts of Virginia.

Chapter 3:

Water Use in Virginia



James River, Richmond VA.
Photograph by Joseph Kleiner, DEQ.

3 Water Use in Virginia

3.1 Water Supply Planning Data Collection in Virginia

Water demand information used in the State Water Resource Plan comes primarily from three sources: local and regional water supply plans, annual water withdrawal reporting, and water withdrawal permit reporting. The 48 local and regional water supply plans include water sources, demand estimates, and future water demand projections, among other information. Annual water withdrawal reports from individual users collected each year through the Annual Water Withdrawal Reporting Regulation[37] provide data on current use, which is important context for water supply plan estimates. In whole more than one thousand surface water intakes and twenty-five hundred groundwater wells were included in the evaluations completed for the 2020 State Water Resources Plan.

3.2 Virginia Statewide Summary

The following section covers statewide water use trends based on the data described above with primary focus on the information submitted in the water supply plans. This information should be viewed as a counterpart to the information provided annually in the "Annual Report on the Status of Virginia's Water Resources", which includes detailed information on water use as reported to DEQ by individual users and permittees annually. This demand information is also covered at the minor basin scale in Appendix A.

3.2.1 Existing Water Sources & Use

All water that is withdrawn in Virginia comes from a source, whether through a well or a surface water intake. Water Supply Plans include the type and amount of demands for existing sources, as well as for transfers of water between users or facilities. Figure 12 provides a spatial overview of the 2020, or current estimated, demands statewide. Most localities in Virginia estimate less than 10 MGD in total demand. Several localities in Virginia make up the majority of demands, particularly when including power generation facilities such as nuclear power plants (as this figure does).

[37] §9VAC25-200

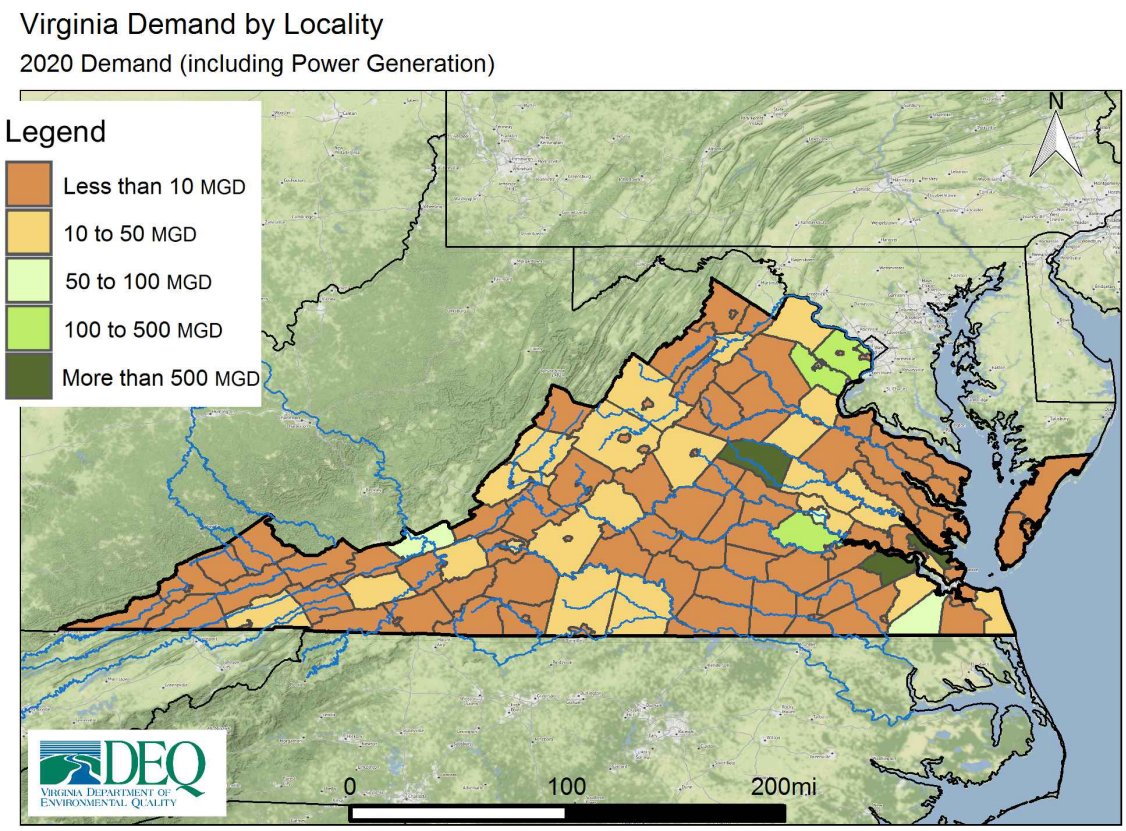


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Figure 12: Current Total Water Demand in Virginia

Table 2 below shows the statewide total of groundwater and surface water sources and current estimated demands as reported by localities categorized by use type. The number of reported groundwater wells is more than twice the number of surface water intakes. However, it is important to remember that in general, surface water intakes are more productive than groundwater wells. For most groundwater users of moderate to large size, multiple wells are needed. Note also that the source count for wells does not include individual domestic or residential wells.

Table 2: Summary of Virginia Water Demand (including Power Generation)

System Type	Source Count	2020 Demand (MGD)	2030 Demand (MGD)	2040 Demand (MGD)	20 Year Percent Change
Surface Water					
Agriculture	456	75.73	77.94	80.15	5.83
CWS	208	884.22	991.25	1098.28	24.21
Large SSU	356	4989.99	5380.03	5770.07	15.63
Small SSU	N/A	0.00	0.00	0.00	0.00
Total SW	**1020**	**5949.94**	**6449.22**	**6948.50**	**16.78**
Groundwater					
Agriculture	500	9.52	9.96	10.41	9.32
CWS	1387	56.57	80.11	103.65	83.23
Large SSU	704	75.95	77.16	78.37	3.19
Small SSU	N/A	137.82	156.25	174.69	26.75
Total GW	**2591**	**279.86**	**323.48**	**367.12**	**31.18**
Total (SW + GW)					
Agriculture	956	85.25	87.91	90.56	6.22
CWS	1595	940.78	1071.35	1201.93	27.76
Large SSU	1060	5065.93	5457.18	5848.44	15.45
Small SSU	N/A	137.82	156.25	174.69	26.75
Total Including Power Generation					
Virginia	3611	6229.78	6772.69	7315.62	17.43
Total Excluding Power Generation					
Virginia	3536	1582.83	1748.98	1915.15	21.00

* Small SSU demands are county-wide estimates of private well usage below 300,000 gallons a month. The number of private wells is not known.

In addition to the number of sources identified to DEQ, Table 2 also provides current estimated (2020) demands statewide by use category. In 2020, Virginia's current daily demand was approximately 1,582 MGD or 1.58 billion gallons per day, when excluding power generation.

Including power generation, total current demand is approximately 6,229.7 MGD. As comparing those two numbers makes clear, power generation facilities are the largest withdrawals in Virginia. However, these facilities return the vast majority of their demand to the source, in other words it is not consumed. This section will generally reference water demands while excluding power generation in order to show trends in all other water use categories.

Table 3 summarizes water demands for all water use categories excluding power generation facilities. Approximately 82% of total demand is from surface water sources including streams, rivers, or springs. The remaining 18% is from groundwater sources including private residential wells.

Table 3: Summary of Virginia Water Demand by Source Type and System Type (excluding Power Generation)

System Type	Source Count	2020 Demand (MGD)	2030 Demand (MGD)	2040 Demand (MGD)	20 Year Percent Change
Surface Water					
Agriculture	456	75.73	77.94	80.15	5.83
CWS	208	884.22	991.25	1098.28	24.21
Large SSU	328	343.47	356.76	370.05	7.74
Small SSU	N/A	0.00	0.00	0.00	0.00
Total SW	**992**	**1303.42**	**1425.95**	**1548.48**	**18.80**
Groundwater					
Agriculture	500	9.52	9.96	10.41	9.32
CWS	1387	56.57	80.11	103.65	83.23
Large SSU	657	75.51	76.72	77.92	3.19
Small SSU	N/A	137.82	156.25	174.69	26.75
Total GW	**2544**	**279.42**	**323.04**	**366.67**	**31.23**
Total (SW + GW)					
Agriculture	956	85.25	87.91	90.56	6.22
CWS	1595	940.78	1071.35	1201.93	27.76
Large SSU	985	418.98	433.47	447.97	6.92
Small SSU	N/A	137.82	156.25	174.69	26.75
Virginia	**3536**	**1582.83**	**1748.98**	**1915.15**	**21.00**

* Small SSU demands are county-wide estimates of private well usage below 300,000 gallons a month. The number of private wells is not known.

Table 4 summarizes both permitted and unpermitted water demands for all water use categories including power generation facilities. Currently, approximately 2072 MGD of surface water demands including power generation are permitted across Virginia, while 3877 MGD in surface water demand are unpermitted. Power generation facilities represent approximately 89.5% of permitted surface water demand, with community water systems the second largest category. Groundwater demands associated with permitted facilities currently account for approximately 64.16 MGD of total groundwater demands, all located within current Groundwater Management Areas east of I-95 and the Eastern Shore.

If power generation is excluded, the percentage of total demands that are associated with unpermitted facilities would be higher as permitted power generation facilities such as Dominion Power's Lake Anna Nuclear Plant represent a significant majority of the permitted surface water demands.

Table 4: Permitted vs. Unpermitted Virginia Water Demand

System Type	Permitted				Unpermitted			
	2020	**2030**	**2040**	**% Change**	**2020**	**2030**	**2040**	**% Change**
Surface Water								
Agriculture	0.69	0.76	0.82	19.40	75.04	77.18	79.33	5.71
CWS	215.83	257.29	298.75	38.42	668.39	733.96	799.53	19.62
Large SSU	1855.86	2230.60	2605.34	40.38	3134.12	3149.43	3164.73	0.98
Small SSU	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total SW	**2072.38**	**2488.65**	**2904.91**	**40.17**	**3877.55**	**3960.57**	**4043.59**	**4.28**
Groundwater								
Agriculture	1.19	1.25	1.30	8.43	8.33	8.72	9.11	9.44
CWS	24.10	35.46	46.83	94.36	32.47	44.64	56.81	74.98
Large SSU	38.87	39.24	39.61	1.90	37.07	37.92	38.76	4.55
Small SSU	0.00	0.00	0.00	0.00	137.82	156.25	174.69	26.75
Total GW	**64.16**	**75.95**	**87.74**	**36.75**	**215.69**	**247.53**	**279.37**	**29.52**

Water demands in water supply plans are organized into one of four categories: Community Water Systems (CWS), Large Self-Supplied User (Large SSU), Small Self-Supplied User (Small SSU), and Agriculture (AG). The following section defines and covers current estimated use for each category:

Community Water Systems (CWS) are defined by 9VAC25-780-30 as a waterworks that serves at least 15 service connections used by year-round residents or regularly serves at least 25 year-round residents, and is regulated by the Virginia Department of Health Waterworks Regulation (12VAC5-590). This definition for CWS is identical to that of "community waterworks," one of the three types of "waterworks" regulated by the VDH (12VAC5-590-10). CWS demands represent approximately 59% of current water demands with a primary reliance on surface water sources for supply. Surface water demand represents approximately 884 MGD, or 94%, of all water demands for CWS in Virginia. Currently, 24%, or 215 MGD, of surface water demands are associated with facilities operating under a surface water withdrawal VWP permit. More than 75% of all CWS demand is unpermitted, or exempt from VWP permit regulations, which represents the majority of demands from surface water sources for all categories when excluding power generation.

Groundwater supplies 56.5 MGD or approximately 6% of CWS facilities statewide. Note that the total number of groundwater wells (1,387) for CWS facilities outnumbers the number of surface water intakes in the category (207). This is largely result of wide reliance on large scale surface water intakes to supply the largest public water suppliers in Virginia. While groundwater wells far outnumber the number of surface water intakes, capacity for individual wells is generally lower than surface water intakes and supply smaller service areas. Currently, 42% of groundwater demands within the CWS category are associated with facilities operating under a Groundwater Withdrawal Permit. As surface water sources within the GWMAs are limited, reliance on groundwater for public supply is more common.

Large Self-Supplied Users (Large SSU) are non-CWS or AG water users that withdraw more than 300,000 gallons per month from wells or surface water intakes. Large SSUs can include industrial, mining, power generation, or other facilities that require large volumes of water for daily operations. Large SSUs are the second largest demand category in the Commonwealth. Current water demands from Large SSUs are approximately 418 MGD, or 26% of total water demands when excluding power generation. Surface water is the primary water source for Large SSUs with approximately 82%, or 343 MGD of current Large SSU demands supplied by surface water.

Groundwater supplies 75 MGD, or approximately 18% of Large SSU demands. Currently, 38.8 MGD of groundwater Large SSU demands are associated with permitted facilities located in the two GWMA's east of I-95 and on the Eastern Shore. An additional 37 MGD or 49% of statewide groundwater demands are unpermitted. Groundwater users in this category are most widely concentrated within GWMA's where high capacity wells are more common.

Small Self-Supplied Users (Small SSU) are those residences and businesses that are self-supplied

by individual wells withdrawing less than 300,000 gallons of water per month. This category is primarily made up of domestic or residential wells. As a result no surface water demands are included in this category. Small SSU demands are estimated by each locality; in other words they represent locality wide estimates rather than individual user estimates. Currently Small SSUs represent approximately 9%, or 137 MGD of total water demands excluding power generation; However Small SSUs are responsible for more than 49% of total current groundwater demands statewide. Domestic well users, although individually small, can have a large cumulative impact.

Agricultural Self-Supplied User (AG) demand is the Smallest use category overall. AG demands include all types of agriculture such as crop irrigation, livestock, and aquaculture. Some AG demands are locality wide estimates, and some represent individual agriculture users included in the water supply plans. AG demands total approximately 5% of current total water demands when excluding power generation. Approximately 99% of all surface water demands identified in water supply plans for agricultural uses do not meet VWP requirements or are unpermitted.

Similar to CWS and Large SSUs, agricultural users primarily rely on surface water sources to meet water demands with over 88%, or 75 MGD of current AG demands met by surface water sources. Approximately 12.5%, or 9.5 MGD in groundwater demands in the AG category are associated with a facility permitted under a Groundwater Withdrawal Permit. Large agricultural users are concentrated within Virginia's GWMAs and primarily rely on groundwater sources to water livestock or crops.

3.3 Population and Water Demand Projections

Changes in population are one of the major driver's of changes in water demands over time. Increasing population within an area generally means increased connections for community water systems or additional demands from homeowners that construct wells. Increasing population in an area also tends to incentivize both new and expanded industrial and commercial water use. On the other hand, where population is decreasing, so too do water demands. Understanding the trends in Virginia's population is an important component in evaluating future water demands. Virginia's current population estimate for July 1, 2019 based on census data from the University of Virginia Weldon Cooper Center for Public Service was 8,535,519.[38] The Commonwealth's population is expected to increase to approximately 9.31 million in 2030 and 9.87 million in 2040 respectively. However, not all parts of the state are expected to experience that growth equally. Figure 13 provides a spatial overview of how population is trending for each locality.

3.3.1 Areas of Population Growth

Although Virginia is still projected to increase in total population, over the past decade population growth has fallen to the lowest rate since the 1920's. The reduced rate of population growth has been driven primarily by the migration of people into other states, which now exceeds the number of people moving to Virginia on average. However a falling birth rate and aging population, which means more deaths on average per year, has also contributed to this statewide trend.

While population growth has slowed considerably over the last decade statewide, growth within Northern Virginia, the City of Richmond, and Hampton Roads metro areas has continued. Nearly 95% of the projected population increase between 2020 and 2040 is located within these three areas. New residents of Virginia commonly locate in these major metropolitan areas, in addition residents of rural parts of Virginia are more likely to move to these areas of higher economic opportunity.

3.3.2 Areas of Population Decline

While major urban centers and surrounding localities continue to see increasing population, many of Virginia's rural communities have experienced declines in population in recent decades. Fifty-four localities are projected to decline in population through 2040. These localities are primarily within the Southwest and Southern portions of Virginia, and on the East-

[38] University of Virginia Weldon Cooper Center, Demographics Research Group. (2020). Virginia Population Estimates. Retrieved from https://demographics.coopercenter.org/virginia-population-estimates

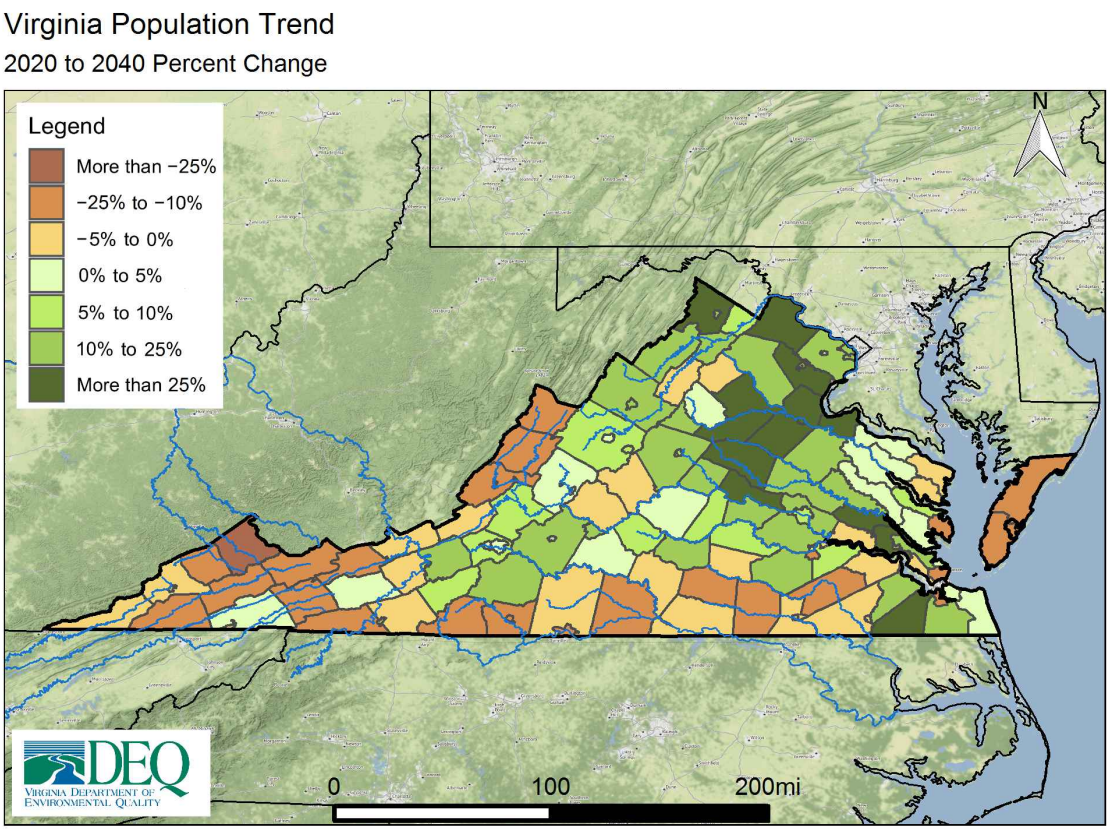

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Figure 13: Projected Change in Population in Virginia 2020-2040

ern Shore. Several factors have influenced the observed and projected decreases in population from the primarily rural localities including: less economic development, an increasing elderly population, and single industry dependence.

A "boom and bust" trend has occurred in many rural areas where population changes in response to opening or closing industries. Additionally, younger generations are increasingly moving to more urban areas, while an aging rural population leads to higher death rates in rural localities. In total, these factors suggest populations will continue to decline across much of the rural portions of the Commonwealth throughout the planning period. For reference, the projected change in population for each locality between 2020 and 2040 can be found in Appendix C.

3.4 Projections of Future Water Demand

Projections of future water demands are one of the key components that form the basis of water supply plans, or any efforts to plan for long term water supplies. Water demands for all categories (including withdrawals for power generation) are projected to increase by approximately 1,085 MGD or 17.4% by 2040. Excluding withdrawals from power generation facilities, water demands are projected to increase by approximately 332 MGD or 21% by 2040. In the following sections, water demand projections and trends are described for each use category.

This section refers back to Tables 2, 3, and 4 which include both the current and future demand information.

3.4.1 Community Water Systems

Demand for CWS facilities is projected to increase by approximately 27% by 2040, making it the fastest growing water use category. The projected increases in demands are generally the result of increasing populations around urban centers. Table 5 shows the ten

largest surface water and groundwater CWS facilities across the state. Demands from the ten largest surface water CWS facilities represent approximately 43% of 2040 total statewide demand when excluding power generation. The largest surface water demands occur within Northern Virginia at the Dalecarlia, Corbalis, and Griffith WTPs, the primary water supplies for the D.C. metropolitan area. While surface water supplies the largest volume of water compared to all other categories, groundwater for CWS facilities is the fastest growing use category with a more than 83% increase in demand projected by 2040.

Table 5: Top 10 Municipal Users in 2040 in Virginia

Facility	2020 Demand (MGD)	2030 Demand (MGD)	2040 Demand (MGD)	20 Year Percent Change	% of Total Surface Water
Surface Water					
Dalecarlia WTP	128.61	135.91	143.2	11.34	9.25
Corbalis WTP	97.68	104.3	110.93	13.56	7.16
Griffith WTP	71.32	76.15	80.99	13.56	5.23
Richmond (City) WTP	63.96	71.02	78.08	22.08	5.04
Western Branch Reservoir	62.58	62.58	62.58	0	4.04
Chesdin Reservoir WTP	33.76	42.38	51.01	51.1	3.29
Henrico County WTP & Service Area	29.87	38.72	47.57	59.26	3.07
Virginia Beach Service Area	28.99	34.47	39.95	37.81	2.58
Roanoke (City) Service Area	18.42	22.39	26.37	43.16	1.7
Hopewell District	22.08	23.38	24.67	11.73	1.59
Total SW	**557.27**	**611.3**	**665.35**	**19.39**	**42.97**
Groundwater					**% of Total Groundwater**
Jcsa - Central System	5.13	8	10.86	111.7	2.96
Western Tidewater Water Authority	3.92	6.17	8.42	114.8	2.3
Three Springs Service Area	2.11	3.55	4.99	136.49	1.36
South River Service Area	2.33	3.56	4.79	105.58	1.31
Northwest River/Western Branch Systems	2.49	3.31	4.13	65.86	1.13
Caroline County Utility System	0.57	2.3	4.02	605.26	1.1
Lake Kilby Water Treatment Facility	2.32	2.39	2.47	6.47	0.67
Dayton Service Area	1.38	1.7	2.02	46.38	0.55
Frederick County Sanitation Authority	0.7	1.35	2	185.71	0.55
Culpeper (Town) WTP	0.73	1.28	1.83	150.68	0.5
Total GW	**21.68**	**33.61**	**45.53**	**110.01**	**12.42**

Table 5 also shows that the largest groundwater supplied CWS facilities are primarily located within the Groundwater Management Areas east of I-95 and in the Shenandoah Valley. These ten largest CWS facilities represent approximately 12% of the total statewide groundwater demand, with significant demand increase projected for many of the largest users. Additionally, Table 4 provides projections for surface water and groundwater demands for CWS facilities operating under a permit. Permitted CWS surface water demands are projected to increase by more than 38%. Permitted CWS groundwater facilities are projected to increase by more than 94% by 2040. While the volume of permitted demands for groundwater and surface water withdrawals is expected to increase, unpermitted demands continue to represent the largest demands in this category throughout the planning period.

As major population centers continue to expand, demands on the largest public water suppliers will continue to increase, particularly in the Northern Virginia, City of Richmond, Hampton Roads, and Roanoke/Salem areas. The observed and projected trend will continue to place increases demands on the largest water suppliers, resulting in increased demands placed on limited surface and groundwater sources. Detailed information on projected demands and potential impact analysis are provided by watershed in Appendix A.

3.4.2 Large Self-Supplied Users

Current total water demand for Large SSU facilities is approximately 419 MGD, which is projected to increase by 6.2% by 2040 when excluding power generation. Statewide water demands in the category are primarily served by surface water sources, which will continue to be the primary water source through 2040. Table 6 shows the ten largest Large SSus. The ten largest users represent approximately 21% of statewide surface water and 17% of statewide groundwater demands. Major manufacturing facilities such as the WestRock Hopewell Plant are the primary users within the category. Growth in this category is dominated by manufacturing and mining operations. For the Large SSU category, demands associated with permitted surface water withdrawals including power generation are expected to increase by more than 40%, while demands associated with permitted groundwater facilities are expected to increase approximately 2%. Demands associated with unpermitted facilities will continue to be the largest portion of total surface water demands for this category through the planning period.

Table 6: Top 10 Large Self-Supplied Users in 2040 in Virginia

Facility	2020 Demand (MGD)	2030 Demand (MGD)	2040 Demand (MGD)	20 Year Percent Change	% of Total Surface Water
Surface Water					
Hopewell Plant	110.76	106.65	102.54	-7.42	6.62
Celco Plant	51.88	53.08	54.28	4.63	3.51
Covington Plant Westrock	39.35	39.35	39.35	0	2.54
Spruance Plant	28.72	29.67	30.63	6.65	1.98
Chesterfield Plant	21.27	25.69	30.11	41.56	1.94
Hopewell Plant	12.42	17.98	23.54	89.53	1.52
Radford Ammunitions WTP 1	15.52	15.51	15.49	-0.19	1
Georgia-Pacific Big Island WTP	9.15	11.15	13.16	43.83	0.85
Riverville Mill WTP	6.5	7.48	8.47	30.31	0.55
Newport News Shipbuilding	8.14	8.14	8.14	0	0.53
Total SW	**303.71**	**314.7**	**325.71**	**7.24**	**21.03**
Groundwater					**% of Total Groundwater**
West Point Mill Water System	14.51	14.51	14.51	0	3.96
Franklin Virginia Mill	14.31	14.31	14.31	0	3.9
Kimballton Plant 1	9.4	9.62	9.84	4.68	2.68
Elkton Plant	6.61	6.61	6.61	0	1.8
Celco Plant	4.33	4.43	4.53	4.62	1.24
Waynesboro Plant	3.91	3.91	3.91	0	1.07
Solenis Llc	2.66	2.66	2.66	0	0.73
Perdue Farms Incorporated	1.81	1.93	2.05	13.26	0.56
Shenandoah Brewery	2.01	2.01	2.01	0	0.55
Kimballton Plant 2	1.67	1.71	1.75	4.79	0.48
Total GW	**61.22**	**61.7**	**62.18**	**1.57**	**16.96**

3.4.3 Small Self-Supplied Users

Water demand in this category is primarily composed of countywide demand estimates for residential homeowner wells, and does not include surface water users. Currently, demands for Small SSU users account for approximately 137 MGD, which is projected to increase by 26.7%, or 36 MGD, through 2040. The largest countywide demands from Small SSUs are shown in Table 7, with the ten largest localities accounting for approximately 17% of 2040 statewide groundwater demands. Small SSUs are the largest groundwater use category in Virginia with demands concentrated around localities surrounding major metro areas including Fairfax, Culpeper, Prince William, and Spotsylvania. As populations expand and development occurs within and around major population centers, increased withdrawals from residential wells will result.

Small SSUs are expected to continue to represent the largest groundwater use category over the planning period. Most notably, localities within the I-95 corridor, especially between Fairfax and Richmond, will see the greatest increases in Small SSUs and population over the planning period according to water supply plan projections. By 2040 the ten localities with the greatest Small SSU demand are projected to increase by more than 46%. Impacts from groundwater demands in this category are evaluated within current Groundwater Management Areas provided in Chapter 4, Section 4.3. However, the impacts from Small SSUs outside of the GWMAs is less understood as fewer studies have occurred outside of the GWMAs, and those that have been completed are inherently at a small scale since fractured rock hydrogeology varies significantly even over short distances.

Table 7: Top 10 County-Wide Small Self-Supplied Use Estimates in 2040 in Virginia

Locality	2020 Demand (MGD)	2030 Demand (MGD)	2040 Demand (MGD)	20 Year Percent Change	% of Total Groundwater
Fairfax County	8.15	8.71	9.26	13.62	2.53
Culpeper County	3.86	6.45	9.03	133.94	2.46
Prince William	6.18	7.13	8.08	30.74	2.20
Spotsylvania	4.40	5.79	7.17	62.95	1.96
Fauquier	4.66	5.34	6.02	29.18	1.64
Hanover	3.33	4.68	6.02	80.78	1.64
Loudoun	4.12	4.67	5.22	26.70	1.42
Bedford County	3.02	3.68	4.34	43.71	1.18
Frederick	2.35	3.30	4.26	81.28	1.16
Albemarle	3.23	3.60	3.96	22.60	1.08
Total GW	**43.30**	**53.35**	**63.36**	**46.33**	**17.28**

3.4.4 Agriculture Demands

Current agricultural water demand represents 85 MGD or 6.0% of total statewide water demand and is projected to increase to 90 MGD by 2040. The ten largest agricultural demands are shown in Table 8. In addition to individual AG facility demands, countywide AG use estimates were also included in many water supply plans. Surface water is the primary water source for the category with the largest users including large scale aquaculture operations such as Coursey Spring Fisheries, Wytheville Fish Hatchery, and Laurel Hill Trout Farm. Demands from these users are largely non-consumptive as most hatchery operations return much of the water withdrawn to the source of withdrawal. Significant surface water users in the county also include estimated cumulative withdrawals from small users within Pittsylvania, Loudoun, and Wythe Counties.

Significant increases in groundwater demands in Floyd and Charlotte county suggest expansion of local agricultural industries and are the only localities statewide projecting increase groundwater demands. Permitted surface water demands in this category are projected to increase by approximately 19.4% through 2040, while permitted groundwater demands are projected to increase by 8.4% through 2040. Overall agricultural demands are relatively

constant. The ten largest surface and groundwater users in this category represent less than 5% of total projected 2040 water demands.

Table 8: Top 10 Agricultural Users or Locality-Wide Estimates in 2040 in Virginia

Locality \ Facility	2020 Demand (MGD)	2030 Demand (MGD)	2040 Demand (MGD)	20 Year Percent Change	% of Total Surface Water
Surface Water					
Coursey Spring Fisheries	11.91	11.91	11.91	0	0.77
Pittsylvania	8.44	8.44	8.44	0	0.55
Loudoun	4.77	4.77	4.77	0	0.31
Wytheville Fish Hatchery	3.28	3.52	3.76	14.63	0.24
Laurel Hill Trout Farm-South Monterey	3.72	3.72	3.72	0	0.24
Paint Bank Fish Cultural Sta.	2.33	2.7	3.08	32.19	0.2
Marion Fish Cultural Station	2.71	2.71	2.71	0	0.18
Laurel Hill Trout Farm- North Monterey	2.06	2.06	2.06	0	0.13
Wythe	1.93	1.93	1.93	0	0.12
Washington	1.92	1.92	1.92	0	0.12
Total SW	**43.07**	**43.68**	**44.3**	**2.86**	**2.86**
Groundwater					**% of Total Groundwater**
Floyd	1.44	1.62	1.81	25.69	0.49
Charlotte	1.12	1.28	1.43	27.68	0.39
Grayson	1.06	1.06	1.06	0	0.29
Carroll	0.69	0.69	0.69	0	0.19
Loudoun	0.62	0.62	0.62	0	0.17
Franklin County	0.45	0.45	0.45	0	0.12
Cumberland	0.34	0.34	0.34	0	0.09
Rappahannock	0.32	0.32	0.32	0	0.09
Madison	0.26	0.26	0.26	0	0.07
Botetourt	0.14	0.18	0.22	57.14	0.06
Total GW	**6.44**	**6.82**	**7.2**	**11.8**	**1.96**

3.4.5 Projected Water Demands By Water Source

Surface Water Demand: Surface water use is the primary water source for Virginia with approximately 1582 MGD, or 82.3% of statewide water demand coming from surface water when excluding power generation. The greatest users of surface water tend to fall within the I-95 and I-64 corridors from Hampton Roads, Richmond, and the Washington D.C. metro area. Figure 14 shows current surface water demands for each locality in Virginia including power generation. Surface water demands are the greatest in localities with significant population centers and large scale water uses such as manufacturing or power generation facilities. The localities with the largest surface water demands include Louisa, Surry, and York Counties, all of which include power generation facilities that use surface water for cooling purposes. When excluding power generation facilities Prince William, Hopewell, Arlington, and Chesterfield Counties rank among the highest surface water demands in Virginia. Surface water demands in these areas are primarily driven by large public water suppliers and industrial users.

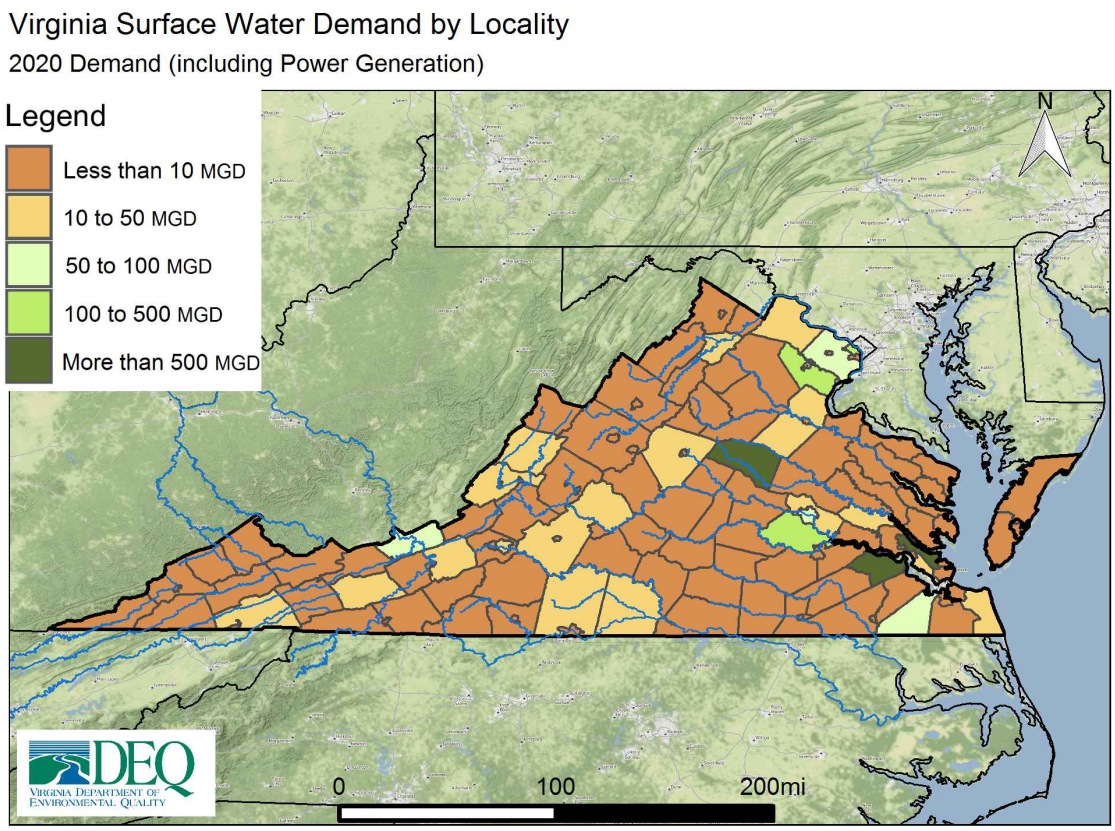

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Figure 14: Current Surface Water Demands in Virginia

Based on water use data and demand projections provided in Local and Regional Water Supply Plans, Figure 15 provides the projected change in surface water demand through 2040. Trends in surface water demands continue to show widespread increase across much of Virginia. However, increased demands are concentrated within Northern Virginia, along the I-95 corridor, and the Roanoke Valley. As populations continue to move towards major metropolitan areas, increased demands from public water suppliers will be the primary driver over the planning period. Detailed water demand and use information is included in Appendix A for all watersheds in Virginia.

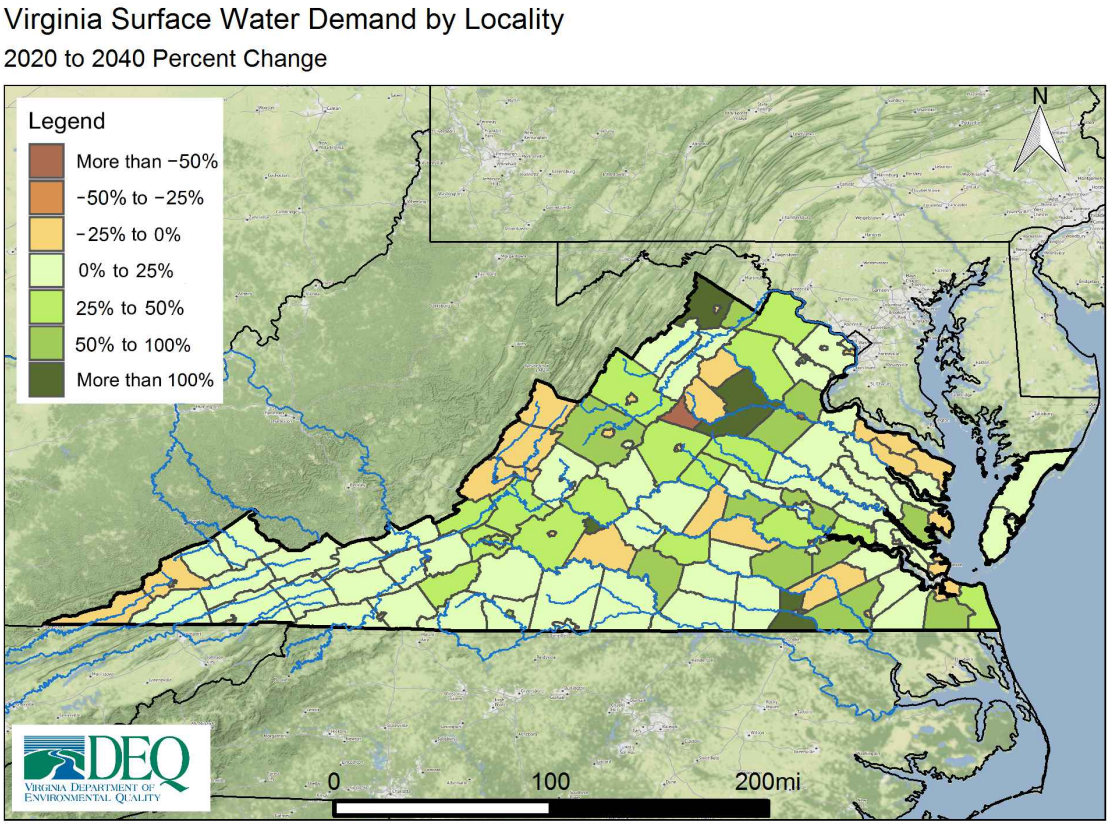

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Figure 15: Projected Change in Surface Water Demands in Virginia 2020-2040

Groundwater Demand: Groundwater demand makes up approximately 279 MGD, or 17.7% of statewide water demands when excluding power generation. Trends in groundwater use across Virginia contrast somewhat with those seen in surface water use as the greatest greatest demands do not follow large population centers. Localities with the greatest groundwater demands include Isle of Wight, Rockingham, Giles, and King William Counties. While major urban centers such as the City of Harrisonburg are included in the localities, the primary users of groundwater in Virginia include Large and Small Self-Supplied Users. Major industrial/manufacturing, commercial, and private domestic well users represent more than 76% of current groundwater demands. The largest self-supplied groundwater users in Virginia are provided in Table 6 and Table 7. With two of the largest groundwater demands within localities outside of current Groundwater Management Areas, understanding of potential impacts and available water supply are limited. Detailed information regarding groundwater in Virginia is provided in Chapter 4 and by watershed in Appendix A.

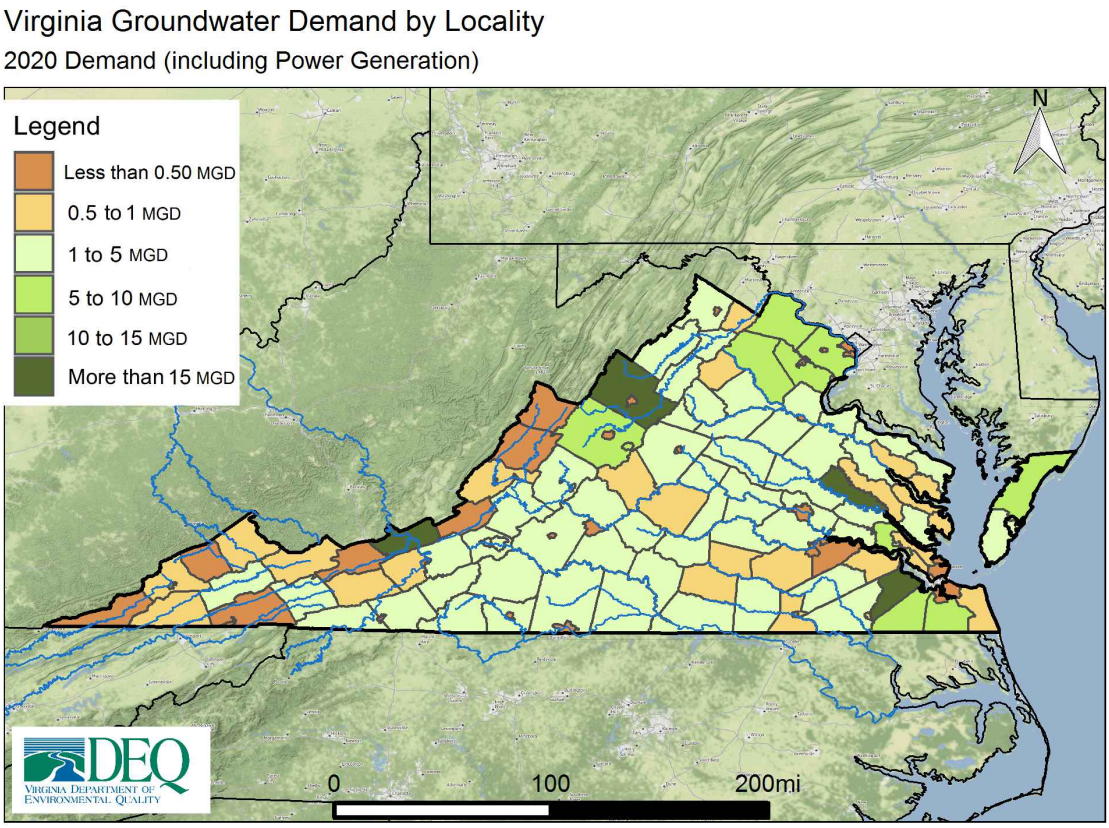

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Figure 16: Current Groundwater Demands in Virginia

Based on water use data and demand projections provided in Local and Regional Water Supply Plans, Figure 17 provides projected changes in groundwater demand through 2040. Groundwater demands are projected to increase by approximately 31% by 2040, nearly twice the rate of surface water. Increases in groundwater demands are primarily focused within the I-95 corridor between Washington D.C and Richmond, primarily driven by rapid increases in demands from Small SSUs within and outside of current Groundwater Management Areas. This is most notable within localities listed in Table 7 including Fairfax, Culpeper, Prince William, and Spotsylvania Counties. As populations continue to be attracted to major metropolitan areas, increased demands from domestic well users will be the primary driver over the planning period. Detailed water demand and use information is included in Chapter 4 and Appendix A for all watersheds in Virginia.

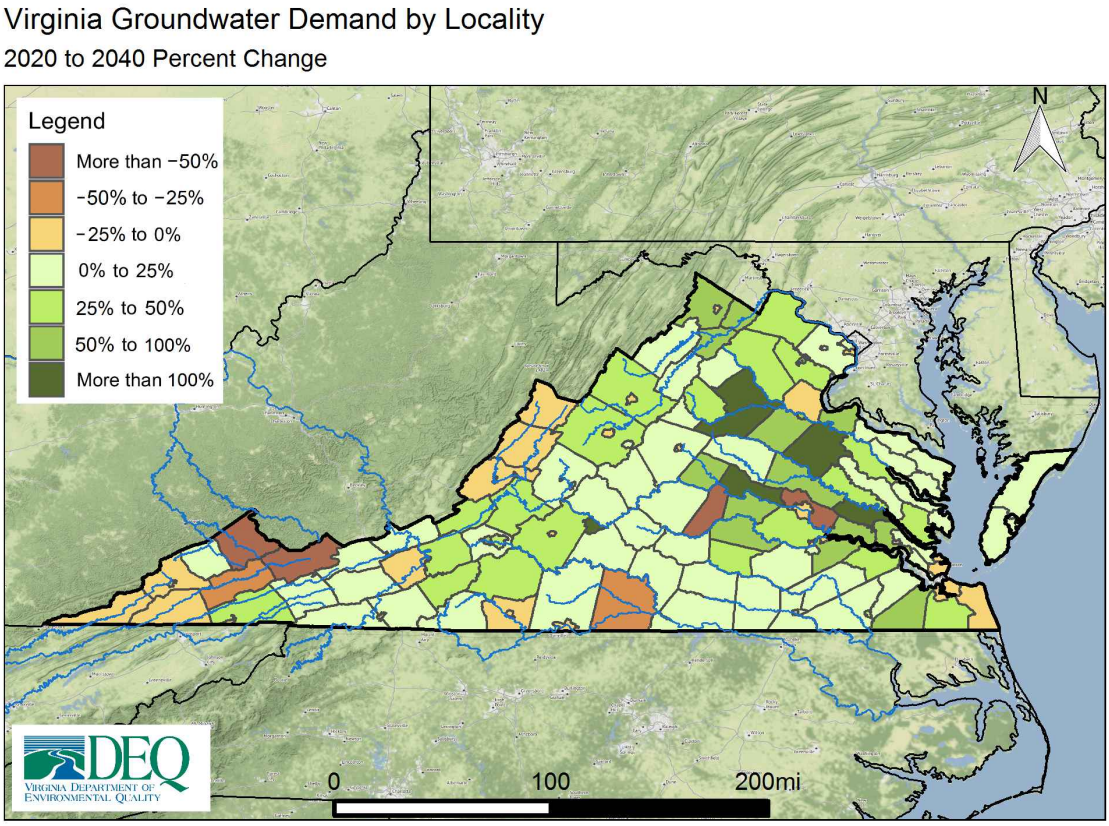

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Figure 17: Projected Change in Groundwater Demands in Virginia 2020-2040

3.5 Comparison to 2015 Water Resources Plan

The 2015 State Water Resources Plan was the first comprehensive statewide water resources plan completed and published by the DEQ. The plan incorporated information from local and regional water supply plans to complete an analysis of potential impacts to beneficial uses including water supply. The State Plan provided an extensive first look into surface and groundwater resources in Virginia, including an assessment of the ability for the sources to meet future water needs by each locality through 2040.

The 2020 State Plan builds upon the foundation of the 2015 State Plan. However, this effort makes several significant advances in data management and analysis, modeling, scope, and presentation. These refinements are discussed throughout this document with details provided in Chapter 1 and Chapter 4. One of the most vital improvements was updated and improved water supply plan demand and source information. The following section will provide information on data improvements from the 2018 Water Supply Plan review process and Annual Water Withdrawal Reporting.

Pursuant to 9VAC25-780-50 of the Code of Virginia, Local and Regional Water Supply Plans are required to be reviewed no later than five years after a compliance determination. In 2018 reviews of all Water Supply Plans were conducted in partnership with local governments, municipal suppliers, and other water users to identify and collect the most up to date water supply information outlined in 9VAC25-780.

Detailed information about the compliance and review process for all localities is available upon request. The following section summarizes several of the key changes from the 2015 State Plan.

Table 9: 2018 Locality Demand Updates

Localities
Augusta
Caroline
Chesterfield
City of Harrisonburg
City of Richmond
Co-op Localities in Northern Virginia
Culpeper
Frederick
King George
Madison County and Town
Northumberland
Richmond
Rockingham
Town of Bridgewater
Westmoreland

Improvements to water demand projections completed during the 2018 Water Supply Planning review included newly developed or updated water demand projection information from a variety of localities, water users, and stakeholders. Approximately 13% of localities provided partial or fully updated demand projections. Localities that fully or partially updated demand projection during the 2018 Water Supply Planning review are listed in Table 9.

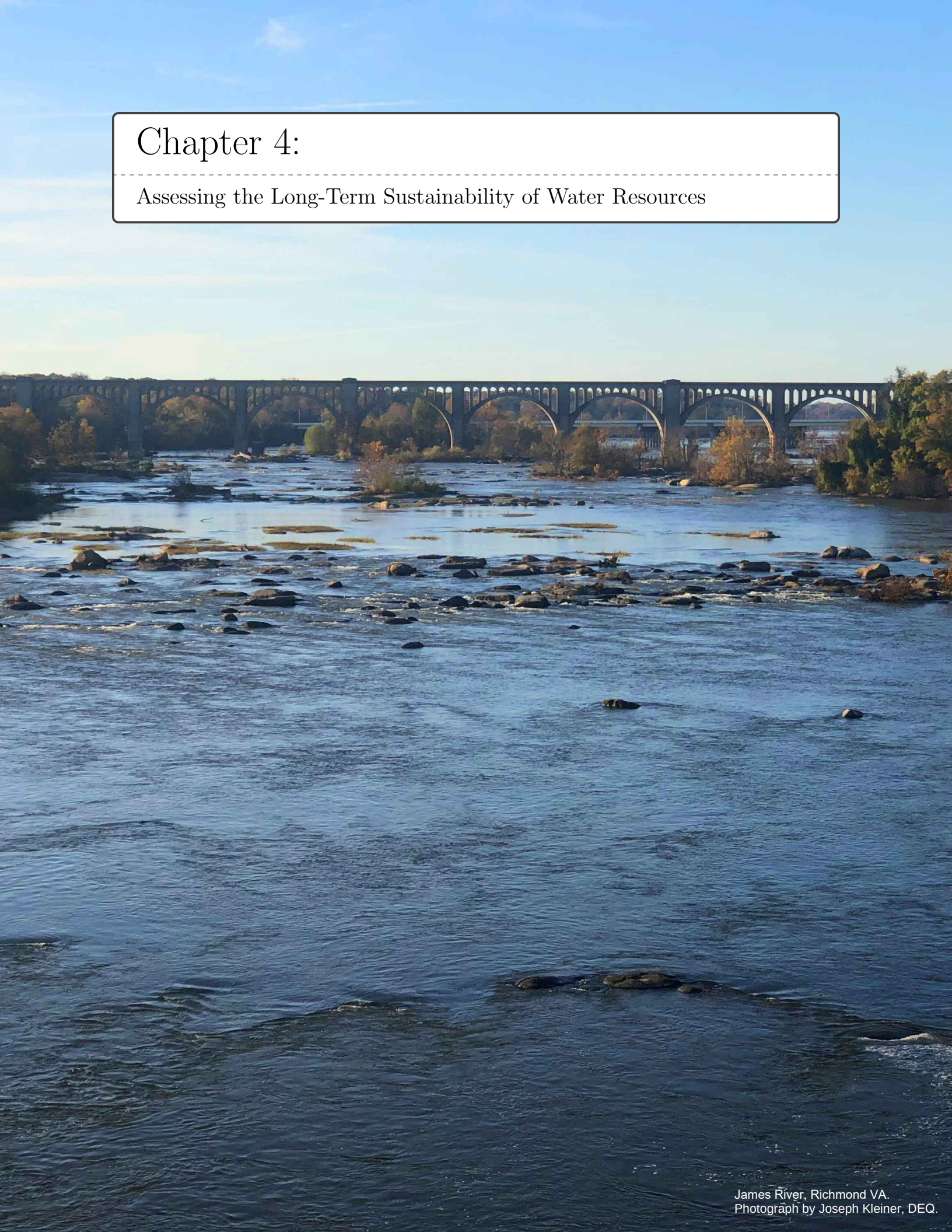
Updated current and future water use information was received from major population and water use areas including the Northern Virginia Co-Op localities, City of Harrisonburg, City of Richmond, as well as more rural areas like the Northern Neck. This provided the DEQ the ability to apply the most readily available information for use in development of the Cumulative Impact Analysis included in Chapter 4.

Demands updated by DEQ staff were generally due to updated water use information such as new or reissued surface or groundwater withdrawal permits, new users or facilities, or significant changes in water use since the publication of the 2015 State Water Resources Plan. In combination with updated water demand projection information, DEQ conducted extensive quality control efforts on facility information collected through Annual Water Withdrawal Reporting. These data are critical to DEQ's ability to understand water resource demands and develop a more accurate understanding of water budgets in watersheds in the Commonwealth. Data from more than 1,900 facilities that report withdrawals were included in the development of the 2020 State Water Resources Plan. In addition, partnership with the North Carolina Department of Environmental Quality allowed for the inclusion of withdrawals in watersheds shared by Virginia and North Carolina. These data in combination with the demand use information collected from local and regional water supply plans were instrumental in developing the CIA analyses completed for twenty minor basins (included in Appendix A), as well as the statewide analysis in Chapter 4.

Collection of the most current and accurate data, especially water use and demand projection information, is instrumental in the DEQ's ability to ensure adequate safe drinking water availability to all citizens and protect all other beneficial uses in the Commonwealth. Analysis of withdrawal information and future water needs provides the foundation for development of local, regional, and statewide water budgets and management decisions. This information collected and analysed by DEQ will also provide important context and references for the Local and Regional Water Supply Plan resubmission due in 2023.

Chapter 4:

Assessing the Long-Term Sustainability of Water Resources



James River, Richmond VA.
Photograph by Joseph Kleiner, DEQ.

4 Assessing the Long-Term Sustainability of Water Resources

4.1 Introduction

The following chapter explores the methodology used to model and assess the long-term sustainability of water resources in Virginia. Included is a description of the hydrologic model itself, inputs to the model, the Cumulative Impact Analysis (CIA) approach, as well as model outputs and the metrics used to evaluate potential impacts to the beneficial uses of Virginia streams. Beneficial uses include the off-stream uses of existing withdrawals, as well as in-stream considerations such as maintaining water quality and the protection of aquatic life (For additional notes on beneficial use, see Chapter 1). Statewide model results can be found towards the end of the chapter in section 4.2.8.

The comprehensive VAHydro hydrologic model is used to evaluate surface water supply availability throughout Virginia. The VAHydro model simulates streamflow with inputs such as precipitation, climate, land use, and topography, as well as local data collected through DEQ water supply planning and reporting programs including all known withdrawals and discharges, as well as operational rules of VWP permits and major hydrologic features such as reservoirs. These model inputs will be described in greater detail throughout this chapter.

The 2020 update to the VAHydro model features an expanded time span, improved handling of consumptive use (point source discharges), climate change scenarios, and higher resolution water withdrawal locations. The expanded spatial resolution of withdrawal locations facilitates analysis of impacts in HUC 10 watersheds, an approximately 10 fold increase in resolution over the 2015 plan which featured HUC 8 level analysis. The 2020 model is built on rainfall-evaporation-runoff (RER) time-series from the Chesapeake Bay Model Phase 6 which runs from 1984-2014 in the Chesapeake Bay watershed drainage, and 1984-2005 in the rivers flowing outside of the Chesapeake Bay watershed, aka the "southern rivers." Extensive efforts were undertaken by DEQ staff to link all water supply planning systems submitted by localities to corresponding facilities in the VAHydro water withdrawal reporting database. This linkage enabled the shift to HUC 10 level analysis, and allows for modeling of monthly varying use patterns based on historical reported data. These system linkages can now be maintained going forward, ensuring that localities will always have the most up to date reporting data to use in their assessment of current demands, and projection of future trends in water use.

To facilitate modeling and analysis in the State Plan, Virginia is divided along hydrologic boundaries into 20 sub-basin units, referred to as "Minor Basins" (Figure 18). These minor basins vary in size from around 900 mi^2 to 6,000 mi^2 and roughly contain 1-3 HUC 8 units. This chapter will highlight model results with a focus on statewide trends, with results for each individual minor basin described in greater detail in Appendix A.

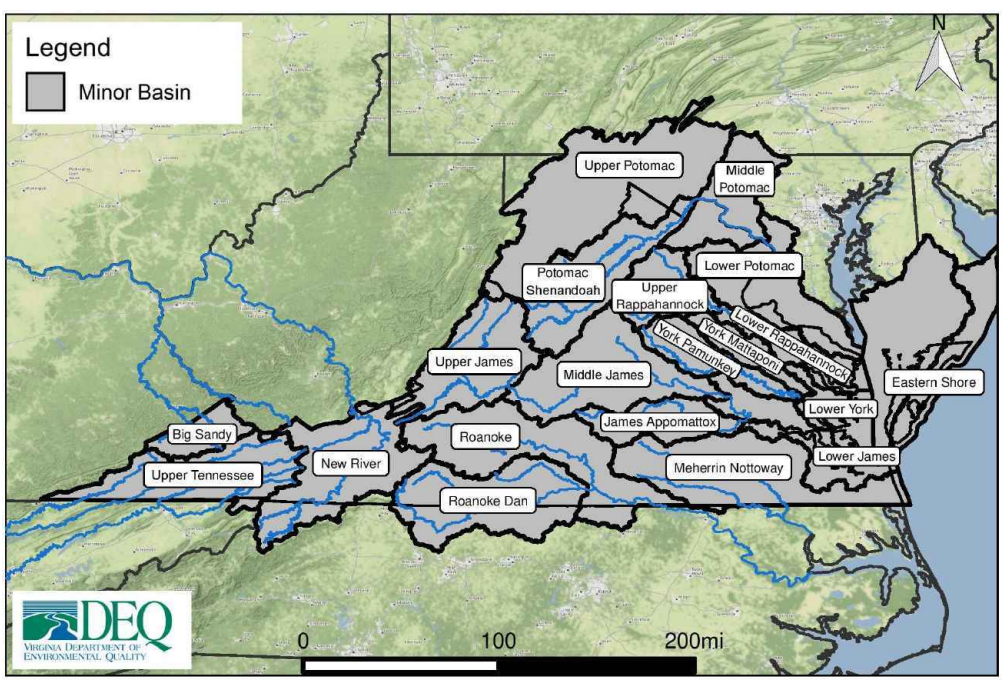


Figure 18: Minor Basin Overview

4.2 Cumulative Impact Analysis - Surface Water

DEQ assesses water supply sustainability through CIA modeling. Each minor basin is divided into high-resolution hydrologic subsections called "river segments" (over 600 river segments in total), roughly the size of HUC 10 hydrologic units. The model simulates a daily water balance for every individual river segment, with each downstream segment being affected by the "cumulative impact" of streamflow changes occurring in upstream segments. Modeled changes in streamflow are primarily driven by water demands, meteorology and land use.

> **Cumulative Impact Analysis (CIA)** is a modeling and analysis approach that takes into account the varied hydrologic process occurring throughout a river network (including meteorology and human water use). By simulating a daily water balance for every individual river segment within a watershed, DEQ is able to evaluate the potential "cumulative impact" of all streamflow changes occurring upstream of any location within the river network.

Beneficial uses can be impacted by flow variations on an annual, seasonal, and even daily time scale. Therefore, the model evaluates cumulative impacts to the water balance on a daily basis, as well as the variation in conditions expected to occur on a seasonal and annual basis. This CIA modeling approach forms the basis for evaluating future sustainability of water supply and protection of beneficial uses; it is an approach that has been used in DEQ's permitting and planning programs for nearly two decades, with constant refinement and improvement over time.

4.2.1 VAHydro Surface Water Model

DEQ develops and maintains the VAHydro web-based platform for water resource management in Virginia. A primary component of the VAHydro system is the VAHydro surface water model, which is used to perform all CIA modeling. The VAHydro surface water model is based on the Phase 6 Chesapeake Bay Program (CBP) watershed model[39], with several key DEQ enhancements including high resolution intake locations and withdrawal amounts, point sources, permit and reservoir operations, land use, and in some cases in order to provide detailed facility operations, additional river segmentation beyond those river segments included in the Phase 6 model.

As noted, the model features an RER hydrology time-series which spans 1984-2014 in the Chesapeake Bay watershed drainage, and 1984-2005 in the southern rivers portion of the state. The multidecadal model time periods, for both the northern and southern rivers portions of the model, are considered representative, and show the full range of seasonal and annual climatic variations including "average" years, "wet" years, and "drought" years. The RER provides a baseline flow time series, or an estimate of the water entering the riverine system on a daily basis. Applied to this baseline are inputs such as water withdrawals, discharges, operational rules for water supply entities, and projected climatic variation. These and other inputs to the model are discussed in greater detail below.

4.2.2 Model Inputs

4.2.2.1 Meteorology

Similar to river segments, the VAHydro model contains a layer of land units based on political boundaries referred to as "land segments" (around 150 total). These regions are delineated according to county and city designations, with some areas being further divided along physiographic boundaries. Land segments are the units used in the VAHydro model for simulating meteorological inputs including rainfall, temperature, snowfall, potential evapotranspiration (PET), dewpoint, wind, solar radiation and cloud cover. This State Plan analysis contains simulations based on historical meteorological conditions as well as a range of climate change projections (see 4.2.4).

The foundation of the VAHydro hydrologic model is HSPF[40]. HSPF is capable of simulating a continuous runoff flow rate, as well as nutrient and pesticide concentrations and sediment loads throughout a watershed. To provide continuous input data for HSPF, the model uses hourly input data derived from statistical analysis of observed precipitation data from measurement stations for the modeling time period (1984-2014, or 1984-2005). As noted, the model can be described as RER with the primary components of rainfall and evaporation driving the volume of water

[39] CBP Modeling; Phase 6 CBP watershed model
[40] HSPF - DOI: 10.1061/(ASCE)EE.1943-7870.0000555

runoff from a particular land segment, with hydrologic processes such as infiltration used to calibrate the simulation to achieve an overall water balance. The model is capable of running simulations at several different timesteps from daily down to hourly time increments. For the purposes of this State Plan, all model scenarios were run using a daily timestep (This generally minimizes model errors and results in improved accuracy).

4.2.2.2 Land Use

A third layer of "land-river segments" consists of an intersection between the river segment and land segment layers. Land-river segments function to route flows, nutrient loads, and sediment sources from land segment model simulations to the river segment models. This is achieved through high-resolution land-use model inputs. The VAHydro model includes tabular land use estimates for every land-river segment in the model.

Northern Rivers: This land use data was generated during the development of the CBP Phase 6 watershed model, using federal, state and county-level data sources. The process of generating the land use dataset involved taking high-resolution land cover data (1m x 1m pixels) obtained from aerial imagery, and translating that data into "land use" as it's used in the CBP watershed model. Land use in the CBP's classification schema takes into account both land surface characteristics (level of impervious surfaces, vegetation, tree cover etc.) as well as how humans use the land (whether the land is used for agriculture, mining, residential etc.).

Southern Rivers: The land use dataset was updated for the southern rivers portion of Virginia through a collaborative project between DEQ and the Virginia Tech Department of Biological Systems Engineering. Through this multi-year project, land cover data was obtained from the Virginia Geographic Information Network (VGIN). Similar to the dataset for the northern rivers portion of the state, this data is high-resolution (1m resolution) and current through the year 2016. For those portions of the southern rivers that flow into Virginia from North Carolina and Tennessee, an additional dataset was obtained from the National Land Cover Database (NLCD) at a 30m resolution, current through 2011. Similar to the process used in the CBP watershed model, these datasets were translated from land cover to land use in order to be used directly in the VAHydro hydrologic model.

Land use is an important factor when developing water quality models, however it is also of particular interest in water quantity modeling in the context of this State Plan. Land use inputs are significant for their effects on processes such as infiltration, runoff amount, and effects on streamflow. The VAHydro model uses the unit runoff values associated with each land use type to generate surface runoff totals for each land-river segment. This land-river segment runoff value represents the amount of water that enters the river segment model associated with the land-river segment. Since a particular river segment may have several associated land-river segments, the total runoff entering the river segment channel is equivalent to the summed total of runoff from each of its associated land-river segments. Included in the VAHydro model are land use inputs for historic, current, and projected future conditions.

4.2.2.3 Withdrawals

Water Supply Planning Inputs - The primary water use inputs used in this State Plan modeling effort are sourced from the data provided by 48 Local and Regional Water Supply Plans as discussed in chapter 3. The data collected includes system and source level data including surface water withdrawals, groundwater withdrawals and purchased transfers of water between systems/localities. In order to evaluate different use types, these demands are categorized as either Agriculture, Community Water Systems, Large Self-Supplied Users, or Small Self-Supplied Users. The comprehensive VAHydro system allows the local data DEQ collects through the water supply planning program to be used in the VAHydro surface water model (See Figure 19).

Estimates of current local water demands submitted through water supply plans provide the basis for the 2020 "current" modeling scenario (See section 4.2.3 for additional notes on scenario development). In each water supply plan, localities provided future projections for every water supply planning system based on projected population and demand changes. Applying this projection data to the 2020 demands provides a reliable method of estimating future demand. The "future" demand scenarios developed for this State Plan include decadal simulations for the years 2030 and 2040. The 2040 projected demands are also evaluated in additional modeling scenarios for evaluating the potential impacts of climate change (Section 4.2.4.2).

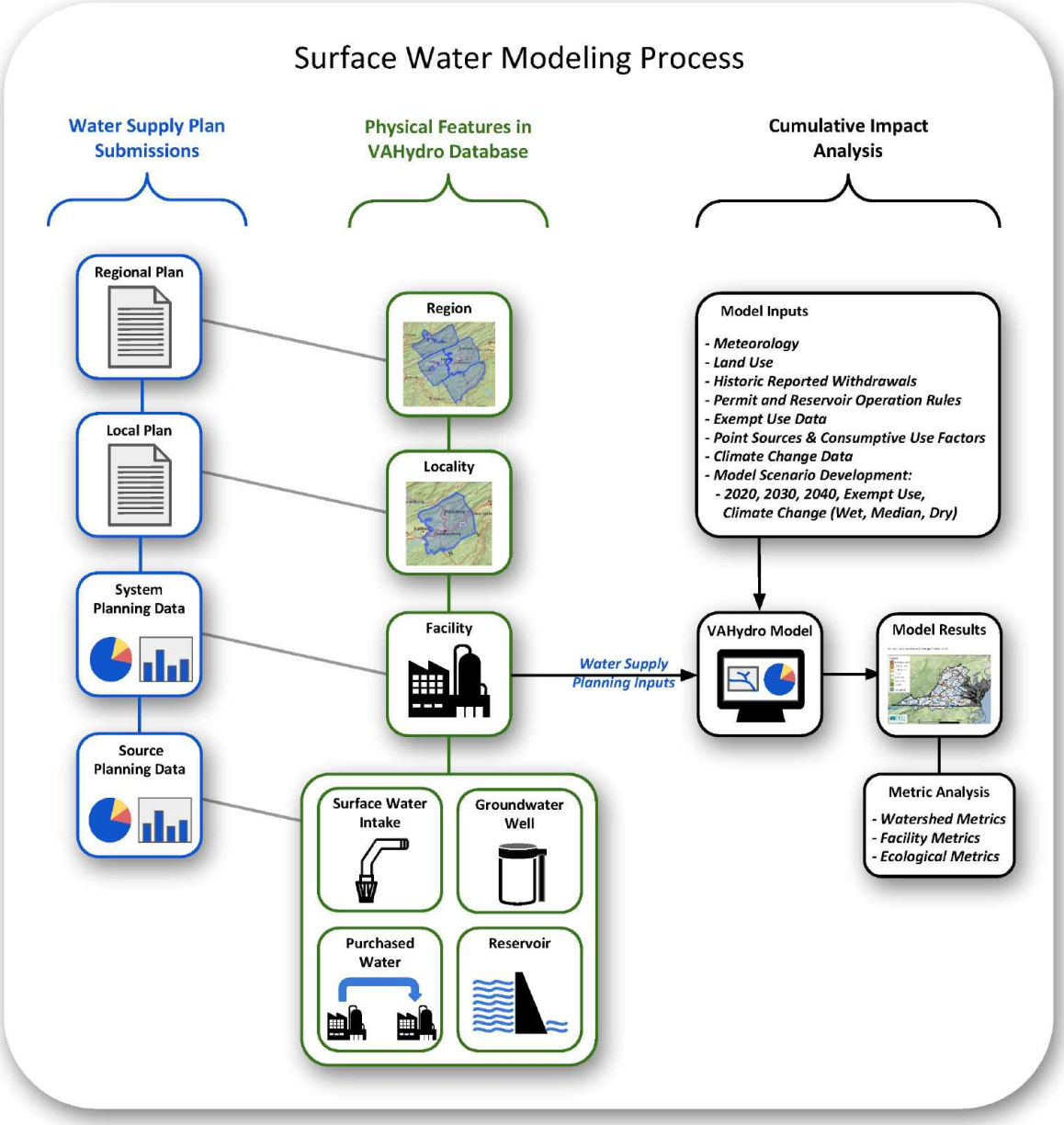


Figure 19: Surface Water Modeling Process

Historic Reported Withdrawals - The VAHydro data system serves as the electronic reporting interface and data repository for annual water withdrawal reporting. VAHydro stores monthly and annual withdrawal data dating as far back as 1982. Additionally, permit withdrawal data reports are entered into the VAHydro system on a quarterly basis. In this way VAHydro always has the most up-to-date withdrawal data possible, with new withdrawal data being entered regularly.

Beyond serving as a means of data entry and storage, the VAHydro system allows the withdrawal data to be used directly in the VAHydro hydrologic model. This data becomes critical for instances where a withdrawing facility is absent from a water supply plan, or where high-resolution location information isn't included in a water supply plan for a particular water system. In 2019 DEQ staff linked all the systems present in local water supply plans to existing facilities already present in VAHydro due to annual water withdrawal reporting requirements (See Figure 19 for a diagram of this linkage). This process ensures that each water supply plan demand is modeled with

the greatest possible spatial accuracy, since facility withdrawal locations may be updated by water users through the VAHydro electronic reporting interface.

Historic reported withdrawals also help to significantly improve model accuracy through the historic monthly distribution of reported water use. Monthly factors are generated using the past five year's worth of reporting data for every facility in the VAHydro system. By multiplying water demands collected through the water supply planning process (2020, 2030, 2040 demands) by these monthly factors, projected demands can be modeled seasonally.

Additional surface water model accuracy is gained through the partitioning of surface water and groundwater demands. Many water withdrawal systems have both groundwater well and surface water intake sources. System level demand data submitted in water supply plans is not always separated into volumes by source type. By taking historic withdrawal reporting data into account, the fraction of a facility's water use that historically comes from surface water can be determined. This surface water fraction is used directly in the VAHydro model as a multiplier for water supply planning data inputs to ensure proper accounting of surface water demands.

Permit and Reservoir Operation Rules -

Permits - All VWP surface water permits issued by DEQ are accounted for in the VAHydro model (see Chapter 1 for VWP Permit Program Regulation and additional notes on the permitting process). VWP permits are entered into the VAHydro model during the initial permit application process. This allows DEQ to evaluate potential permits by conducting a CIA using the applicant's water demand to assess potential impacts on existing in-stream and off-stream beneficial uses.

Once permits are issued, they remain in the VAHydro model, complete with any operational rules as defined in the permit. This includes any specific flowby requirements, tiered or seasonally varying withdrawal operations, demand partitioning between surface water and groundwater sources for facilities with both wells and intakes, or any additional low flow or water quality requirements. These VWP operations are modeled explicitly in regular CIA model runs, as well as the water supply planning model scenarios evaluated in this State Plan. The incorporation of VWP permit operations into the model helps ensure a proper accounting of the local water balance, which in turn allows for an accurate assessment of potential impacts to downstream water availability for other existing intakes, aquatic life, water quality or recreational uses.

Reservoirs - Many reservoirs are explicitly modeled in the VAHydro system. This means the model has been resegmented and parameterized to include a high-resolution reservoir model. These models include detailed information such as stage-storage-surface area tables, maximum capacity, amount of unusable storage, riser structure dimensions, tiered flowby/release rules, and other reservoir-specific water supply management operational information. Modeling these reservoir features provides a more accurate simulation of reservoir storage and impacts on the flow regime such as timing and magnitude of streamflow, flow attenuation, evaporation, and effects on flow under drought conditions.

Incorporating reservoirs into the VAHydro model also allows for an improved simulation of reservoir withdrawals. This is critical for evaluating changes in reservoir storage that may impact user's withdrawals. This is of particular importance for simulating times of extreme drought, when reservoir storage may become insufficient to meet surface water demand. In some cases where a VWP permitted facility is not directly withdrawing from a reservoir, that withdrawal's operations may still be closely linked to a nearby reservoir. This is due to withdrawal rules that often depend on storage remaining in a particular reservoir. The VAHydro model is equipped to handle these unique situations and can provide an accurate evaluation of water availability.

4.2.2.4 Point Sources & Consumptive Use

In order to provide an accurate accounting of the overall water balance, point source discharge estimates are accounted for in the VAHydro model. Many facilities that withdraw water throughout Virginia ultimately return some portion of their withdrawal volumes back to the stream network through point source discharges. The term consumptive use (CU) refers to the fraction of water withdrawn that is evaporated, transpired, incorporated into products or crops, consumed by humans or livestock, or otherwise not returned to the immediate water environment. By ensuring CU is considered for every facility, the VAHydro model is capable of simulating and maintaining a more realistic water balance. This topic is covered in depth in section 4.2.6.

4.2.3 Model Scenarios

This State Plan features a set of 7 unique model scenarios, designed to simulate a range of potential meteorologic and withdrawal demand conditions, and the resulting cumulative impact effects. See Table 10 for scenario abbreviations, meteorology and demand information. Scenarios were developed to assess potential impacts to streamflow and water availability resulting from projected future water demand by the years 2030 and 2040 as compared to "current" 2020 demands. Climate change scenarios were developed to help examine how streamflow is impacted when 2040 demands are simulated in conjunction with a range of potential precipitation and temperature conditions that may occur under a changing climate. An additional scenario was developed to evaluate potential impacts resulting from users excluded, or exempt, from VWP permit requirements by 9VAC25-210-310. This scenario is discussed in more detail in Section 4.2.5. These scenarios form the foundation for all cumulative impact analyses presented throughout this State Plan. Results are presented statewide in Section 4.2.8 and in the minor basin focuses of Appendix A.

Scenario Descriptions:

2020 "Current" Scenario: The baseline scenario was developed to model cumulative impacts under current conditions. The primary inputs are estimates of current water demands submitted through local and regional water supply plans, combined with current meteorological conditions.

2030 Scenario: This scenario was developed to model cumulative impacts under future conditions for the year 2030. 2030 demands were interpolated from 2020 and 2040 demands - in other words 2030 represents the midpoint between 2020 and 2040 demands. The 2030 demand scenario utilizes current meteorological conditions.

2040 Scenario: This scenario was developed to model cumulative impacts under future conditions for the year 2040. The primary inputs are estimates of future water demands using projections submitted through local and regional water supply plans, combined with current meteorological conditions.

Dry Climate Scenario: This scenario was developed to model cumulative impacts under future climate change conditions. The primary inputs are estimates of 2040 future water demands using projections submitted through local and regional water supply plans, combined with future climate change meteorological conditions that are considered "Dry" based on total precipitation and evaporation changes. (See section 4.2.4.2 for specifics on climate change scenario development).

Median Climate Scenario: This scenario was developed to model cumulative impacts under future climate change conditions. The primary inputs are estimates of 2040 future water demands using projections submitted through local and regional water supply plans, combined with future climate change meteorological conditions that are considered "Median" based on total precipitation and evaporation changes. (See section 4.2.4.2 for specifics on climate change scenario development).

Wet Climate Scenario: This scenario was developed to model cumulative impacts under future climate change conditions. The primary inputs are estimates of 2040 future water demands using projections submitted through local and regional water supply plans, combined with future climate change meteorological conditions that are considered "Wet" based on total precipitation and evaporation changes. (See section 4.2.4.2 for specifics on climate change scenario development).

Exempt User Scenario: This scenario utilizes the maximum potential withdrawal demand for exempt users, combined with permitted withdrawal limits for those users that have withdrawal permits (see section 4.2.5 for specifics on exempt value data sources). For users that are exempt because their demands are below the threshold that requires a permit, estimates of current 2020 water demands submitted through local and regional water supply plans are used. This scenario utilizes current meteorological conditions.

Table 10: Model Scenario Overview

Scenario Abbreviation	Meteorology	Water Demands	Area Modeled
2020 "Current"	Current Conditions	2020 Demand	Statewide
2030	Current Conditions	2030 Demand	Statewide
2040	Current Conditions	2040 Demand	Statewide
Dry Climate	Future "Dry" Climate Change Conditions	2040 Demand	Northern Rivers
Median Climate	Future "Median" Climate Change Conditions	2040 Demand	Northern Rivers
Wet Climate	Future "Wet" Climate Change Conditions	2040 Demand	Northern Rivers
Exempt User	Current Conditions	Exempt User Demand	Statewide

4.2.4 Climate Change Model Meteorology in the State Plan

4.2.4.1 Climate Scenarios Overview

The climate change simulations completed for the 2020 State Plan use precipitation and evaporation inputs drawn from a set of three different climate change models selected by the USGS and Chesapeake Bay Program modeling team. These models vary from low to high in their total precipitation and evaporation changes, and are referred to in this document as the "Dry", "Median", and "Wet" climate scenarios (more details can be found in section 4.2.3). Overall, changes in evaporation ranged from +1 inches per year in the Dry Scenario to +2.5 inches per year in the Wet Scenario. Total annual rainfall across the scenarios varied from -3 inches in the Dry Scenario to +12 inches per year in the Wet Scenario as compared to current meteorology.

Of the three scenarios, only the Dry scenario results in widespread reductions in drought flows that results in a substantial potential for impacts to water supply and other beneficial uses. There was significant geographic variation in dry scenario impacts across the Commonwealth; however, because of the limits to climate change model resolution, variations over small geographic distances, especially in headwater watersheds, should not be used to predict the precise location of impacts. Results of the climate models should be viewed as a basin level planning tool that can support the development of adaptive management strategies based on different combinations of future rainfall and temperature changes as predicted by the best available global climate models. For more information on the 31 model ensemble evaluated by the USGS and Chesapeake Bay Program modeling teams see [Bhatt, 2019].

Because climate change models predict increases in temperature and some uncertainty in future rainfall patterns through the next 30 years and beyond, it is important to quantify the potential effect of rainfall uncertainty and higher temperature/evaporation on the water budget in Virginia streams. While there is little uncertainty about the likelihood of increased evaporation, the effect of future temperature increases on the magnitude, intensity and timing of future rainfall events is less clear. The climate change scenarios in this State Plan are intended as a first step to address this concern. However, it is important to understand how those models compare and contrast with the historical trends.

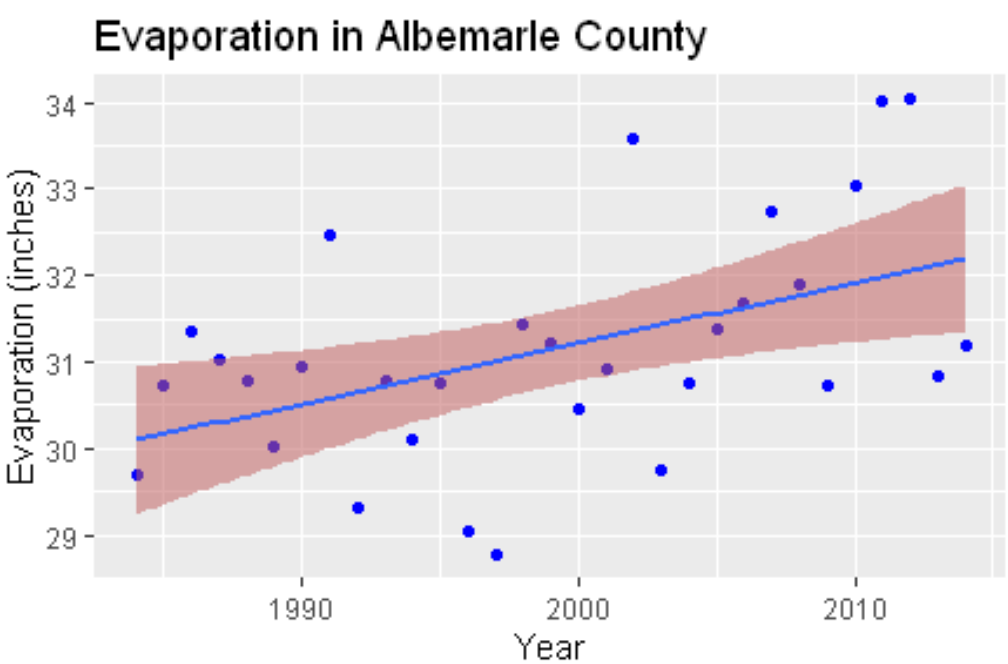


Figure 20: Estimated historical annual potential evaporation in Albemarle County, from 1984-2014 using the Chesapeake Bay Watershed Model Phase 6.[Bhatt, 2019]

4.2.4.2 Historical Climate Trends in Virginia and Future Climate Change

Drought in Virginia is driven largely by the difference between annual rainfall and evaporation. Extreme droughts in most Virginia streams are the result of a combination of low rainfall during winter, which leads to depleted "base flows", combined with low summer rainfall and/or high summer evaporation [Austin, 2014]. Global climate models, and the specific climate scenarios evaluated in the State Plan, differ with respect to whether future rainfall in Virginia will increase or decrease as a result of the increased temperatures from climate change. However, all global climate models project increased temperatures in Virginia which will result in increased evapotranspiration. Observed meteorological data from 1961-2010 show that increases in temperature of at least 1 degree Celsius have already occurred in many parts of the Chesapeake Bay watershed. Modeled evapotranspiration based on observed temperature from 1984-2014 shows this increase in temperature has already resulted in measurable increases in total evapotranspiration. Without increased precipitation to offset the increases in evapotranspiration that have already occurred, future extreme droughts in Virginia will inevitably have lower water availability than historical droughts. Given that not all scenarios predict an increase in precipitation, evaluating a range of potential scenarios for how climate change may impact in-stream and off-stream beneficial uses is critical to long-term management of water resources.

4.2.4.3 Historical Trends in Temperature and Evaporation

Increasing air temperatures have been measured throughout the watersheds of the eastern United States since the 20th century, and a 2014 USGS study of temperature data from 1961-2010 showed a median monthly temperature increase of at least 1°F in 32 of 85 long term monitoring stations [Rice and Jastram, 2014]. The Phase 6 Chesapeake Bay watershed model uses observed temperature to estimate potential evaporation from 1984-2014, and suggests evaporation has increased in most of Virginia over that period, with some areas having an increase of over one inch of total annual evaporation (see example in Figure 20). In a normal year, there is 10 to 15 inches more rainfall than evaporation in Virginia; during extreme historical drought, the difference between total annual rainfall and total annual potential evaporation can be reduced to between 0 to 5 inches. Therefore, one additional inch of evaporative loss can result in a substantial change in available water.

4.2.4.4 Relationship Between Increases in Historical Temperatures and Rainfall

A 2017 USGS study of trends from 1960-2010 in Chesapeake Bay tributaries [Rice et al., 2017] found increases in average rainfall and flow in most rivers north of the Maryland-Pennsylvania border, but no significant trends southward except for the James River which had a decrease in average flow. From the Potomac River south, the lowest average monthly rainfall also decreased, though it was not statistically significant (see Figure 21B). One limitation of this study is that it only looked at rainfall and stream flow, therefore effects from changing land cover, land use, evaporation, withdrawals or discharges were not accounted for.

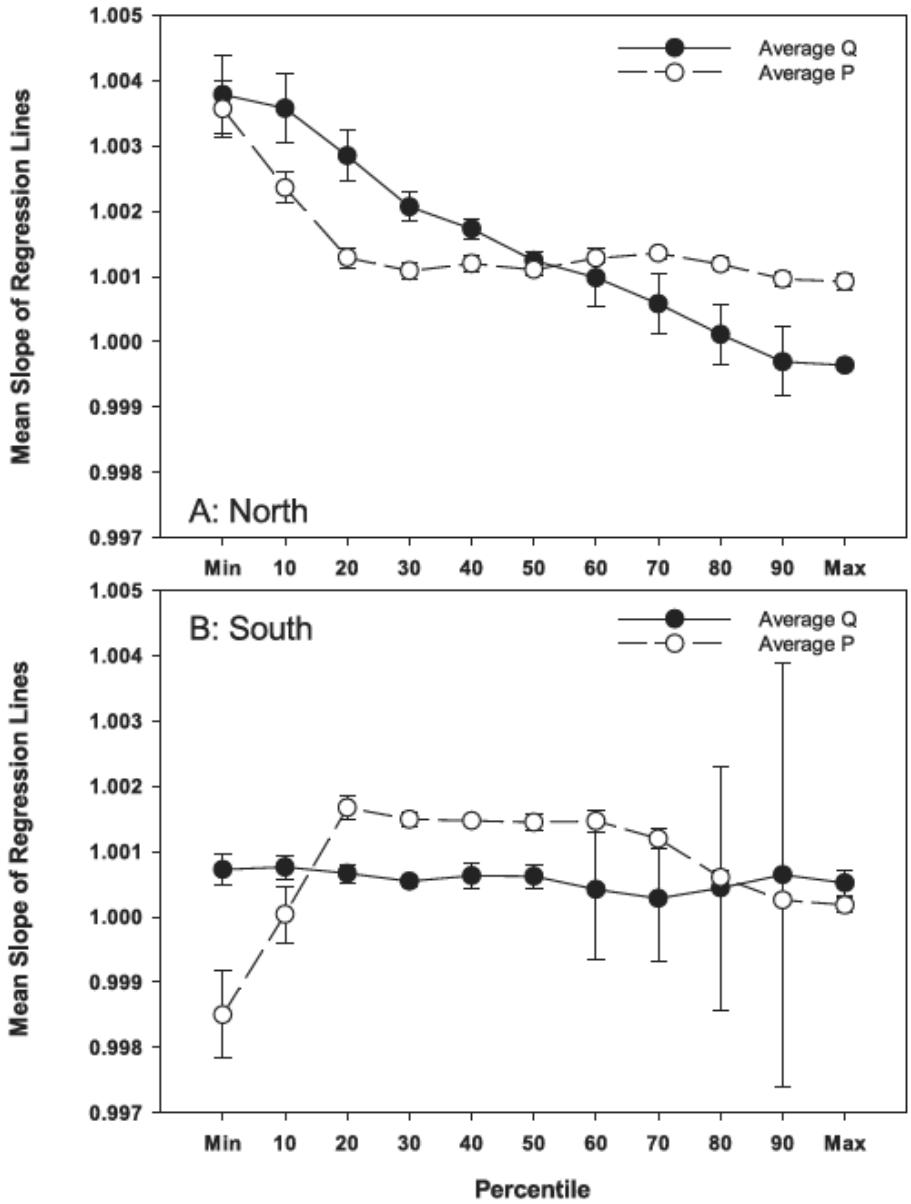


Figure 21: Changes in flow (Q) and rainfall (P) percentiles from 1927-2014 in Chesapeake Bay streams north (A) and south(B) of the Maryland/Pennsylvania border. Y-axis values greater than 1.0 show increases, less than 1.0 are decreases. Trends in the northern streams were statistically significant, while those in the south were not. Excerpted from [Rice et al., 2017].

4.2.4.5 Separating Withdrawals and Discharges from Meterological Effects in Historic Stream Flows

The VAHydro model can be run with a constant withdrawal, discharge and land use in order to isolate rainfall and evaporation effects on flow. Figures 22 and 23 show the results of a VAHydro surface water model run for 1984-2014 with a static land use, withdrawal and discharge. This model shows a trend of increasing 90 day low flow in the Potomac, and a trend towards decreasing 90 day low flow in the James. Because neither watershed has a statistically significant trend, this cannot definitely demonstrate increased or decreased drought severity as a result of climate changes over this short time period. However, agreement with the general trends seen in the USGS study, while accounting for the potential for changes in land use, withdrawals, and point sources, supports the conclusion that meteorological factors cause the apparent north-south trend in low flows in Virginia. It is important to note that [Rice et al., 2017] spanned an 87 year period, nearly 3 times as long as the CBP/VAHydro model. An expanded model time period would provide important information to understand these trends further. Future modeling efforts should also perform an analysis of annual variation in low flow in all rivers in Virginia to determine if there are other watersheds with decreasing low flow trends as a result of changing meteorology.

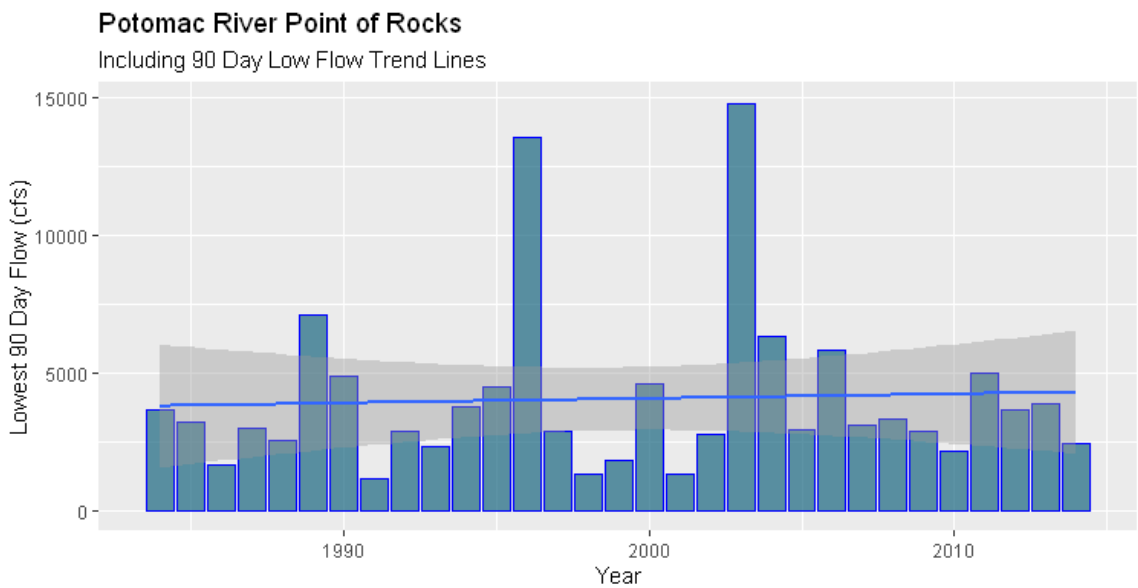


Figure 22: Annual modeled 90 day low flow from 1984-2014 using the VAHydro surface water model with historical meteorology and static withdrawal and discharge at Potomac River Point of Rocks. This model was selected because it had a constant water supply demand over time and therefore any changes to low flows are primarily due to observed changes in rainfall and evaporation. Modeled 90 day low flow had an increasing trend, but this trend was not statistically significant.

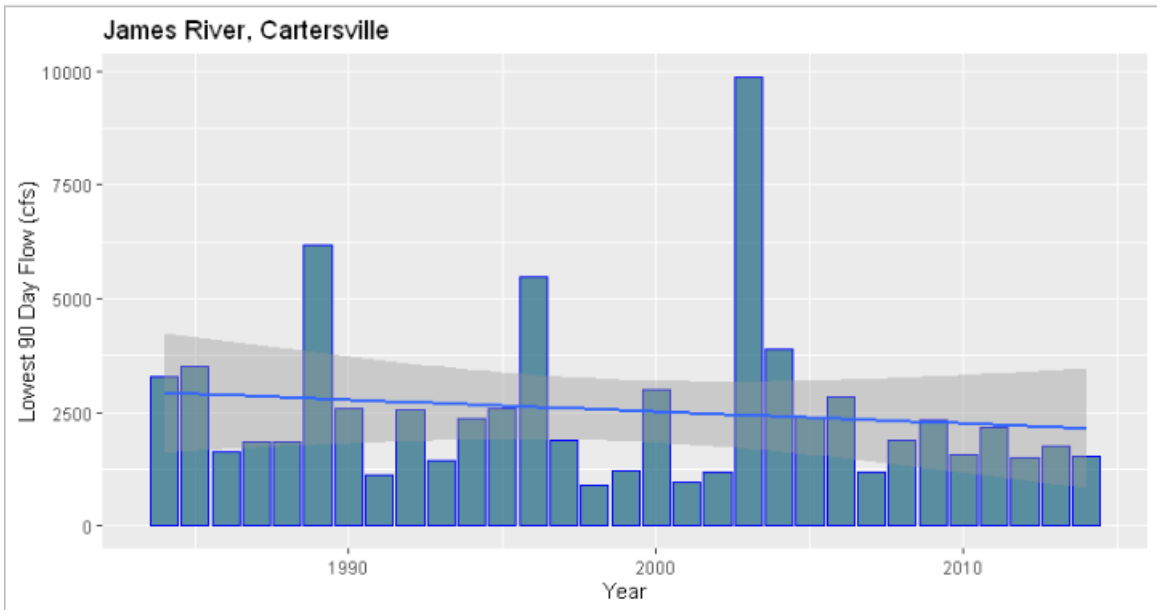


Figure 23: Annual modeled 90 day low flow from 1984-2014 using the VAHydro surface water model with historical meteorology at James River Cartersville. Changes in modeled 90 day low flows were not statistically significant.

4.2.4.6 Increases in Temperature and Evapotranspiration as a result of Increases in Greenhouse Gas Emissions (GHG)

All of the 31 global circulation models (GCMs) considered by the CBP project an increase in temperature in Virginia in all months of the year (see Figure 24) as a result of increasing greenhouse gas emissions. Increased temperature in the region results in increased evaporation from lakes and streams and increased transpiration from plants (collectively referred to as evapotranspiration). This will place additional stresses on water supply systems, especially in times of drought. An increase in long-term average temperature does not guarantee that temperatures will be higher than historic values in every single year.

4.2.4.7 Changes in Rainfall Amounts, Intensity, Geographic and Temporal Distribution as a Result of Climate Change

All future climate scenarios suggest increases in rainfall intensity for the largest 1% of storms, but the magnitude of rainfall varied within the 31 ensemble models evaluated. Of the climate models considered by the CBP, approximately 75% of scenarios project increasing mean annual and monthly rainfall, with 25% projecting no change or decreases in annual/monthly rainfall. Six of the 31 ensemble models considered by the Chesapeake Bay program display a similar north-south gradient to that observed in the 2017 USGS study [Rice et al., 2017]. Global climate models are "down-scaled" using historical rainfall and temperature patterns, so simulations do not attempt to capture the changes in growing season length or changes in seasonal precipitation patterns.

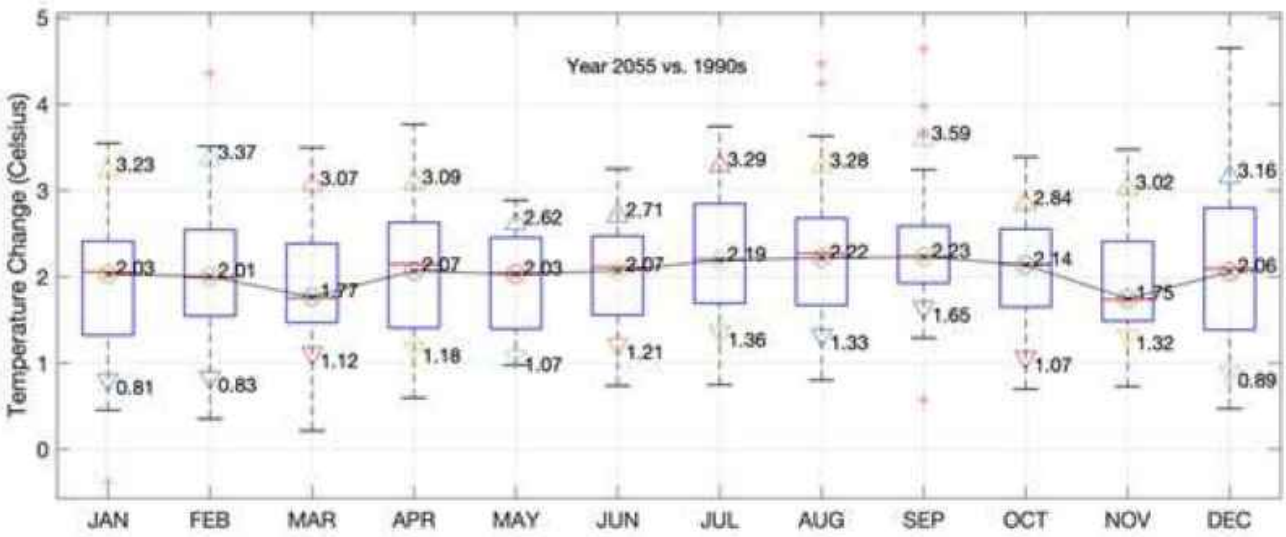


Figure 24: Box-plot showing range of monthly temperature changes, projected by the 31-member ensemble of down-scaled Global Climate Models for RCP 4.5 for the Chesapeake Bay Watershed in year 2055 [Bhatt, 2019].

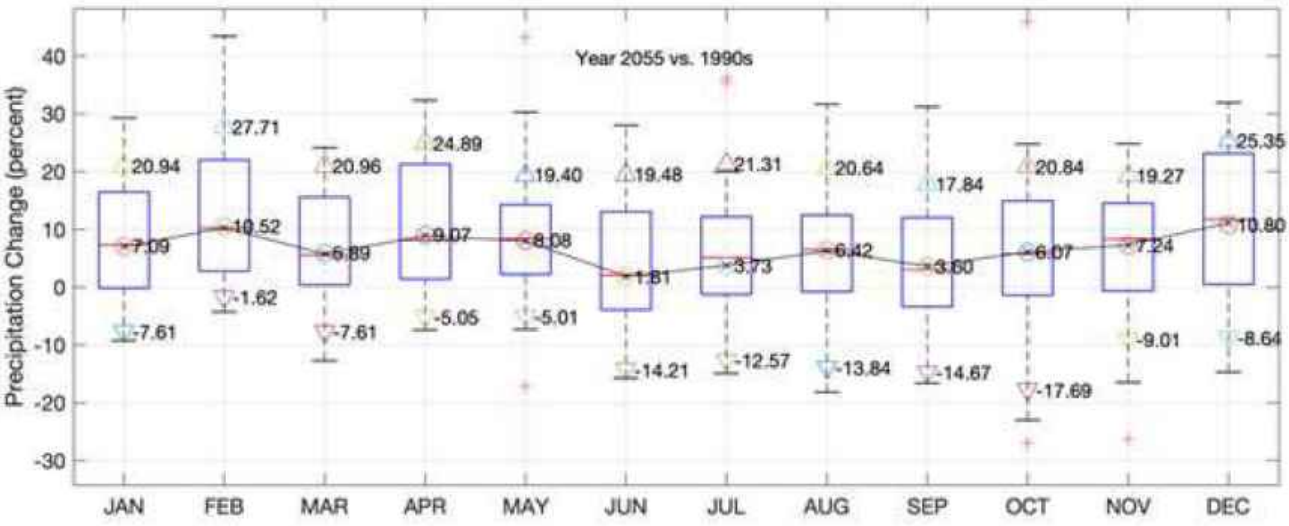


Figure 25: Range of modeled precipitation changes in the 31-member ensemble examined during development of the Chesapeake Bay model climate change analysis. Approximately one in four models suggest decreases in precipitation by 2055, while three of four suggest increases.

4.2.4.8 VAHydro Climate Change Model Scenario Timespan

The climate change model runs from calendar year 1990 through the end of calendar year 2000. This is consistent with TMDL analysis time frame, but also consistent with the convention of calculating changes to global temperature after 1990. Because this is only a 10 year window, it is likely that many watersheds have a historical low flow period that is outside of the climate change simulation time period. Of the 270 river segments modeled in Virginia, 173 have a simulated lowest 90 day flow period that falls within the 1990-2000 (climate simulation) time period. The remaining 97 river segments have a lowest simulated 90 day period that falls outside the 1990-2000 period. For these segments, it can be assumed that the climate driven flow decreases during an extreme drought could be more severe than those simulated here.

4.2.4.9 Areas of Greatest Certainty and Uncertainty Regarding Climate Change

While the amount of temperature increase by 2040 due to greenhouse gases is not known, emissions are expected to continue, and average annual temperature will therefore continue to increase to some extent. These increasing temperatures will result in greater evapotranspiration losses. The ensemble of GCM models differ with respect to changes in average annual rainfall, 25% of the models project a decrease, the remaining 75% project an increase in our region. Evaporation varies in a narrow range from year to year, whereas precipitation can differ by a factor of two between wet and dry years. However, a model analysis from 1984-2014 suggests an increase in evapotranspiration of as much as one inch in Virginia during that time period, and 90% of the GCMs project at least one inch more potential evaporation by 2055. If Virginia watersheds are subject to one inch in additional annual evaporation during a severe drought, it can result in a 5-10% decrease in 90 day low flow. High precipitation years are nearly certain, but a cessation of low precipitation years is not, as evidenced by significant portions of Virginia being affected by droughts in 2001-2002, 2007-2008, 2010-2011, 2017, and 2019. Each of these instances would be exacerbated should an additional inch of evaporation become common during droughts.

4.2.5 Exempt User Scenario

The State Plan includes a new scenario that evaluates the potential impacts from the cumulative maximum possible demands from surface water users excluded, or exempt, from VWP permit requirements by Va. Code § 62.1-44.15:22 B.[41] and 9VAC25-210-310 A. This scenario uses the largest value from: 1) VDH Waterworks Operations permits issued for the facility; 2) information supplied by the user with the estimated maximum capacity of the intake structure in place as of July 1, 1989; 3) the maximum annual water withdrawal reported prior to July 1, 1989; or 4) the maximum annual water withdrawal reported after July 1, 1989. This data comes from existing sources and was provided by the users or by other agency permits that apply to a given facility. Future state plans will continue to explore this topic. In order to effectively manage surface water resources and address the uncertainty related to these demands, DEQ determined the most conservative, or maximum possible, demand should be evaluated in this scenario. However, DEQ does not agree that the maximum values used in this scenario represent an allocation for, or the expectation of, a future withdrawal of that volume; nor does DEQ concede that any particular exempt user is necessarily entitled to withdraw any particular maximum value used in this scenario. For the purpose of the State Plan, the sources of data evaluated for exempt users are:

- Estimated intake maximum capacity.
- The "safe yield" of the stream at the intake location, which was historically estimated as the lowest single day flow that occurs once every 30 years at intake location (1Q30).
- The estimated maximum daily pump capacity as reported to VDH.
- The maximum single monthly withdrawal prior to July 1989.

Table 11: Summary of Exempt Data Sources for Non-tidal Intakes

Scenario Data Source Type	No. of Intakes	Total (MGD)
Intake Capacity	95	1558
Below Permit Threshold	882	74
Pre-1989	249	957
RFI 2009	65	4779
Safe Yield/1Q30	30	1774
VDH Capacity	45	503
*401 Certification	4	71
*VWP Permit	86	431

* These source types represent facilities permitted with either a 401 Certification or VWP Permit

Tables 11 and 12 summarize the total withdrawal amounts by each exemption data source type for tidal and non-tidal withdrawals. Data source types "VWP Permit" and "401 Certification" are those that are permitted by DEQ's VWP program, or by the U.S. Army Corps of Engineers respectively. The source type "Below Permit Threshold" represents users that are exempt because they do not withdraw a large enough quantity to require a permit. For these users, the 2020 water supply plan demand was used for modeling purposes. This is in contrast to all other exempt categories which do withdraw sufficient quantities of water to require a permit if they were not otherwise exempt.

There are over 1,500 exempt intakes in Virginia, and using the maximum possible exempt demand for all intakes results in approximately 10 BGD in total demand from non-tidal waters, or more than 7 times the current annual average daily use. Exempt demands for all facilities in the scenario can be found in the State Plan dataset which is available upon request. While consumptive withdrawals from tidal wa-

[41] Va. Code § 62.1-44.15:22 B

Table 12: Summary of Exempt Data Sources for Tidal Intakes

Scenario Data Source Type	No. of Intakes	Total (MGD)
Intake Capacity	38	3708
Below Permit Threshold	366	16
Pre-1989	45	1954
RFI 2009	39	981
Safe Yield/1Q30	1	227
VDH Capacity	7	107
*401 Certification	1	2260
*VWP Permit	9	5

* These source types represent facilities permitted with either a 401 Certification or VWP Permit

ters may still exhibit negative impacts due to significant consumptive use, a cumulative impact analysis was not performed for withdrawals from tidal waters. Because the magnitude of exempt withdrawals in tidal waters is large, approximately another 10 BGD, this may need to be a subject of further study and should be considered in future efforts to evaluate tidal withdrawals generally.

4.2.5.1 Exempt User Scenario Consumptive Use Assumptions

The exempt use scenario assumes that the consumptive use percent for each exempt user is based on the historic use type. However, there is no guarantee that the owner of a given surface water intake will operate under the same use type in the future. Therefore, this analysis may underestimate cumulative impacts in any stream where the operator of an exempt intake makes changes to its operation that impact consumptive use. On the other hand, there is also the possibility that an intake could be transitioned to a less consumptive use type, thereby making the potential cumulative impact smaller.

4.2.6 Modeling Withdrawals, Discharges and Consumptive Use

While the majority of surface water withdrawals are returned to streams and estuaries as point source discharges, a significant fraction leaves the system as irrigation, evaporation/transpiration, transmission losses, finished products from manufacturing, or human and livestock consumption. As previously mentioned, the portion of water that is not returned to the system is referred to as "Consumptive Use" (CU). This is an important variable in calculating a current and future water balance, therefore its application in a model warrants consideration.

The amount of consumption in Virginia ranges from between 1% to 100% depending on the use type and season. Summer CU is nearly twice that of CU in the winter (see Figure 26). Municipal withdrawals amount to approximately 60% of all non-power withdrawals in 2020 and are therefore responsible for much of the monthly variation and future growth in CU shown in Figure 26. Statewide monthly CU for all non-power uses is estimated as varying from between 200 to 400 MGD in 2020. Non-power uses are isolated in order to highlight the monthly trends in non-power facilities, as power facilities are generally considered non-consumptive. The peak monthly CU for non-power facilities is estimated to be nearly 500 MGD by 2040.

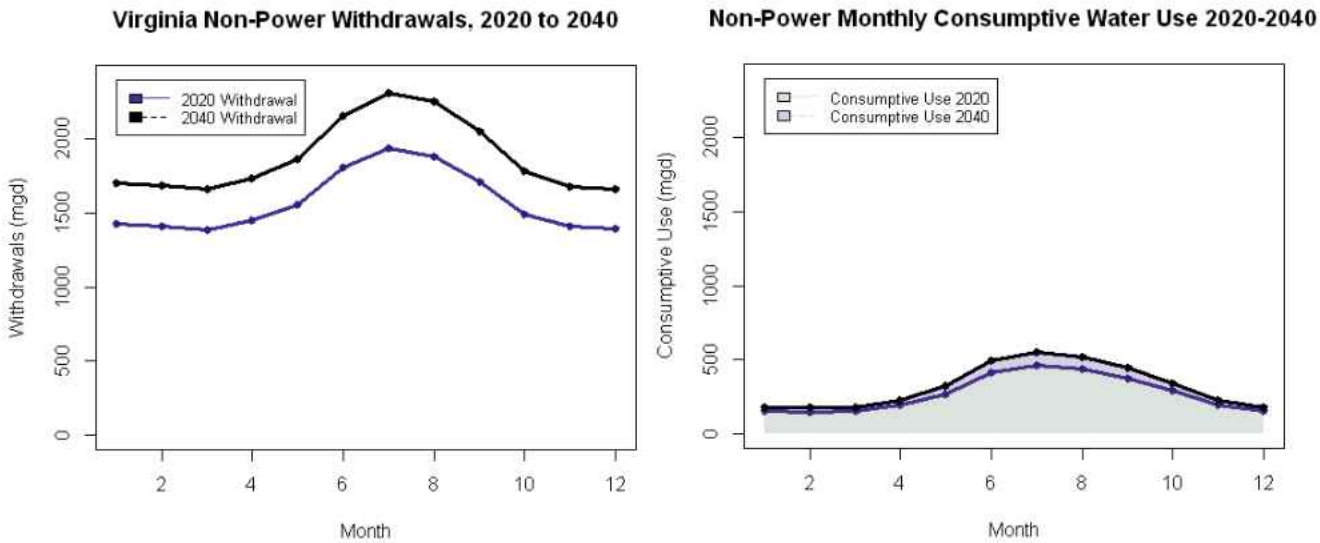


Figure 26: Average monthly simulated withdrawals (left) and consumptive use (right) for all uses except power generation. Simulated values for 2020 are based on a total annual demand of nearly 1,600 MGY, and 2040 are based on an annual demand of approximately 1,900 MGY.

4.2.6.1 Estimating Consumptive Use Factors

Throughout 2017-2019 DEQ collaborated with the Virginia Tech Department of Biological Systems Engineering through a USGS Water-Use Data and Research program (WUDR) grant on a project titled "Virginia's Consumptive Use Data Transfer, Export, and Analysis."[42] Primary results of this project include the development of a set of data retrieval tools to supply point source NPDES Discharge Monitoring Report (DMR) data to Virginia's VAHydro data system. By applying the tools developed through this project, DEQ was able to incorporate all reported point source discharges from Virginia and surrounding states into VAHydro.

Using this wealth of historic discharge data, CU factors (representing the fraction of a withdrawal that is considered consumptive) can be developed. CU

[42] McCarthy (2019), http://hdl.handle.net/10919/89928

factors are a critical component of the VAHydro model, and a necessary prerequisite for modeling future scenarios. By multiplying water demands (such as facility-level 2020 or 2040 demand) by a CU factor, the model is able to scale those demands to more accurately simulate the overall water balance of the stream system.

These percentages are calculated using several methods depending on data availability and use type. When reliable long-term withdrawal and discharge data is known for a given system, CU factors specific to that system are used. Most municipal systems are estimated by using the "winter base rate" method, provided that long term monthly withdrawal data is available. This method estimates summer time CU as the difference between summer and winter time demands (see 4.2.6.2). The remainder of systems were estimated based on analysis of NPDES data and comparison with CU values from scientific literature in the eastern United States.[43] Because return flows are calculated as a function of the amount of water withdrawn, the resulting models can better represent seasonal trends in CU, the effects of addition or removal of facilities, and the ability to project changing point source flows based on changes in future demands. Table 13 shows the default values for the various categories in this analysis.

Table 13: Consumptive Use Factor Defaults

Sector Name	Factor Source	Factor
Aquaculture	VPDES Matched	0%
Agriculture	Literature median	100%
Irrigation	Literature median	100%
Industrial	Literature	10%
Commercial	Literature	10%
Power	VPDES Median/ Literature	2%
Municipal	Winter Base Rate	0-30% by month

4.2.6.2 Modeling Consumptive Use

The VAHydro model estimates the amount of water returned to the stream each day by subtracting the CU percent from the total daily withdrawal, then routing the return flow to the next downstream river segment unless an alternative return point is known. Because total annual, and monthly percent of annual demand is the same for each year for a given scenario, monthly CU does not vary from year

[43] McCarthy (2019), http://hdl.handle.net/10919/89928

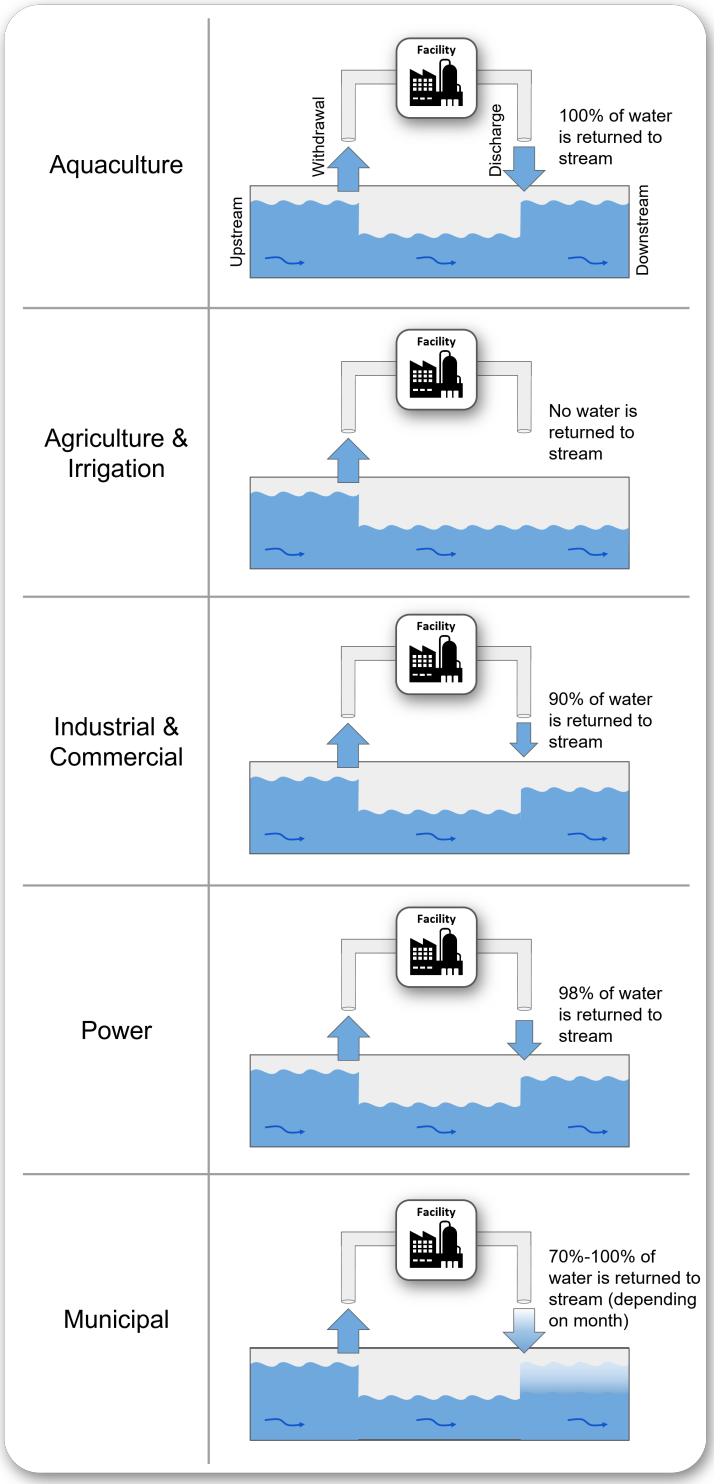


Figure 27: Impact of sector-level consumptive use factors on a stream system where the discharge point is located downstream of the intake. Also depicted is the reduction in streamflow that can occur between the intake and the discharge for systems that are not fully consumptive.

to year within any given scenario. This may underestimate some increases in demand in dry years when drought restrictions are not in place, and overestimate CU during wetter years. Future analyses should include variations in demand based on meteorological factors to assess drought flow reductions due to CU occurring early in drought periods before restrictions are in place.

Location of Withdrawals and Return Flows

Most surface water withdrawn is used, treated and returned to the same river some miles downstream of the withdrawal. When the location of a return flow is known, models are configured to route return flow to the model river segment of the outfall location. When return flow locations are not known, return flows are modeled as returning to the stream in the next downstream watershed from the point of withdrawal (see Figure 28). Some systems (especially large municipal service areas) are structured such that discharge points are located in entirely different watersheds from their withdrawal. For example, the withdrawals in Spotyslvania County's Ni River Reservoir are used in the northern portions of that reservoir, and the majority of treated wastewater flows are returned to the tidal section of the Rappahannock River. DEQ's model is generally adjusted to simulate these effects where they are known to occur.

Low Flow Increases due to Withdrawals from Reservoirs and Groundwater

In general, CU should result in a net decrease in stream flows, with a greater decrease during times of drought due to the smaller baseline water budget. However, due to the use of "stored water", namely reservoirs and groundwater pumping, some streams will actually see an increase in low flows. This is because instead of pumping directly from streams during drought, water is withdrawn from reservoirs or groundwater wells, then returned to streams as a result of the wastewater treatment process. Not all groundwater pumping is assumed to be returned to the stream. Groundwater withdrawals are only assumed to be returned to streams if they are a) part of a conjunctive system with surface water intakes, or b) part of a municipal system with total groundwater withdrawals > 100 MG in a single year. Domestic private well withdrawals (Small Self-Supplied Users) are assumed to be treated on-site (septic), and therefore do not add or subtract from the stream water balance.

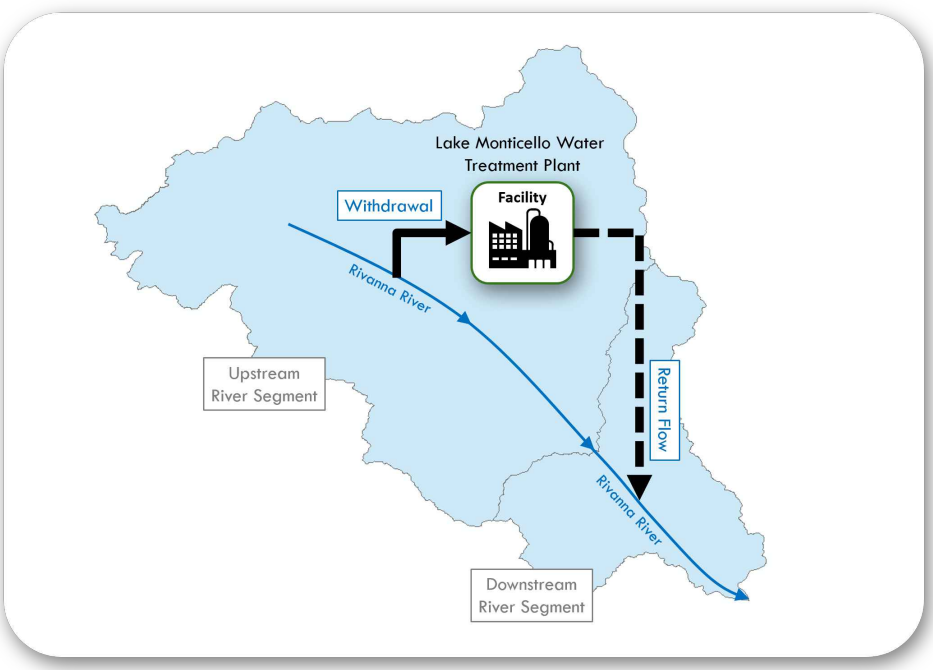


Figure 28: Default location of return flows from municipal wastewater treatment.

Consumptive Use for Power Plant Cooling

Power plants without historical data are assumed to have a CU percentage of 2%, based on the median value from the 2018 VPDES study. Despite a 2020 average daily demand of approximately 3,000 MGD (3 billion gallons per day) in Virginia's non-tidal rivers (including power plants in the WV and MD parts of the Potomac), evaporative losses from cooling amount to less than 100 MGD in total CU.

Municipal Withdrawals Using Winter Base Rate Method

Where possible, CU for public water supply withdrawals with long-term records are estimated using a variation on the "winter base rate method" [Ducnuigeen et al., 2015]; [Li et al., 2017], plus a standard factor for transmission losses (10%, see 4.2.6.3). This method relies upon the assumption that outside watering activities are minimal during the winter, which is a valid assumption throughout Virginia. However, in some areas where winter demands are higher than summer, the WBR is not applicable. For those systems, we used the "Standard Municipal Distribution" given below. Figure 389 shows the range of consumptive use fractions/percentages, which are as low as 0.1 (10%) during winter months, and as high as 0.4 (40%) during summer months in a small subset of systems.

- "Standard Municipal Distribution": CWS systems with seasonal populations or large industrial users are estimated with a standard municipal distribution, based on the "winter base rate method" for Virginia as a whole.

- *In the Potomac River basin outside of Virginia* an analysis of CU was performed by ICPRB. Demands in West Virginia, Maryland, and Pennsylvania were compiled by ICPRB, with CU factors that were obtained from a combination of site-specific (where available), and literature factors (see [Ahmed et al., 2020]).

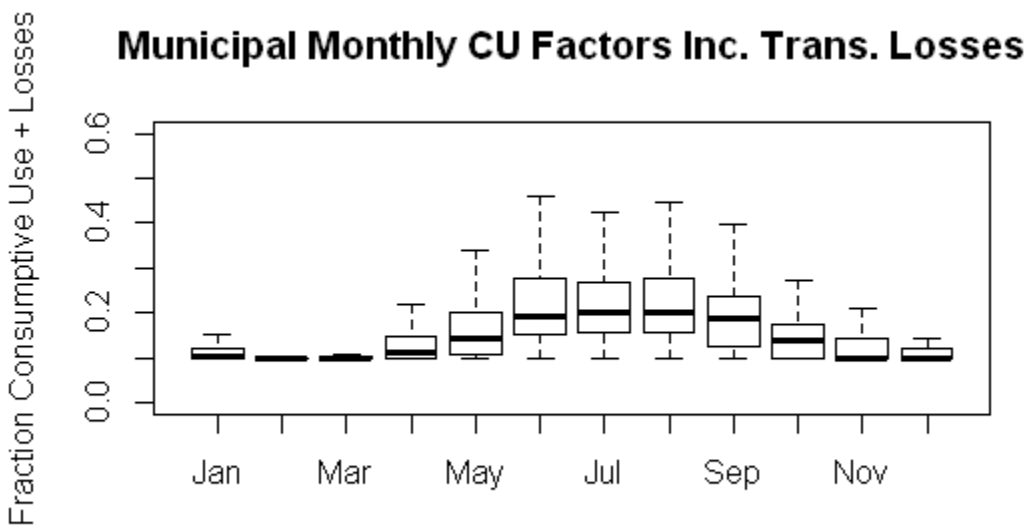


Figure 29: Summary of estimated consumptive use fractions for all municipal facilities where the Winter Base Rate method could be applied. Median values ranged from 0.1 (10%) to 0.2 (20%) in the summer, with summer-time evaporative losses as high as 0.4 (40%) in some areas.

4.2.6.3 Transmission Losses

Municipal water systems deliver water to service areas through a large network of pipes (the distribution system) of varying age and condition, and then water is returned through another network of conveyances to the wastewater treatment facilities (the collection system). Consequently there can be a wide range of transmissions losses, or "leakage from pipes during water transmission". Transmission losses may be permanently lost via evapotranspiration, they may return to the stream as base flow, or they may be delayed and effectively lost from the short term water budget. However, estimating the amount that is

permanently lost is very difficult, and can vary seasonally and annually within the same system. This model used a value of 10% to represent the percent of water withdrawn and not returned to the stream due to transmission losses for all systems. Improved quantification of the fate and magnitude of transmission losses in water-stressed watersheds should be prioritized in future planning efforts (more on this can be found in Appendix B).

4.2.7 Metrics for Cumulative Impact Analysis

The goal of the modeling performed in developing this State Plan is to obtain information about the approximate location, direction, and magnitude of impacts to in-stream and off-stream uses from increasing water demand, changing climatic conditions, and water supply system management actions. This section details a set of metrics selected to summarize the results of model simulations as they pertain to a variety of beneficial uses.

4.2.7.1 Watershed Metrics

- 7Q10
- 30 day low flow (L30)
- 90 day low flow (L90)
- Overall Change in Flow
- Aquatic Life Impacts

Water Quality Metrics: Because decreases to in-stream flows can reduce the waste assimilative capacity of a stream, 7Q10, a common flow metric used to establish point source discharge limits, is used to assess potential risk to assimilative capacity from water supply system changes. This statistic describes a 7-day low flow condition that is expected to occur only one time in a 10-year period, and is generally the lowest flow statistic used in this analysis, with the exception of the 30 day low flow. During routine water withdrawal permit development, assessment of changes to 7Q10, or other site specific metrics is performed to insure that no adverse impacts to water quality or to downstream permitted discharges that are operating within the legally established bounds of their permits. By pointing out areas that are projected to see decreases in 7Q10 by 2040, this analysis will enable stakeholders to avert unforeseen conflicts between withdrawals and discharges. Due to the shortened time period of the climate change scenarios, 7Q10 cannot be reliably estimated and therefore is not used in these scenarios.

Drought Flow Metrics: There are two drought flow metrics used in these analyses: 1) the 30 day low flow and 2) the 90 day low flow. The 30 day low flow describes the lowest 30 day flow simulated during the entire modeling period, whereas the 90 day low flow is the lowest 90 day flow simulated in the modeling time period. Because the 30 day low flow is generally smaller than the 90 day low flow, they are considered more sensitive to changes in consumptive use. Although there is some overlap, in many model segments, the 30 day low flow does not occur in the same year as the 90 day low flow. In the 1984-2014 period covered by this model, only 1/3 of river segments had a 90 day low flow that occurred during the same year as the 30 day low flow. This is generally because 30 day low flows are often caused by short term, acute periods of no rainfall, whereas the 90 day lowest flow is almost invariably the result of an extremely dry winter, followed by a summer with low to moderate rainfall and high temperatures.

Water supply systems that do not have reservoir storage or significant groundwater resources to draw upon are particularly vulnerable to changes in the 30 day low flow. Large reservoir based systems ordinarily have greater than 100 days of stored water available to them, so 30 day low flow changes do not present a particular challenge, however, 90 day low flows can be a useful indicator for evaluating vulnerability to a prolonged drought for reservoir planning purposes. Because the climate change scenarios cover only 1990-2000, it is not possible to make a direct comparison between the climate change L90/L30 and those in the 2020 and 2040 "demand scenarios". Therefore, when assessing potential climate change impacts to drought flows, a separate L30 and L90 are calculated for only the 1990-2000 period.

Overall Change in Flow: Overall change in flow (consumptive use) describes the net loss of water from the riverine system that is not returned through point source discharges. This metric represents the ratio of long term average modeled flow for a particular model scenario, compared to long term average baseline flow. In essence, watershed level consumptive use describes the overall change in flow expected for a particular model scenario. This can help describe potential impacts to downstream withdrawals, while also providing a basis for evaluating impacts to aquatic life.

Ecological Metrics: Using Virginia-specific research conducted by USGS and DEQ, a new approach was developed for evaluating impacts to aquatic life based on the potential for a loss of "fish species richness", which can also be termed as "fish biodiversity". The new "elfgen" framework may allow quantification of potential species loss resulting from flow change, and may offer an improved understanding of aquatic life risk variability due to geographic location, stre-

am size and local scale. This new framework is an advancement over the August Low Flow (ALF)[44] metric used in the 2015 State Plan, as it incorporates large long-term biological monitoring datasets to inform ecological risk. Ecological metrics for assessing impacts to aquatic life are covered in detail in Section 4.2.8.4.

4.2.7.2 Facility Metric

- Potential Unmet Demand

Each facility that withdraws surface water from non-tidal streams is simulated individually, with monthly varying demand patterns based on historical use. During each simulated day the model calculates an estimate of water available for each withdrawal from the river at the facility intake location. Some systems with permits or known operational rules have drought triggers built into the simulation that reduces demand when a given drought trigger is hit. If the available water is less than demand on a given day, or if demand is reduced due to a drought trigger, a calculation of "unmet demand" is recorded. With some large systems, there may be times when the model calculates unmet demand when that demand may be readily met by some reservoir in another part of the system or from a groundwater source. Thus, unmet demand does not always mean that a system would run out of water in the given scenario, but extended periods of simulated unmet demands are an indication of water system stress, the need to use conservation storage, or the need for reliance on groundwater resources. Perhaps more importantly, differences in unmet demand between scenarios will be a good indicator of potential water system stress. Potential unmet demand in the State Plan refers specifically to the maximum 30 day potential unmet demand provided in MGD. Analysis of facility specific unmet demand can be found in Appendix A for each minor basin.

[44] August Low Flow is an ecological flow metric used in the 2015 State Plan. It is calculated by taking the median of the minimum flows occurring during the month of August over the simulation period. ALF was replaced by the elfgen framework for the 2020 State Plan.

4.2.8 Statewide Surface Water Model Results

The following section covers results of the statewide cumulative impact modeling that was completed as described above. Note that this section is intended as a high level overview of surface water modeling results and the major trends identified. Results and discussion at a smaller and more specific scale are provided in Appendix A, which includes separate sections for each minor basin. In addition to reading this section, readers should review the sections within Appendix A for the areas in Virginia in which they are interested.

4.2.8.1 Water Supply Plan Demand Scenario Results

The following series of figures compares the 2030 and 2040 demand scenarios to the current demand scenario. The change in streamflow depicted on each map is the change expected when comparing two scenarios; in this case future demands compared to current (2020) demands. Each page includes two figures comparing the 2030 or 2040 demand scenario to current demand using either the 30 day low flow, 90 day low flow, and 7Q10 metrics. This allows for comparisons of simulated impacts between the 2030 and 2040 demand scenarios. The scenarios and metrics are identified in the paragraph below and in the figure captions.

Figures 30 and 31 compare the 30 day low flow simulated with the current demand scenario with the 30 day low flow simulated in the 2030 and 2040 demand scenarios respectively. Figures 32 and 33 compare the 90 day low flow simulated with the current demand scenario with the 90 day low flow simulated in the 2030 and 2040 demand scenarios respectively. Figures 34 and 35 compare the 7Q10 simulated with the current demand scenario with the 7Q10 simulated in the 2030 and 2040 demand scenarios respectively.

In addition to the figures, Table 14 provides a major basin level summary of the percentage of non-tidal river segments in each major river basin with a more than 10% reduction in each metric when comparing the 2020 and 2040 demand scenarios. In combination, these figures and tables are useful in identifying where challenges in meeting future surface water demands are most likely based on the projected increase in cumulative demands provided in the water supply plans. River segments showing a more than 10% reduction when comparing 2020 and 2040 demands scenarios are those where increasing demands drive reductions in short-term or acute drought flows, and therefore challenges in meeting those demands.

At the major basin scale described in Table 14, the Meherrin, York, Roanoke, Rappahannock and Shenandoah Basins each have reductions of 10% or more in streamflow in at least 5% of non-tidal river segments. The 30 day low flow is a metric that is particularly relevant to direct stream withdrawals with limited or no storage, as even a short-term drought can impact capacity.

> Impacts for the **30 day low flow** metric in the 2040 demand scenario are most common where demands are increasing but no storage is available, particularly in the headwaters of streams or rivers.

Reductions in the 90 day low flow, which represents a long-term drought, are less widespread but still present in the 2040 demand scenario (Figure 33). At the major basin scale, the Meherrin, York, and Rappahannock River Basins show the greatest percentage of river segments with at least a 10% reduction (Table 14). The 90 day low flow is the least sensitive metric as it represents the longest period of time, and therefore average streamflows are generally higher than in the 30 day low flow or 7Q10. Where reductions are simulated in the 90 day low flow, this indicates areas where projected increases in demands could impact both direct withdrawals as well as reservoir operations and long-term storage.

7Q10 is the most sensitive metric as it represents only the lowest seven day period which would be expected to reoccur every ten years, and therefore greater reductions in streamflow are seen when comparing the 2020 and 2040 demand scenario in Figure 35. The 7Q10 metric is most commonly associated with point source discharge permits (waste assimilative capacity); areas where reductions are simulated are those where projected demands could potentially impact downstream discharge operations. As with the lowest 30 day flow, the most impacted basins include the Shenandoah, Roanoke, and Meherrin. However, unlike the other metrics, the Tennessee and James River Basins also show simulated streamflow reductions due to the greater sensitivity of the 7Q10 metric.

Note that the Overall Change in Flow metric, which is also included in Table 14, is discussed in the following section.

The water supply plans provided projections for how demands may increase for each category and locality through 2040. Although total water demands excluding power generation are projected to increase statewide from around 1.57 billion gallons to 1.9 billion gallons between 2020 and 2040, the 2040 demand scenario indicates only minor to moderate reductions in stream flows compared to current demands in most of the river basins in Virginia. However, this does not mean that streamflows during a drought under even the current demands on Virginia's streams and rivers are sufficient to meet all demands and uses.

Even **under current demands**, some parts of the state experience drought flows that impact water supply and other beneficial uses. These areas also tend to be where streamflows are simulated to decrease in the 2040 demand scenario, namely the headwaters of streams or areas with limited storage.

Table 14: Percentage of Major Basins with a >10% Stream Flow Reduction in the Future Demand Scenario

Major Basin	**Lowest 30 Day Low Flow***	**Lowest 90 Day Low Flow***	**7q10***	**Overall Change in Flow**
Big Sandy	0.00	0.00	0.00	0.00
James	2.06	2.06	8.25	2.06
Meherrin	19.23	11.54	19.23	7.69
New River	0.00	0.00	0.00	0.00
Potomac	3.18	1.91	4.46	12.74
Rappahannock	5.88	5.88	5.88	11.76
Roanoke	8.77	1.75	10.53	12.28
Tennessee	4.76	0.00	14.29	0.00
York	20.00	15.00	15.00	0.00

* Calculations for these metrics are based on comparison to the 2020 Demand Scenario.

30 Day Low Flow (Percent Change 2020 to 2030)

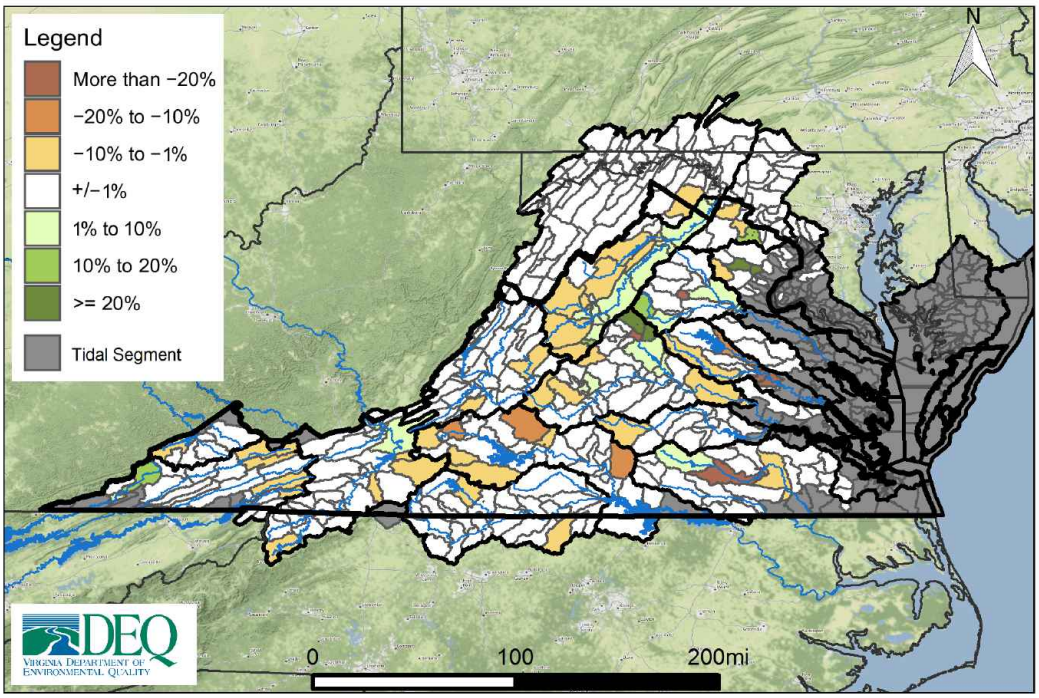


Figure 30: Change in 30 Day Low Flow between the 2020 and 2030 Demand Scenarios

30 Day Low Flow (Percent Change 2020 to 2040)

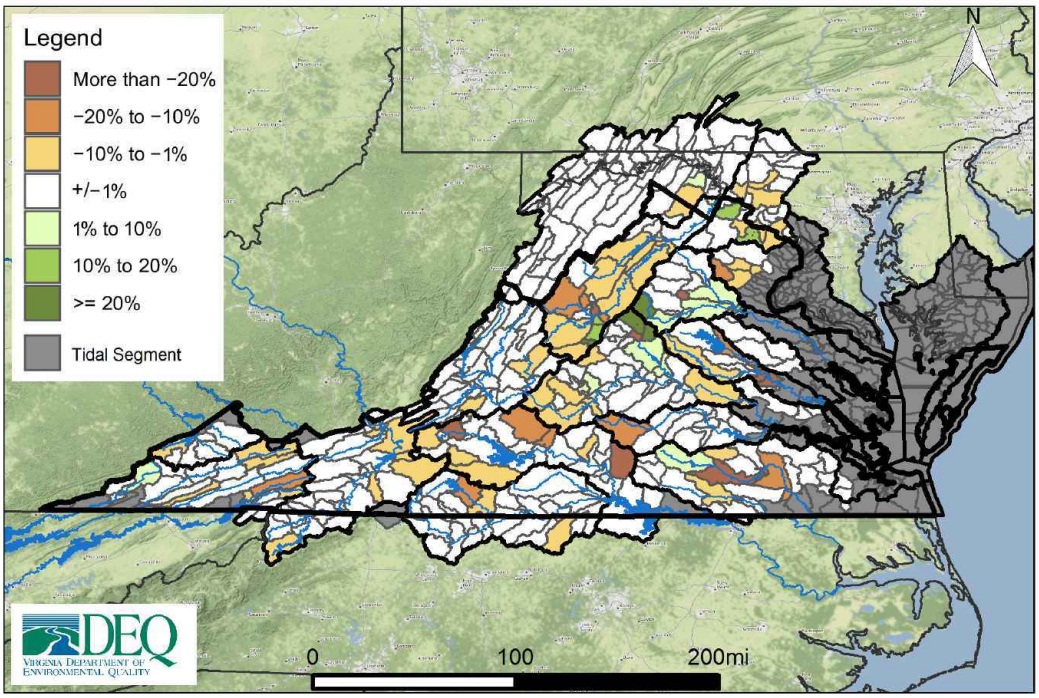


Figure 31: Change in 30 Day Low Flow between the 2020 and 2040 Demand Scenarios

90 Day Low Flow (Percent Change 2020 to 2030)

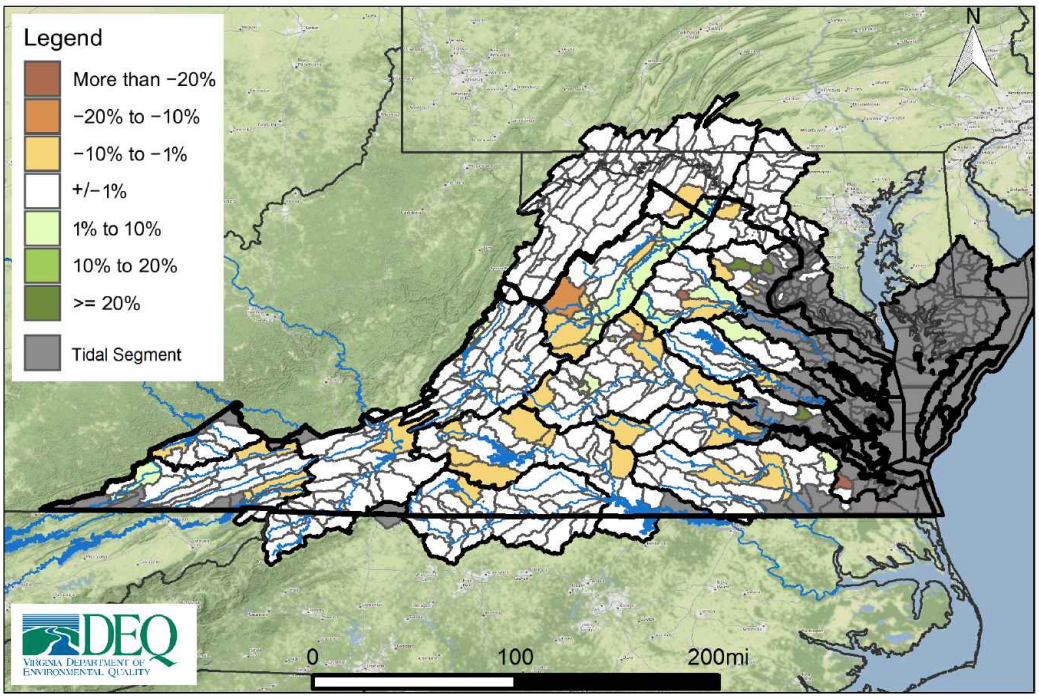


Figure 32: Change in 90 Day Low Flow between the 2020 and 2030 Demand Scenarios

90 Day Low Flow (Percent Change 2020 to 2040)

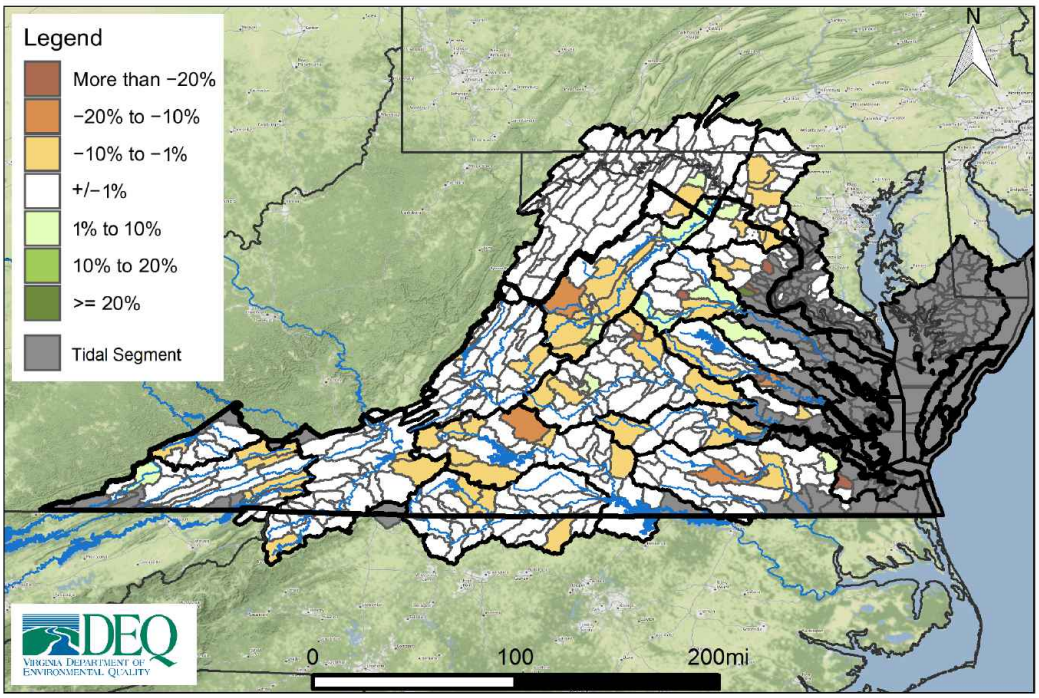


Figure 33: Change in 90 Day Low Flow between the 2020 and 2040 Demand Scenarios

7Q10 (Percent Change 2020 to 2030)

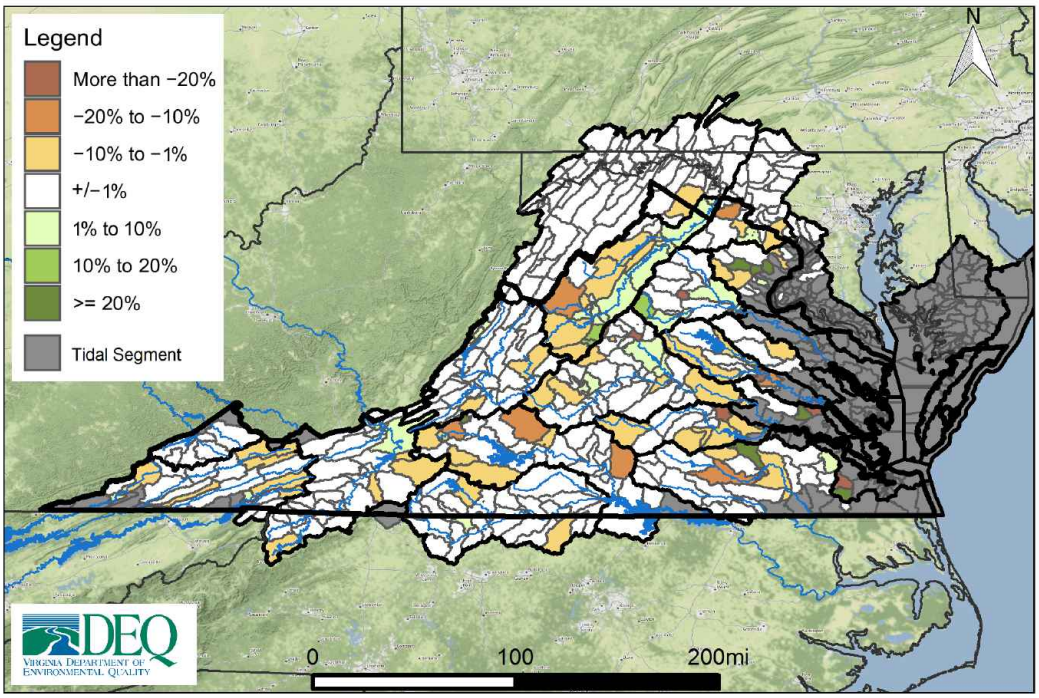


Figure 34: Change in 7Q10 between the 2020 and 2030 Demand Scenarios

7Q10 (Percent Change 2020 to 2040)

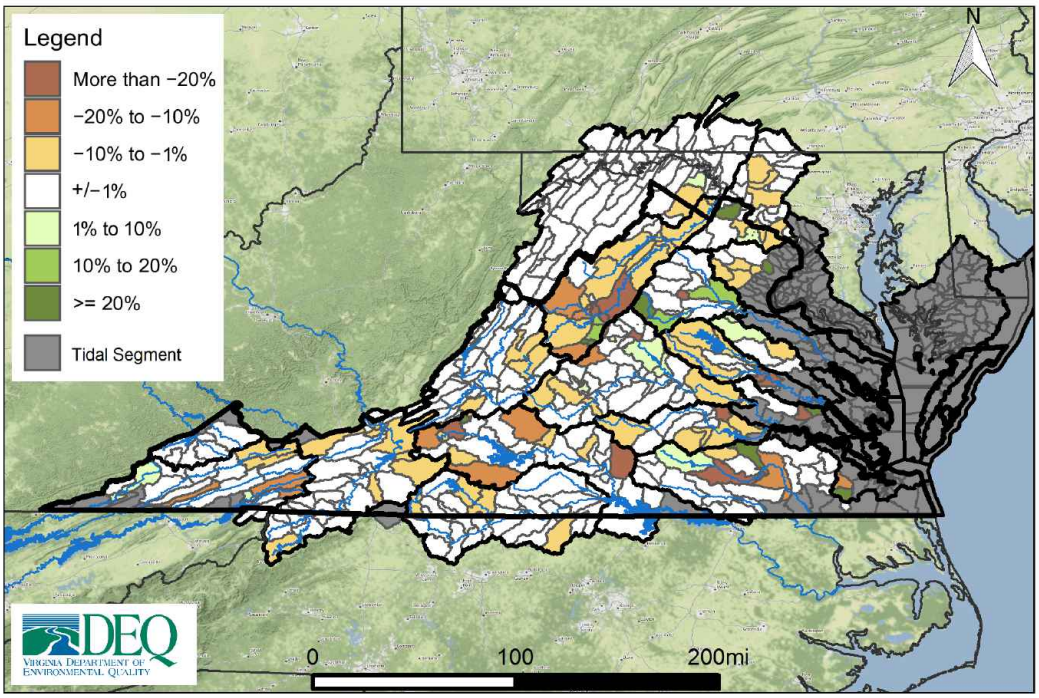


Figure 35: Change in 7Q10 between the 2020 and 2040 Demand Scenarios

Overall Change in Flow: The figures above show a comparison between two scenarios. An additional way to evaluate impacts to streamflow is to examine the total reduction in streamflow resulting from all withdrawals within a river segment, while taking into consideration any discharges back to the source. To use a common industry term, the overall change in flow metric evaluates "consumptive use", or the amount of water removed from the river that is not returned through discharge. This can help describe potential impacts to downstream withdrawals, while also providing a basis for evaluating impacts to aquatic life. In general, total reductions in streamflow can result in a reduction in aquatic biodiversity.[45] The relation between streamflow and aquatic biodiversity is discussed in more detail in the Impacts to Aquatic Life, Section 4.2.8.4.

Figure 36 shows the overall change in streamflow for the 2030 demand scenario, while Figure 37 shows the overall change in streamflow for the 2040 demand scenario. Table 14 provides a summary of the metric along with all other metrics at major basin scale.

To summarize, these results show that in the 2040 demand simulation, the overall change in flow (consumptive use) in the majority of river segments in Virginia is below 5%, which suggests a minimal impact on aquatic life. The greatest reductions in overall flow are seen in the Potomac, Rappahannock, and Roanoke River Basins with at least 10% of river segments in those basins showing at least a 10% reduction in overall flow. In those basins in particular, the 2040 demand scenario does result in reductions in overall flow in some segments at or above thresholds which would likely impact aquatic life. A more detailed evaluation of how this metric relates to species richness change, and an overview of the river segments with the highest reductions in overall flow is provided in section 4.2.8.4. Minor basin specific discussions of this metric are found in Appendix A.

[45] Rapp, J.L., R. Burgholzer, J. Kleiner, D. Scott, and E. Passero. 2020. "Application of a New Species-Richness Based Flow Ecology Framework for Assessing Flow Reduction Effects on Aquatic Communities." Journal of the American Water Resources Association 56 (6):967–980.

Overall Percent of Flow Change (2030)

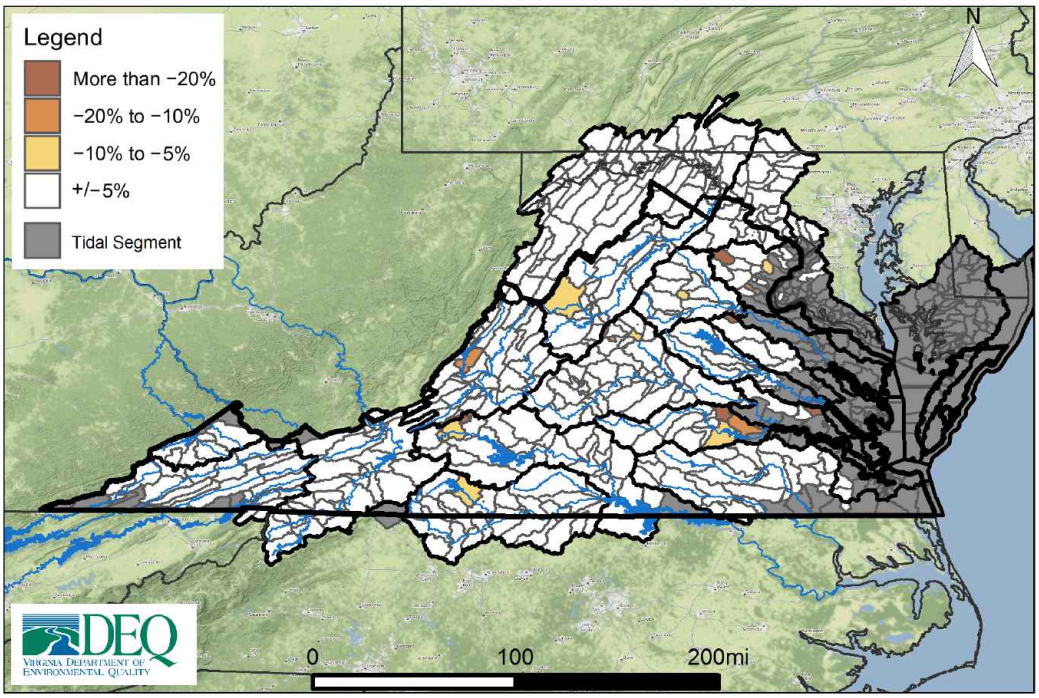


Figure 36: Overall change in flow in percent for the 2030 demand scenario

Overall Percent of Flow Change (2040)

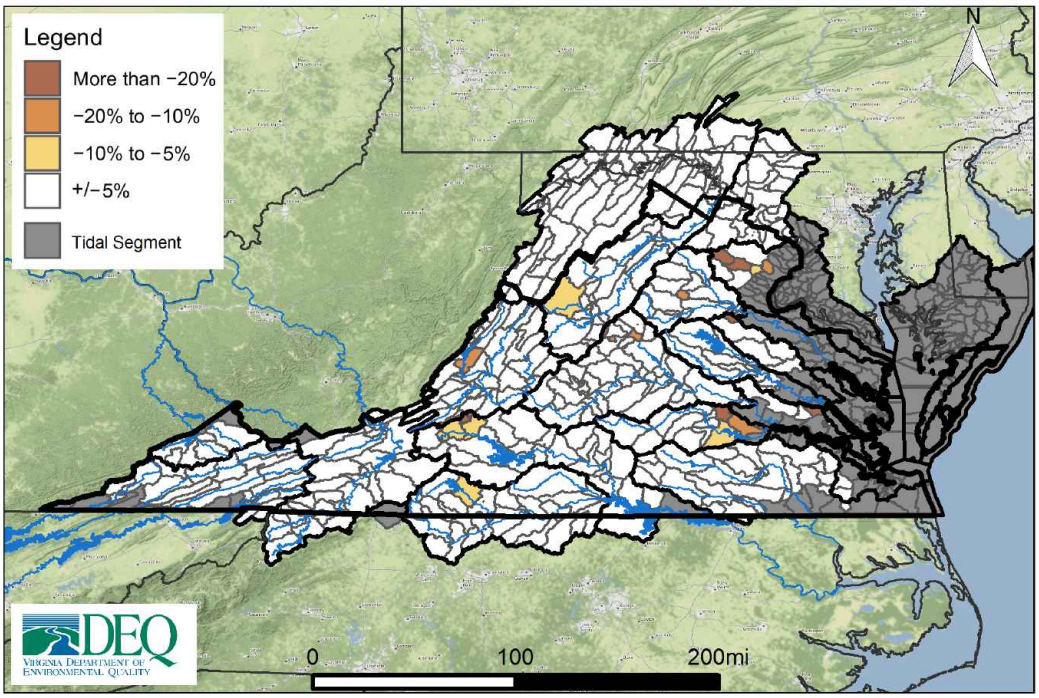


Figure 37: Overall change in flow in percent for the 2040 demand scenario

4.2.8.2 Climate Change Scenario Results

Virginia is expected to experience a range of precipitation and temperature changes that may vary spatially and from year to year. The potential for both more severe and prolonged droughts as well as for higher intensity and more frequent rain events must be considered.

> The **dry, median, and wet climate scenarios** are not intended as predictions of future climate conditions in Virginia, but as representations of several possibilities that climate change models indicate could occur. Should they occur, these results provide an evaluation of how streamflows may be impacted.

The purpose of the climate scenarios is to build upon existing climate modeling to provide a foundation for state and local government, as well as other stakeholders, to better evaluate what practical water resource challenges may be associated with the range of climate conditions Virginia could experience. For the purpose of the State Plan, the dry climate scenario will be focused on given its greater potential impact on water supply and other beneficial uses.

Figure 38 depicts the percent change in the 30 day low flow for the dry climate scenario in conjunction with 2040 demands, as compared to the current climate and demand scenario. Reductions in streamflow in this scenario may be caused by reduced precipitation, increased demand, or as is generally the case, a combination of both. Figures 40 and 39 depict the 30 day low flow for the median and wet climate scenarios (in conjunction with 2040 demands) as compared to the current climate and demand scenario.

Figure 41 depicts the percent change in the 90 day low flow for the dry climate scenario in conjunction with 2040 demands, as compared to the current climate and demand scenario. Figures 43 and 42 depict the 30 day low flow for the median and wet climate scenarios (in conjunction with 2040 demands) as compared to the current climate and demand scenario.

Table 15 provides a major basin level summary of the percentage of non-tidal river segments in each basin with a more than 10% reduction in a given metric when comparing the dry climate scenario and 2040 demands to the current climate and demands.

Streamflow is simulated to decrease by 10% or more during both the 30 day low flow and 90 day low flow in nearly 80% of all non-tidal segments within the James, Potomac, Rappahannock, and York basins when comparing the dry climate scenario to current conditions (see Table 15). Reductions in simulated drought flows of 50% or more are not uncommon, and the overall trend is consistent across the non-tidal river segments in the Chesapeake Bay drainage area, with the exception being areas that are highly regulated by reservoir releases. As opposed to the demand scenarios discussed above, these simulated reductions are largely driven by the dry scenario meteorology described in the climate meteorology section rather than increasing demands.

One way to think about the dry climate change scenario is as a form of "stress test." Specific river segments or facilities that are simulated to be impacted in the dry climate scenario will not necessarily be impacted in the future, but the extent of the simulated streamflow reductions across Virginia in the dry scenario suggests an evaluation of climate resiliency related to water supplies may be warranted. The temperature and rainfall pattern changes that are simulated in these scenarios are all within a reasonable bound based on the predictions of the best available global climate models of increasing atmospheric CO_2. More variability in general may be the most predictable result.

> All stakeholders including state and local government, water authorities, and individual water users may need to take steps to **incorporate climate modeling data** where available into resource planning efforts.

At minimum, climate change suggests that Virginia has the potential to experience droughts that are more severe than those experienced in the past. Even if such events are rare, it will become increasingly important that water supply planning occur at a scale that facilitates a regional evaluation of sources and demands, as well as evaluating regional opportunities for diversifying sources, developing storage, and building interconnections and redundancy where possible among neighboring systems.

Note that more localized versions of these figures as well as a table identifying potential unmet demand on a facility level during the dry climate scenario can be found in Appendix A.

Table 15: Percentage of Major Basins with a >10% Stream Flow Reduction in the Dry Climate Scenario

Major Basin	**Lowest 30 Day Low Flow***	**Lowest 90 Day Low Flow***	**7q10***
Big Sandy	-	-	-
James	76.29	83.51	47.42
Meherrin	-	-	-
New River	-	-	-
Potomac	92.99	90.45	72.61
Rappahannock	88.24	88.24	41.18
Roanoke	-	-	-
Tennessee	-	-	-
York	80	85	35

* Calculations for these metrics are based on comparison to the 2020 Demand Scenario.
Note: Climate scenarios were not completed in areas located outside of the Chesapeake Bay Basin.

30 Day Low Flow (Percent Change 2020 to Dry Climate Change)

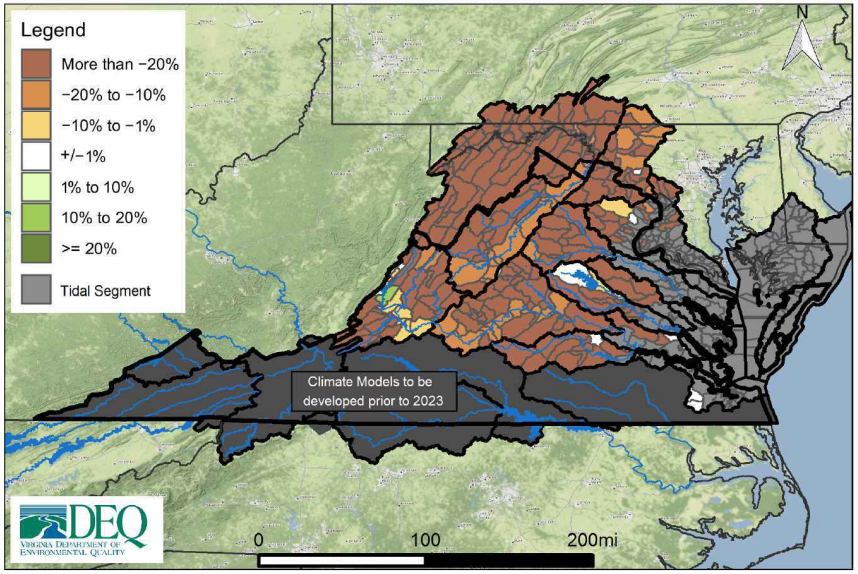


Figure 38: Change in 30 day low flow between current climate/demand scenario and the dry climate/2040 demand scenario

30 Day Low Flow (Percent Change 2020 to Wet Climate Change)

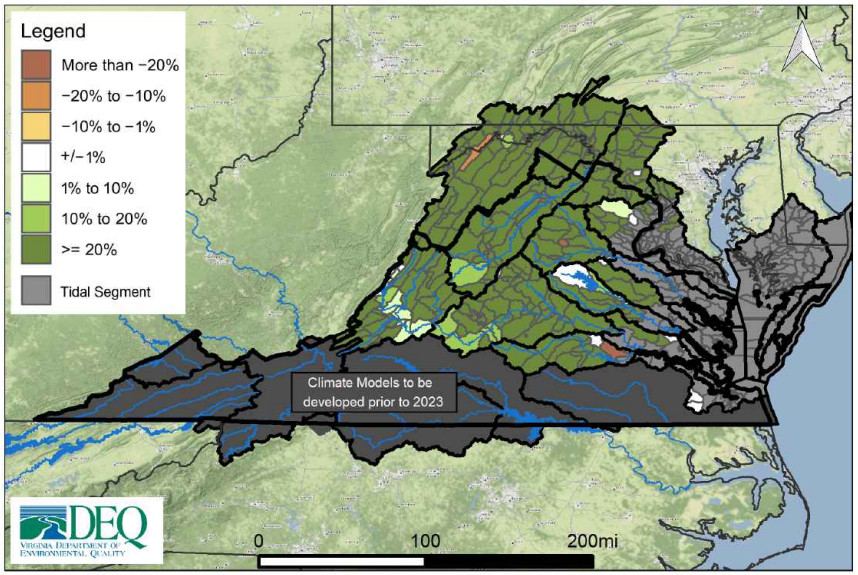


Figure 39: Change in 30 day low flow between current climate/demand scenario and the wet climate/2040 demand scenario

30 Day Low Flow (Percent Change 2020 to Med Climate Change)

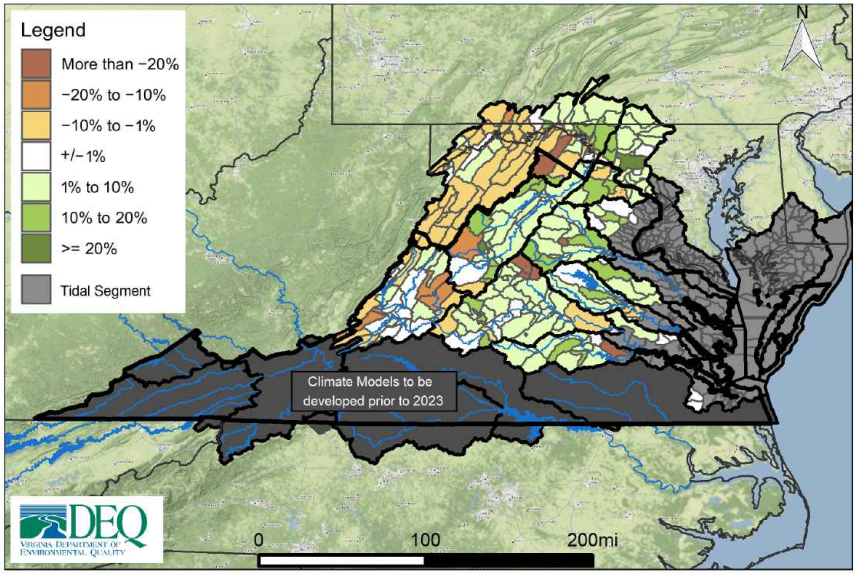


Figure 40: Change in 30 day low flow between current climate/demand scenario and the median climate/2040 demand scenario

90 Day Low Flow (Percent Change 2020 to Dry Climate Change)

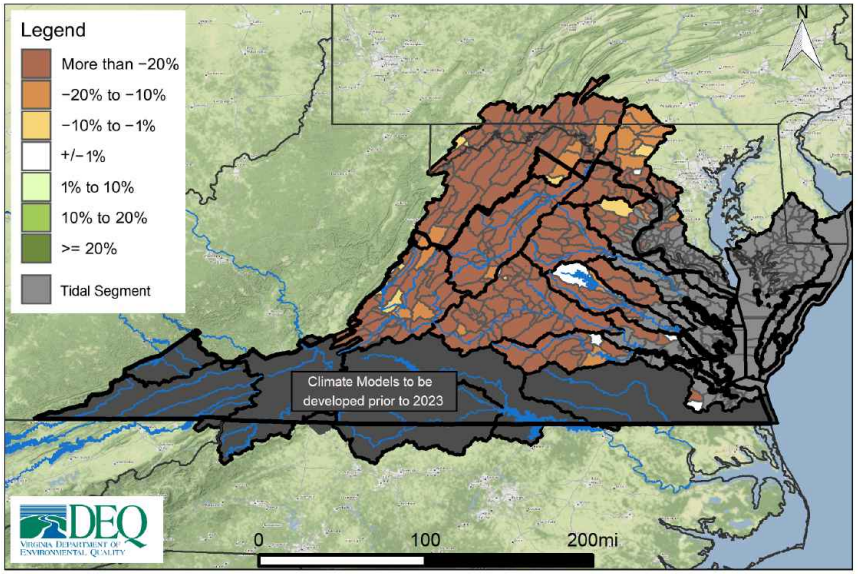


Figure 41: Change in 90 day low flow between current climate/demand scenario and the dry climate/2040 demand scenario

90 Day Low Flow (Percent Change 2020 to Wet Climate Change)

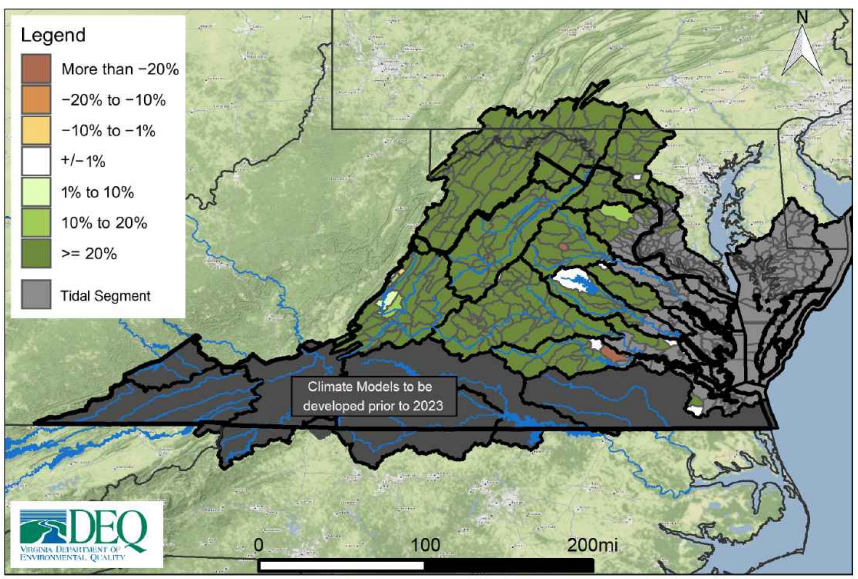


Figure 42: Change in 90 day low flow between current climate/demand scenario and the wet climate/2040 demand scenario

90 Day Low Flow (Percent Change 2020 to Med Climate Change)

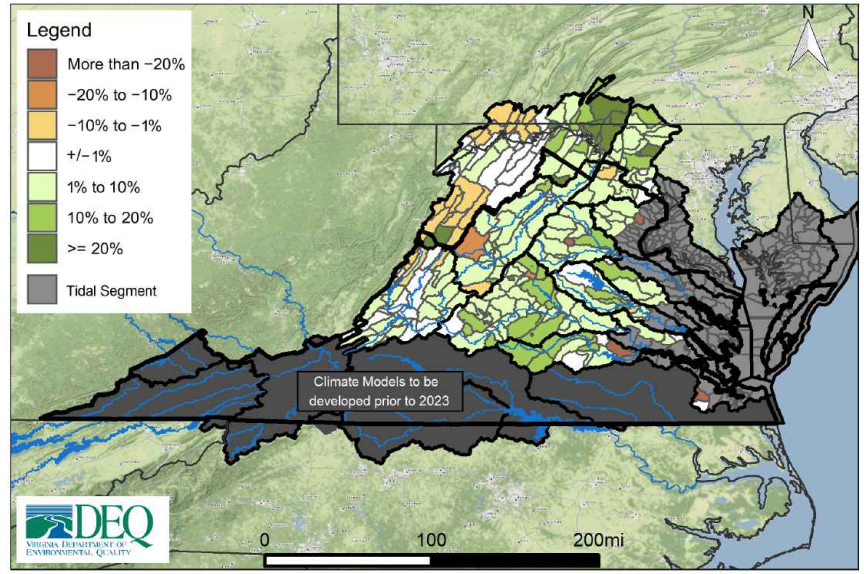


Figure 43: Change in 90 day low flow between current climate/demand scenario and the median climate/2040 demand scenario

4.2.8.3 Exempt User Scenario Results

The exempt user scenario examines impacts from users excluded, or exempt, from VWP permit requirements per Va. Code § 62.1-44.15:22 B. A more detailed discussion of the data and assumptions used in this scenario can be found in Section 4.2.3. Note that this scenario uses current climate meteorology.

Figure 44 depicts the percent change in the lowest 30 day flow between the exempt user scenario and current (2020) demand. Figure 45 depicts the percent change in the Lowest 90 Day Flow between the exempt user scenario and current (2020) demand. Figure 46 depicts the percent change in the 7Q10 between the exempt user scenario and current (2020) demand. Finally, Figure 47 depicts the overall change in flow in percent (consumptive use) for the exempt user scenario. Table 16 provides a major basin level summary of the percentage of non-tidal river segments in each basin with a more than 10% reduction in a given metric when comparing the 2020 and exempt user scenario.

The exempt user scenario results in reductions of 10% or more over large portions of Virginia for short-term (30 day low flow) and long-term droughts (90 day low flow) compared to the 2020 demand scenario. That includes over 40% of the non-tidal river segments in the James River Basin, and 50% or more of the non-tidal segments in the Meherrin, Tennessee, and York Basins (see Table 16). While a 10% reduction in streamflow represents a threshold where impacts to beneficial uses become more probable, the exempt user scenario often results in simulated streamflow reductions of greater than 50% across all metrics in areas where particularly large or numerous exempt demands are located. Should these demands be realized, impacts to beneficial uses including public water supply and aquatic life would be significant. The "Potential Unmet Demand" facility metric can be used to evaluate the impacts to specific water users in this scenario. This metric identifies which facilities would need to rely on other sources, or would not be able to meet their surface water demands due to insufficient streamflow. This metric is covered in detail for each minor basin in Appendix A.

Potential unmet demand is simulated for multiple facilities, including public water supplies, in almost every minor basin in the exempt user scenario.

Simulated reductions in overall flow, or consumptive use, are also significant in the exempt user scenario. Although a given facility's consumptive use factor does not change in this scenario, the increased withdrawals associated with the maximum possible exempt demand also results in a proportional increase in the amount of water withdrawn and not returned to the source. Reductions in overall flow of 50% and greater are simulated in some river segments, particularly in segments below impoundments with no operational rules requiring releases downstream. The relationship between impacts to aquatic life and overall change in streamflow are discussed further in Section 4.2.8.4.

In summary, the exempt user scenario indicates that the cumulative maximum possible exempt user demands, in combination with permitted demands, exceed the water budget in many of Virginia's streams and rivers. Or in other words, there is insufficient streamflow to meet the cumulative maximum exempt demands during drought flows, even before considering impacts to other beneficial uses. This manifests as potential unmet demand for small and large exempt users, as well as for permitted users. Substantial impacts to other beneficial uses, such as aquatic life, waste assimilative capacity, and even recreation, are also likely based on the simulated reductions in streamflow. This scenario represents a significant step in evaluating impacts from unpermitted, or exempt, surface water withdrawals, and can be used to focus future evaluations on areas of highest potential concern. As a whole, it underscores the importance of evaluating potential exempt demands cumulatively and in the context of the regional water resources.

Table 16: Percentage of Major Basins with a >10% Stream Flow Reduction in the Exempt User Scenario

Major Basin	**Lowest 30 Day Low Flow***	**Lowest 90 Day Low Flow***	**7q10***	**Overall Change in Flow**
Big Sandy	50.00	50.00	33.33	0.00
James	44.33	39.18	49.48	3.09
Meherrin	53.85	30.77	57.69	3.85
New River	28.13	28.13	28.13	0.00
Potomac	24.84	16.56	22.93	1.27
Rappahannock	11.76	5.88	11.76	17.65
Roanoke	31.58	21.05	31.58	1.75
Tennessee	61.90	47.62	66.67	0.00
York	50.00	45.00	50.00	0.00

* Calculations for these metrics are based on comparison to the 2020 Demand Scenario.

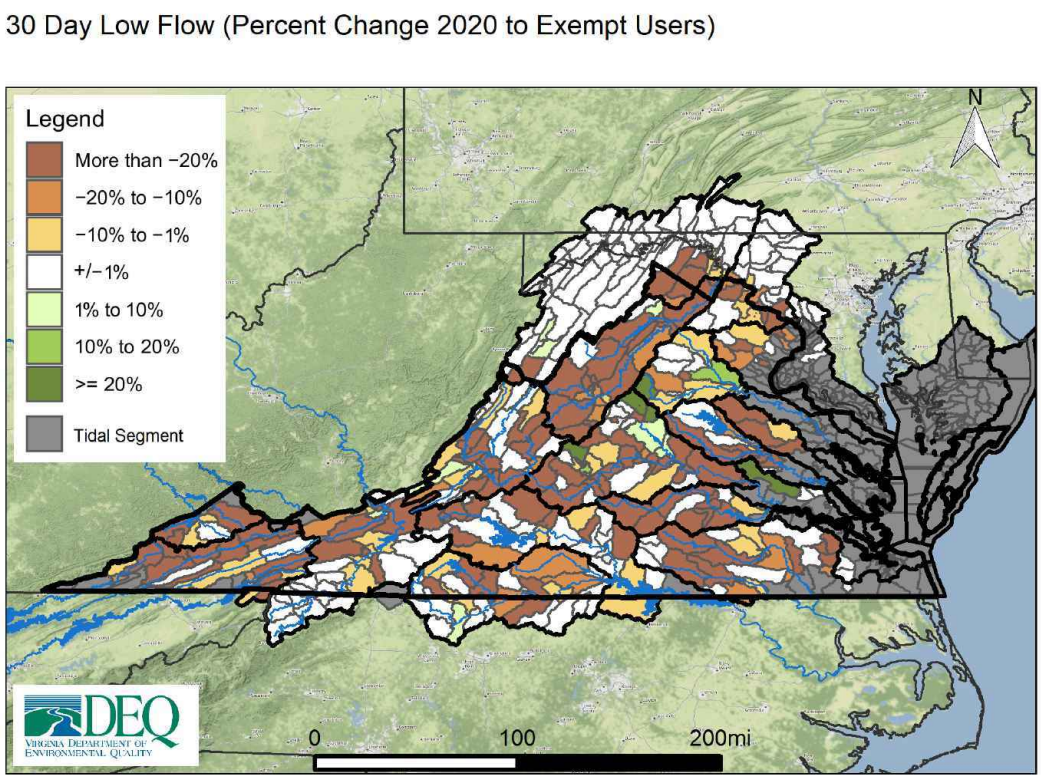


Figure 44: Change in 30 day low flow between 2020 demand scenario and exempt user scenario

90 Day Low Flow (Percent Change 2020 to Exempt Users)

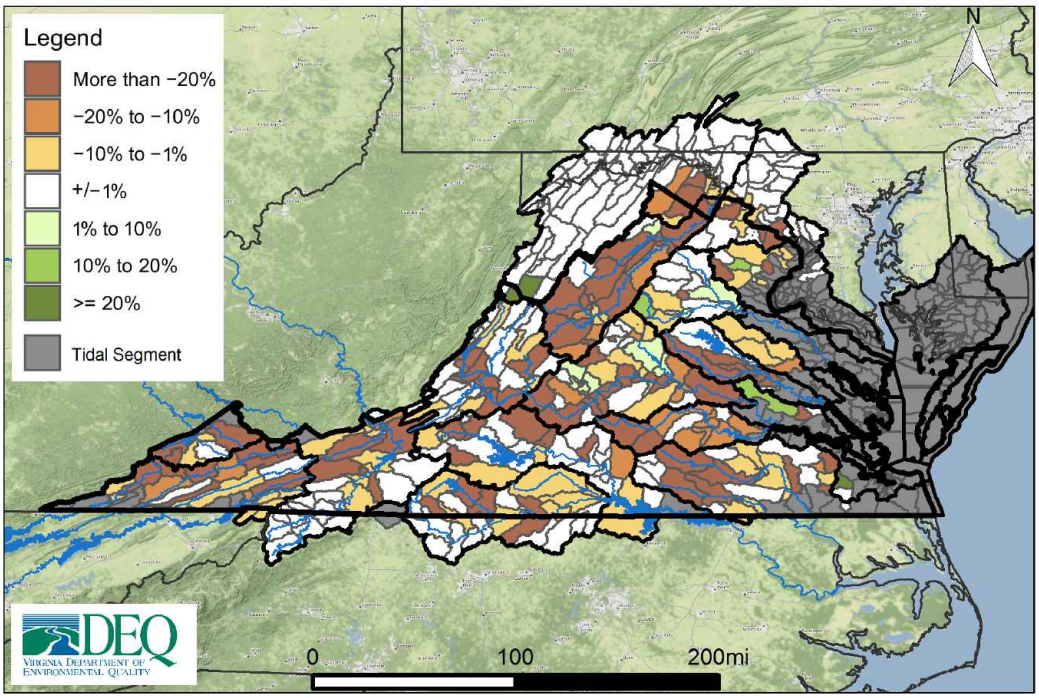


Figure 45: Change in 90 day low flow between 2020 demand scenario and exempt user scenario

7Q10 (Percent Change 2020 to Exempt Users)

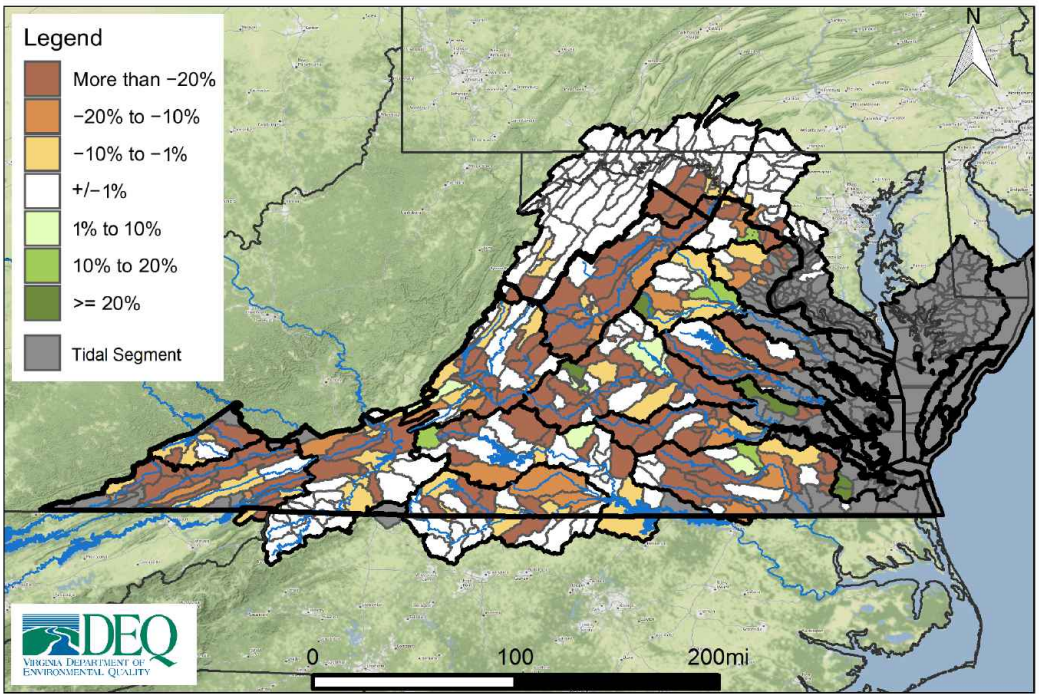


Figure 46: Change in 7Q10 between 2020 demand scenario and exempt user scenario

Overall Percent of Flow Change (Exempt Users)

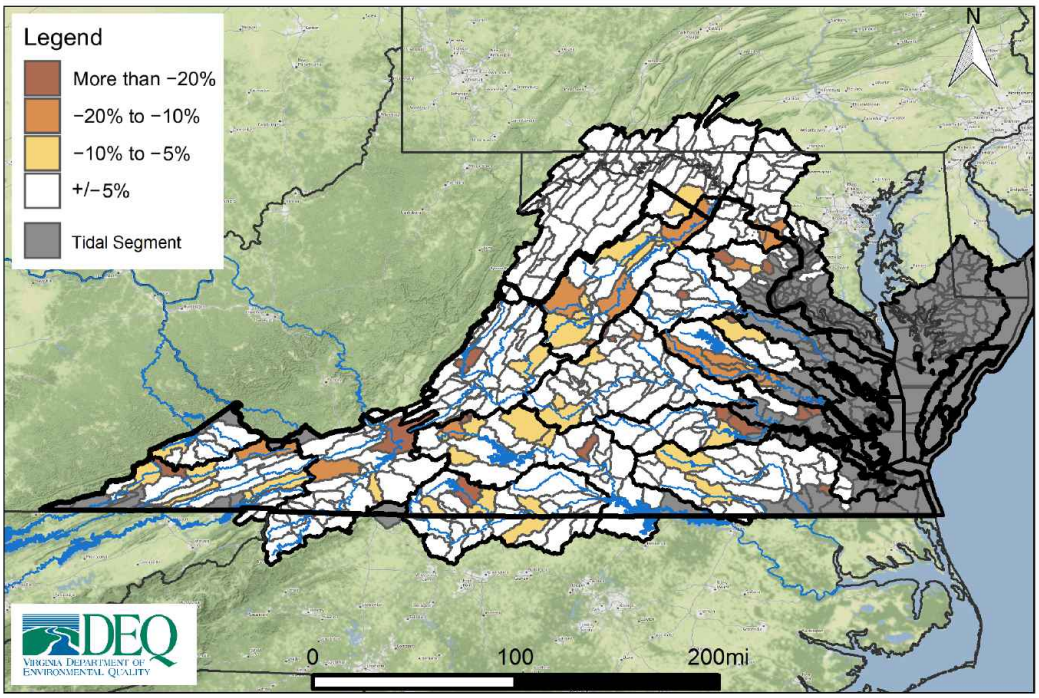


Figure 47: Overall change in flow in percent for exempt user ccenario

4.2.8.4 Impacts to Aquatic Life

Background:

Balancing the multiple surface water beneficial uses in Virginia is an ongoing challenge in water resources management. This includes maintaining offstream human demands such as public water supply, agriculture and commercial uses, as well as protecting the instream beneficial uses of fish and wildlife habitat. In order to protect instream beneficial uses, DEQ through its water withdrawal permits manages environmental flows, or the quantity, timing and quality of water flows required to sustain freshwater ecosystems and the human livelihoods that depend on those ecosystems. Flow recommendations for protection of aquatic life and the metrics used to evaluate them[46] have varied over the years as understanding of stream biology has evolved, and additional datasets have become available. Two major types of data-driven efforts have historically been undertaken to quantify critical conditions for aquatic organisms:

- **"Flow-Habitat"** analysis, such as Instream Flow Incremental Methodology (IFIM), involves developing extensive habitat maps followed by modeling of streamflow reductions and the resulting decreases in habitat. This approach can help identify conditions at specific locations in the stream under critical periods, but it is very data intensive and costly.

- **"Flow-Ecology"** analysis traditionally uses statistical analysis of flow regimes (distribution of high, medium, low, and hydrograph shape) that are found to coincide with the life-stage needs of specific types of aquatic organisms. This analysis characterizes risk to organisms from flow alteration in streams by the percentage deviation from reference flow regime conditions. Building on years of providing flow recommendations for protection of aquatic life based on habitat and flow-ecology principals, DEQ has started applying a new flow-ecology framework named "elfgen" *(pronounced elf-jen)*, for characterizing relations between streamflow and aquatic organisms to predict risk of species richness loss.

elfgen:

The elfgen framework[47][48] provides enormous opportunity through the application of high-resolution hydrologic datasets and large long-term aquatic species databases (Figure 48). These existing datasets provide critical value added through the application of elfgen, which is rooted in a conceptual framework, the River Continuum Concept (RCC). This concept states that instream biodiversity can be expected to increase with stream size, up to a point where it either plateaus or switches to decreasing trend in very large rivers. This phenomenon is primarily due to streams with greater flow generally being able to support greater amounts of diverse aquatic habitat. See the Conceptual Framework depicted in Figure 48 for an illustration of the role stream size plays in supporting biodiversity.

Evaluating Impacts to Aquatic Life - *elfgen*

In response to a need for better environmental flow metrics, DEQ has developed a new framework for characterizing relations between streamflow and aquatic organism species richness. Part of an evolving approach to managing environmental flows for maintaining aquatic life; this methodology builds on existing minimum instream flow approaches, allowable withdrawals as a percentage of flow, and extensive flow-habitat studies. For the first time this new framework may allow quantification of potential species loss resulting from flow change, and may offer an improved understanding of aquatic life risk variability due to geographic location, stream size and local scale.

A key component of the elfgen framework is a set of automated R tools which take the RCC concept combined with accessible datasets to produce graphical analyses of relations between streamflow and species richness (or the number of unique fish species) at the hydrologic unit scale (HUC 6 through HUC 10). These become a powerful tool for visualizing the HUC-specific relations between streamflow and ecology. Using the simplified plot in the lower portion of Figure 48 as reference, the rate of change (slope) of the increasing trend of biodiversity with average annual flow varies based on geographic location. This means some HUCs may exhibit a steep flow-ecology relation, while others may exhibit a shallower slope. By taking the average annual flow value at a specific withdrawal point or river segment outlet location, it becomes possible to calculate the maximum species richness expected at that location.

[46] Traditional environmental flow metrics include August Low Flow, along with flow-habitat and flow-ecology approaches.
[47] Kleiner et al. - DOI: https://doi.org/10.1111/1752-1688.12876
[48] Rapp et al. - DOI:https://doi.org/10.1111/1752-1688.12876

Once a location is identified, elfgen can be used to quantify potential species loss resulting from flow change. If average annual flow is reduced by X%, the total richness at that location may shift along the flow-ecology relation resulting in an overall Y% loss of richness. The plot in Figure 48 is a simplified representation of elfgen flow-ecology relations, which are actually natural log-linear, rather than straight lines. This is a critical finding, as small streams (those towards the left on the plot, with lower average annual flow) are expected to result in greater richness loss when compared to large rivers for equivalent percent reductions in average annual flow.

Application of elfgen:

Flow Change: The elfgen approach is designed to evaluate potential changes in species richness resulting from changes in average flow. In order to produce location-specific assessments of richness change, it is necessary to have location-specific data for flow change. One of the watershed metrics described in Section 4.2.7 is watershed level consumptive use. The consumptive use metric represents the ratio of long term average modeled flow for a particular model scenario, compared to long term average baseline flow. In essence, watershed level consumptive use describes the overall change in flow expected for a particular model scenario. Since this metric is automatically calculated in the VAHydro model for each river segment upon model run completion, it is perfectly suited for producing river segment-level assessments of richness change using elfgen.

River Segment Richness Change: In order to calculate river segment-level richness change, elfgen was first used to produce relations between streamflow and species richness at the HUC 8 scale (Resembling the simplified plot in the lower portion of Figure 48). This was achieved using long term datasets for both ecological and hydrologic data. Ecological data (Fish species richness) was sourced from the VAHydro-EDAS dataset [Tetra Tech, Inc., 2012]. Hydrologic data (Average Annual Flow) was sourced from the National Hydrography Dataset Plus

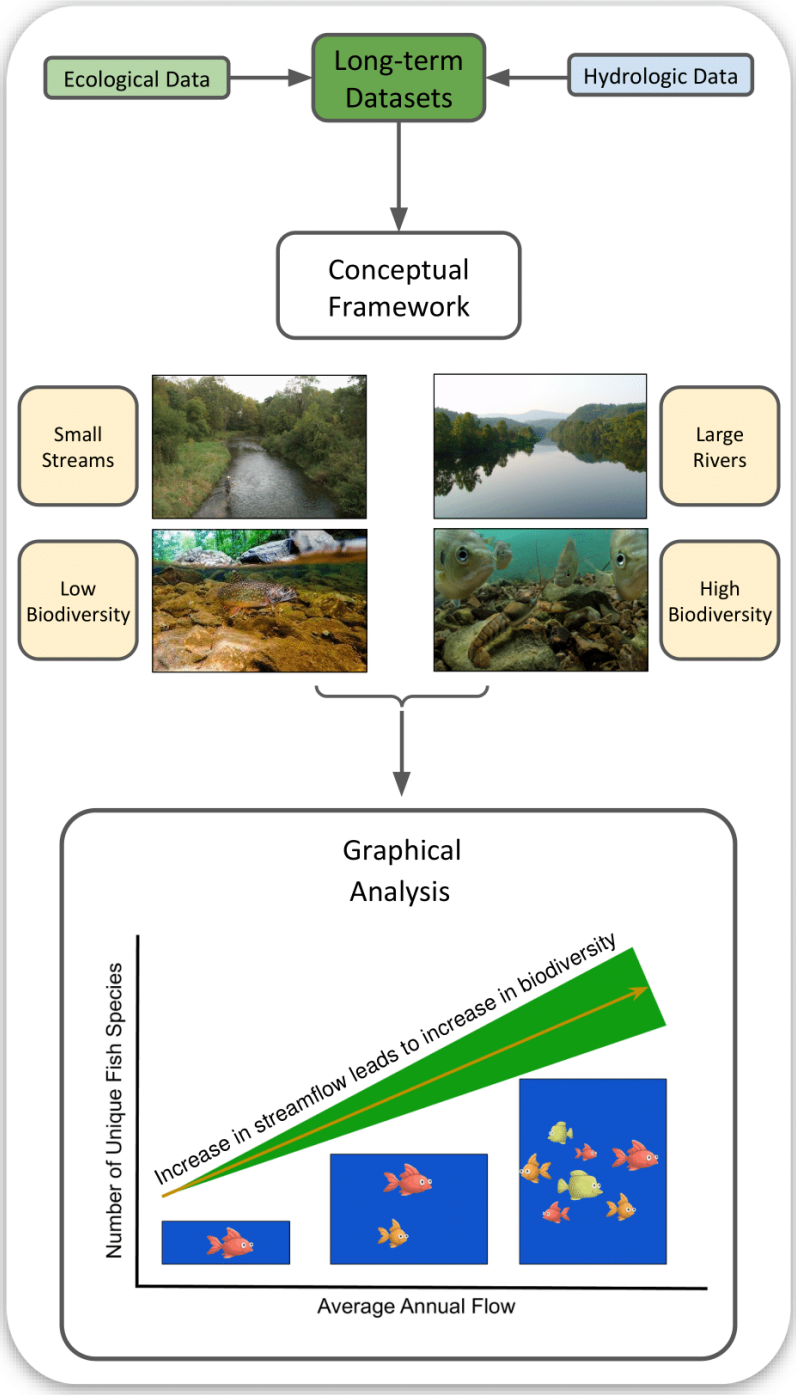


Figure 48: Aquatic Life Impacts Analysis - elfgen

Version 2 (NHDPlus V2) Enhanced Runoff Method (EROM) dataset [McKay et al., 2012]. Flow-ecology relations were produced for every river segment using the HUC 8 containing the river segment outlet location. This provides a reliable approximation of the flow-ecology trend present at each river segment. Using the average annual flow at the river segment outlet location, elfgen is used to calculate the potential loss of richness resulting from the river segment-level consumptive use amount described above. For this State Plan, three model scenarios were evaluated for potential richness change using the elfgen framework: 2020, 2040, and exempt user scenarios (See results detailed below).

Statewide Richness Change Results:

Maps of statewide richness change model results by river segment for the 2020, 2040, and exempt user scenario can be seen in Figures 49, 51 and 50 respectively.[49] Table 17 provides the top 30 river segments with the highest risk of richness loss across the 3 scenarios. All river segments with greater than 1% richness loss for the exempt user scenario appear in this table. The table is ordered descending by exempt user scenario percent richness change as this scenario represents the greatest potential for increased consumptive use, and therefore poses the greatest challenge for instream aquatic life.

Model results show areas with potential risk of richness loss are spread throughout the state, as seen in Figures 49, 50 and 51. This is also evident looking at Table 17 which shows 12 of the 17 non-tidal Minor Basins contain river segments with significant potential risk of negative ecological impacts.

Potential Impacts - 2040 Scenario: Figure 51 shows relatively few areas where richness is predicted to decrease by the year 2040 (under current climate conditions) resulting from increases in consumptive water use. The southwest portion of the state shows little to no increased risk by 2040. Several river segments in the James, Roanoke Dan and Shenandoah transition from no change (+/- 0.05%) to a slightly elevated risk of richness loss (-0.1% to -0.05%). A couple headwater river segments in the North Fork Rivanna River in the James River Basin, Rivanna River in the Upper Rappahannock, and Opequon Creek in the Upper Potomac shift from (-0.1% to -0.05%) to (-1% to -0.1%). Two river segments, Swift Creek in the James Appamatox and Lake Pelham in the Upper Rappahannock, shift from (-1% to -0.1%) to (-5% to -1%). Two headwater segments of T. Nelson Elliott Dam (Lake Manassas) in the Lower Potomac, and the Ni River Reservoir of the York Mattaponi also shift from (-5% to -1%) to (-10% to -5%). No river segments show richness decreases of over 10% resulting from increases in consumption by 2040. See Table 17 for additional data detailing the greatest richness change risk throughout Virginia.

Potential Impacts - Exempt User Scenario: The exempt user scenario presents the greatest potential impacts, with elevated risk of richness loss predicted throughout Virginia. Many of those river segments that show a modest increase in risk of ecological loss in the 2040 scenario exhibit more sever potential impacts under the exempt user scenario. Figure 50 shows over 10 river segments throughout Virginia that transition from no change (+/- 0.05%) in the 2040 scenario to a slightly elevated risk of richness loss (-0.1% to -0.05%) in the exempt user scenario. Over 25 river segments shift from (-0.1% to -0.05%) in the 2040 scenario to (-1% to -0.1%) in the exempt user scenario. Similarly, over 20 river segments shift from (-1% to -0.1%) to (-5% to -1%). Four segments shift to an elevated risk of richness loss of (-10% to -5%), along with two river segments showing richness decreases of over 10% resulting from increases in consumption under the exempt user scenario.

Summary - Areas With Greatest Risk: A detailed accounting of the top 30 river segments with the highest risk of richness loss are presented in Table 17. For each of the 3 model scenarios presented, values are displayed for the watershed level consumptive use percentage (CU (%) columns) which drive the richness change within each river segment. Columns are also provided displaying the predicted richness loss as both a percentage of the total richness present (Chg (%)) and as a count of the number of species lost (Chg (#)).

Reducing stream flows by less than 10% of average streamflow is generally considered to provide a high level of ecological protection. For the top 30 river segments displayed in Table 17, consumptive use in the exempt user scenario is almost always greater than 10%. The result of this level of flow alteration is reductions in species richness of -1% to -30%. Although many of these locations only show single digit percent changes in richness, it is believed that these still may be an indication of elevated risk. For 11 of the river

[49] Note: River change calculations are unavailable for river segments that are tidal, drain into surrounding states, average annual flows at river segment outlet exceeds 530 cfs, or flow-ecology relations were not considered statistically significant (p-value >0.05); see gray segments in Figures 49, 50 and 51.

segments presented in this table, the predicted number of species loss is 1 or greater. This is an indication that if flows are reduced under exempt demands, there is risk of losing unique species from those areas, lowering the overall biodiversity.

Although the exempt user scenario shows the greatest risk of richness loss in Table 17, the 2040 scenario projects richness loss above 1% for a small number of river segments. Several river segments are projected to have greater than 1% loss of richness. This is driven by large values for consumption expected by the year 2040 in some areas. In a few cases, in the Lower Potomac and Upper Rappahannock, the 2040 scenario is projected to result in greater richness loss than the exempt user scenario. This is an indication that even without the presence of large exempt water withdrawals, stream health may be at risk due to projected 2040 demand increases alone. For more detailed discussion on the withdrawals, facilities, and other factors driving the level of consumption and resulting ecological risk in each river segment, visit the individual minor basin focuses in Appendix A.

Trends and Takeaways: Increasing water demands by 2040 are projected to result in an elevated risk to aquatic health in several areas. The large magnitude of consumptive use under the exempt user scenario would likely lead to an even more severe level of risk for a number of regions across Virginia. As noted earlier, many of the river segments showing the greatest risk of species richness loss are small headwater streams. These areas will require additional planning for the long-term sustainability of instream beneficial uses.

The elfgen framework helps provide an improved understanding of aquatic life risk resulting from flow change and human consumptive use. More localized assessments of risk are now possible with the aid of automated modeling tools and high resolution long-term datasets. It is now possible to predict the risk of ecological loss throughout Virginia in areas where detailed habitat studies are unavailable. It is important to note that flow-habitat analyses using IFIM data still have value for assessing risk to aquatic like. DEQ uses IFIM data for evaluating habitat impacts for locations where the elfgen framework is not suitable, namely locations with large average annual flow (Greater than 530 cfs). Combining flow-habitat with flow-ecology approaches helps DEQ develop reliable data-driven flow recommendations for protection of aquatic life in its withdrawal permitting program. This application of elfgen is part of an evolving approach to managing environmental flows for maintaining aquatic life, as such it will continue to be refined as DEQ implements the elfgen framework for planning and permitting activities.

Caveats and Limitations: The information presented in the 2020 State Plan can be used to evaluate ways of applying research on relations between aquatic species richness and streamflow to allow low-cost site-specific quantification of potential impacts to aquatic life as a result of withdrawals or diversions. It is not intended to be a replacement for IFIM and other habitat methods, although it may be useful to assist localities and water users to determine where these more resource intensive approaches may be necessary to evaluate and understand local impacts.

DEQ currently views this as a screening level metric that will be further adapted and refined as it is applied in our suite of cumulative impact analysis tools. A process for incorporating these tools into informed resource management decisions remains necessary and may benefit from constructive input from the public and stakeholders.

DEQ acknowledges the elfgen framework is best suited to non-tidal locations with average annual flow below 530 cfs. This highlights the natural relation between fish biodiversity and stream size, and the need to analyze ecological impacts in those streams with the greatest potential risk of ecological loss.

Richness Change (Percent): 2020

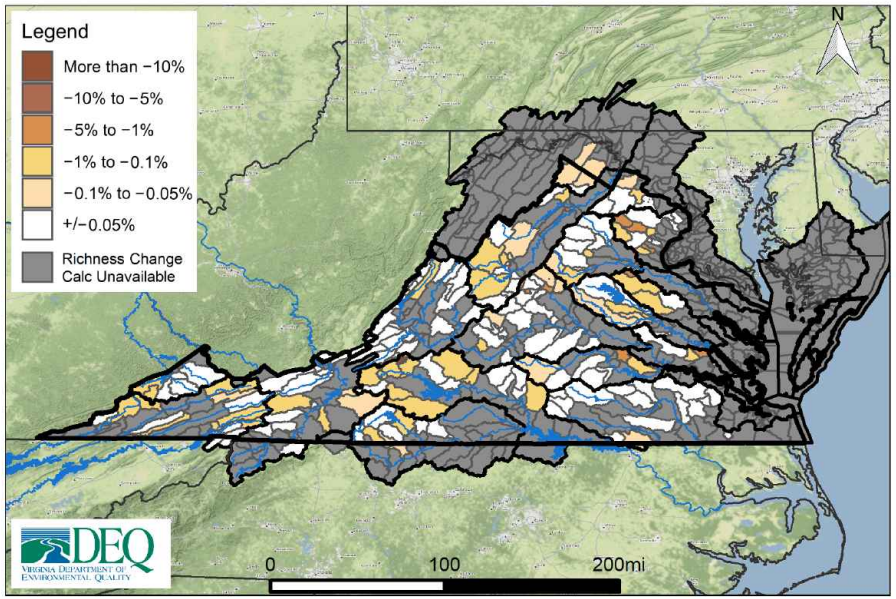


Figure 49: Richness Change as a Percent for 2020 Scenario

Richness Change (Percent): Exempt Users

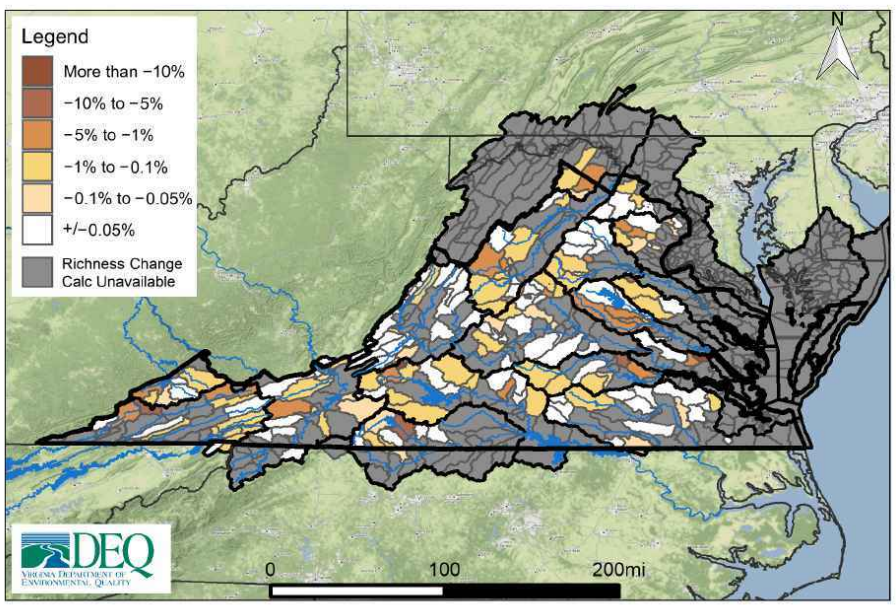


Figure 50: Richness Change as a Percent for Exempt User Scenario

Richness Change (Percent): 2040

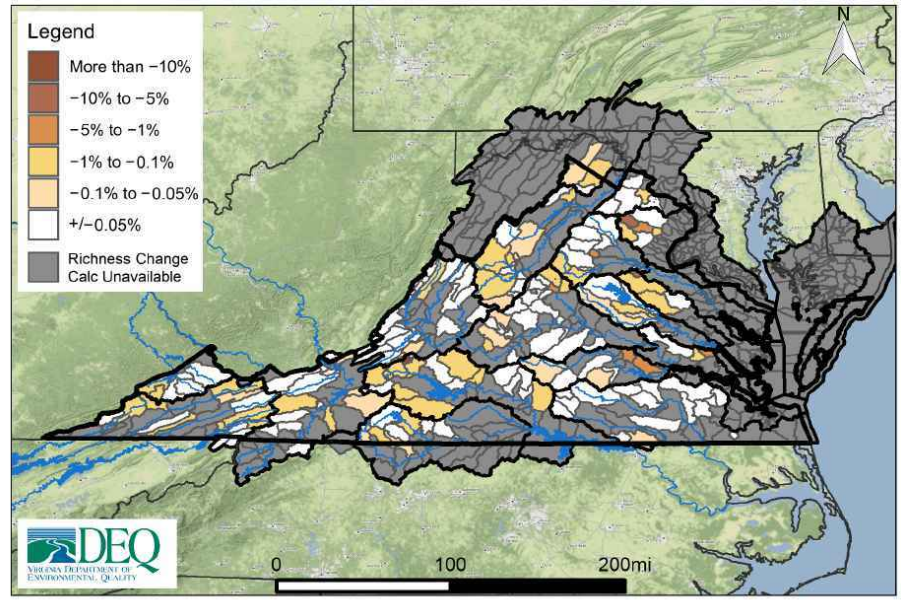


Figure 51: Richness Change as a Percent for 2040 Scenario

Table 17: Richness Change (Top 30 River Segments at Risk of Loss)

River Segment	Minor Basin	2020			2040			Exempt		
		CU (%)	Chg (%)	Chg (#)	CU (%)	Chg (%)	Chg (#)	CU (%)	Chg (%)	Chg (#)
Beaver Creek	Middle James	8.24	-1.16	-0.27	12.05	-1.73	-0.40	89.60	-30.53	-7.12
Diascund Creek	Lower James	40.86	-2.87	-0.59	48.42	-3.62	-0.74	98.36	-22.43	-4.61
Mill Creek @ Meadows Pond	York Pamunkey	12.43	-1.95	-0.31	12.43	-1.95	-0.31	47.32	-9.40	-1.49
Ni River Reservoir	York Mattaponi	27.37	-3.16	-0.64	48.72	-6.60	-1.34	55.94	-8.10	-1.64
Swift Creek Reservoir	James Appomattox	22.19	-2.02	-0.53	33.80	-3.33	-0.87	59.06	-7.21	-1.88
Guest River	Upper Tennessee	1.19	-0.20	-0.07	1.17	-0.19	-0.06	28.42	-5.49	-1.83
Smith River below Philpott	Roanoke Dan	4.98	-0.48	-0.13	5.69	-0.56	-0.15	43.67	-5.45	-1.46
Catawba Creek	Roanoke	41.54	-2.93	-0.64	50.43	-3.83	-0.83	59.25	-4.90	-1.07
Tinker Creek	Roanoke	21.22	-3.10	-0.64	26.01	0.00	0.00	31.22	-4.86	-1.01
Sugar Hollow	Middle James	29.46	-4.04	-1.10	29.96	-4.13	-1.12	29.96	-4.13	-1.12
Chickahominy River	Lower James	2.54	-0.13	-0.03	3.00	-0.15	-0.03	56.16	-4.08	-0.93
T. Nelson Elliott Dam	Lower Potomac	26.07	-2.73	-0.72	43.75	-5.20	-1.37	34.96	-3.89	-1.02
Rocky Pen Run	Upper Rappahannock	66.36	-5.85	-1.07	79.33	-8.46	-1.55	47.89	-3.50	-0.64
Lake Pelham: Mountain Run	Upper Rappahannock	4.96	-0.70	-0.16	12.41	-1.83	-0.43	21.45	-3.33	-0.78
Lower Falling River	Roanoke	0.14	-0.02	0.00	0.16	-0.02	-0.01	21.36	-2.84	-0.88
North Anna River above Little River near Doswell	York Pamunkey	3.55	-0.32	-0.08	6.35	-0.58	-0.15	24.98	-2.54	-0.67
Swift Creek	James Appomattox	8.82	-0.69	-0.19	13.69	-1.10	-0.31	24.36	-2.08	-0.59
Broad Run at Confluence with Cedar Run	Lower Potomac	13.71	-1.27	-0.35	22.35	-2.18	-0.60	18.12	-1.72	-0.48
Clinch River	Upper Tennessee	1.36	-0.19	-0.08	1.49	-0.21	-0.08	11.23	-1.65	-0.65
North River & Dry River	Potomac Shenandoah	4.42	-0.46	-0.12	6.50	-0.68	-0.18	14.25	-1.56	-0.40
Roanoke River (Salem)	Roanoke	4.54	-0.42	-0.13	5.90	-0.56	-0.16	14.52	-1.43	-0.42
Opequon Creek	Upper Potomac	0.56	-0.08	-0.03	1.31	-0.20	-0.06	8.93	-1.39	-0.45
South River near Dooms	Potomac Shenandoah	-0.88	0.09	0.02	-2.57	0.27	0.07	11.56	-1.33	-0.32
South Anna River	York Pamunkey	0.60	-0.05	-0.01	0.70	-0.06	-0.02	12.96	-1.22	-0.32
Powell River	Upper Tennessee	2.79	-0.42	-0.17	2.35	-0.36	-0.14	7.76	-1.21	-0.49
South Rivanna River Reservoir	Middle James	10.15	-1.01	-0.34	12.24	-1.23	-0.41	11.98	-1.20	-0.40
Cooks Creek @ Mount Crawford	Potomac Shenandoah	1.03	-0.14	-0.03	1.43	-0.20	-0.04	8.27	-1.18	-0.23
North Anna River @ Confluence with South Anna	York Pamunkey	1.91	-0.17	-0.04	3.63	-0.32	-0.09	12.64	-1.16	-0.31
South Anna River	York Pamunkey	0.68	-0.06	-0.02	0.69	-0.06	-0.02	12.24	-1.13	-0.30
Little River	York Pamunkey	1.74	-0.17	-0.04	1.74	-0.17	-0.04	10.47	-1.09	-0.26

*River Segments are ordered descending by Exempt Scenario percent richness change ("Chg (%)" column 10)

4.3 Cumulative Impact Analysis - Groundwater

Cumulative impact analyses of groundwater demands on confined aquifer systems in the Virginia Coastal Plain and Eastern Shore were also completed for the State Plan. In portions of the Virginia Piedmont, as well as Tidewater regions, groundwater is a more significant source than in portions of Virginia west of the fall-line. This area is characterized by confined aquifer systems such as the Potomac Aquifer that are highly productive and offer relatively high quality water. However, the high transmissivity of confined aquifer systems means withdrawals can impact groundwater levels regionally and cumulatively, and understanding total demands is critical to evaluating long-term sustainability of this resource.

DEQ models the cumulative impact of permitted groundwater withdrawals in the Eastern Virginia Groundwater Management Area and the Eastern Shore Management Area in accordance with the 1992 Ground Water Management Act. These "Total Permitted" scenarios reflect the total withdrawal volume permitted for all permit holders in each management area, in addition to estimates for unpermitted use from withdrawals that fall below the permitting threshold such as those associated with domestic and residential use.

As part of the State Plan effort, groundwater demands based on information submitted by localities in water supply plans were used to develop scenarios to estimate cumulative impacts on the Coastal Plain and Eastern Shore aquifer systems resulting from changes in demands. These evaluations include not only projected use for large users such as municipal and industrial users, but also estimates for residential/domestic use (Small SSUs) per locality. As these domestic/residential components are not regulated, these efforts represent an important effort to understand the impacts they may have on these aquifer systems.

4.3.1 Groundwater Models and Inputs

DEQ uses two distinct regional groundwater models covering the two distinct groundwater management areas. The VAHydro Virginia Coastal Plain Model (VCPM) which covers the Eastern Virginia Groundwater Management Area, and the VAHydro Virginia Eastern Shore Model (VESM) which covers the Eastern Shore Groundwater Management Area. Both models are SEAWAT[50] models originally developed by USGS and adapted and updated by DEQ over the last decade. A detailed summary of the refinements made to these models, as well as the inputs and assumptions made by each model, is included in the "Annual Simulation of Potentiometric Groundwater Surface Elevations of Reported and Total Permitted Use", published annually by DEQ and available upon request. This section will focus on the scenarios developed for the State Plan specifically.

The groundwater modeling scenarios completed for the State Plan have two primary demand components that comprise the total pumping rates. The first consists of estimates for demands associated with users that would typically be operating under a permit, or exceeding 300,000 gallons in any month. 2020 and 2040 pumping rates were calculated based on projections provided by localities in water supply plans for these facilities. For the purpose of the State Plan, this portion of the total simulated pumping will be called the "permitted demands". The second component is made up of unpermitted demands, which refers primarily to domestic or residential use. Both regional models historically use estimates of domestic use based on USGS analysis of census population data and samples of domestic wells.

The WSP scenarios build upon these estimates by incorporating current and future projections from water supply plans for domestic use distributed proportionally to the original USGS estimates. Domestic use of groundwater is growing in many parts of Virginia and these scenarios are designed to evaluate how these increasing demands may impact water levels, in conjunction with permitted demands, in these two major aquifer systems in Virginia. Figure 52 provides a summary of the original domestic estimates and the 2020 and 2040 demand estimates for each locality included in the two regional models. This component of the total pumping will be described as estimated "domestic demands" for the purpose of the State Plan.

[50] Langevin, C.D., Thorne, D.T., Jr., Dausman, A.M., Sukop, M.C., and Guo, Weixing, 2008, SEAWAT Version 4: A Computer Program for Simulation of Multi-Species Solute and Heat Transport: U.S. Geological Survey.

County	2003 USGS Model Value (MGD)	2020 (MGD)	2040 (MGD)
Accomack County*	2.00	3.18	2.93
Caroline County	1.20	1.12	1.24
Charles City County	0.51	1.17	1.49
Chesterfield County		2.44	3.57
Essex County	1.67	0.61	0.75
Gloucester County	1.42	1.84	2.29
Hanover County	0.87	3.35	6.07
Henrico County	1.30	2.08	0.00
Isle of Wight County	1.13	2.15	3.31
James City County	0.48	0.83	0.94
King and Queen County	1.26	0.52	0.60
King George County	0.77	1.07	2.16
King William County	0.66	0.92	2.99
Lancaster County	0.69	0.40	0.47
Mathews County	0.69	0.73	0.78
Middlesex County	1.00	0.78	0.93
New Kent County	0.92	0.76	1.00
Northampton County*	0.65	0.95	0.80
Northumberland County	1.51	0.61	0.73
Prince George County	0.60	0.00	0.00
Richmond County	1.23	0.48	0.54
Southampton County	0.07	1.09	1.49
Spotsylvania County	0.47	4.40	7.18
Stafford County		1.65	1.59
Surry County	0.92	0.51	0.71
Sussex County	0.39	0.27	0.27
Westmoreland County	1.59	0.45	0.51
York County	1.78	0.31	0.35
Chesapeake city	0.52	2.56	2.48
Franklin City		0.04	0.06
Newport News		0.01	0.01
Portsmouth		0.00	0.00
Suffolk city	0.39	1.58	1.54
Virginia Beach city	0.48	0.67	0.65
TOTAL	**27.17**	**39.52**	**50.41**

*Assigned to the VAHydroGW-ES model, all others to the VAHydroGW-VCPM model

Figure 52: Comparison of Domestic Use Estimates in WSP Groundwater Demand Scenarios

4.3.2 Groundwater Model Scenarios

The groundwater modeling for the State Plan was completed with two primary scenarios focused on evaluating impacts to the aquifers resulting from pumping at projected demands provided by localities in water supply plans for 2020 (2020 Demand Scenario) and 2040 (2040 Demand Scenario). These two scenarios are completed by taking either the 2020 or 2040 demands and simulating the total pumping rate for fifty years. 2020 demand and 2040 demand scenarios were completed for both the VCPM and VESM regional models. A scenario which evaluates 2040 demands in conjunction with injections of treated water into the Potomac Aquifer proposed by Hampton Roads Sanitation District's (HRSD) Sustainable Water Initiative for Tomorrow Project (SWIFT) was also completed in the VCPM regional model (2040 Demand with SWIFT Scenario). Tables 18 and 19 provide a comparison of pumping rates for each scenario for permitted and domestic demands for each regional model. These figures also include the pumping rates for the "2019 Total Permitted" and "2018 Reported Use", which are simulations completed annually to evaluate the total permitted withdrawal volume of all groundwater withdrawal permittees and the most recent reported use associated with those users respectively. This allows comparison between simula-

tions completed for both water supply planning and permitting purposes.

For the VCPM and VESM models, the 2019 total permitted scenario and 2018 reported use scenarios use the USGS domestic demand estimates while the remaining scenarios use the domestic demands estimated as described above using locality provided projections. For the VCPM model, the 2040 demand scenario has the highest total pumping rate, largely due to a higher domestic pumping rate compared to the 2019 total permitted scenario, which includes the highest permitted pumping rate. The 2040 demands with SWIFT scenario has the lowest pumping rate due to the simulation of 81.45 MGD injected into the Potomac aquifer which reduces the total pumping rate significantly. For the VESM model, the 2019 total permitted scenario has the highest pumping rate while the 2020 and 2040 demand scenarios are not significantly different in total pumping. This is in large part due to limited projected demand increases on the Eastern Shore, particularly where domestic use is concerned. Domestic pumping decreases between the 2020 and 2040 demand scenarios in the VESM as both Northampton and Accomack Counties project decreases in Small SSU (domestic) demands over the planning period.

Table 18: VAHydro Virginia Coastal Plain Model Scenarios Pumping Rates (MGD)

Scenario	**Permitted Demands**	**Domestic Estimates**	**Injection Amount**	**Total Pumping**
2019 Total Permitted	94.6	25.2	-	119.8
2018 Reported Use	66.7	25.2	-	91.9
2020 Demand Scenario	62.0	35.4	-	97.4
2040 Demand Scenario	88.1	46.7	-	134.8
2040 Demand with SWIFT	88.1	46.7	81.45	53.4

Table 19: VAHydro Virginia Eastern Shore Model Scenarios Pumping Rates (MGD)

Scenario	**Permitted Demands**	**Domestic Estimates**	**Total Pumping**
2019 Total Permitted	10.38	2.65	13.03
2018 Reported Use	5.72	2.65	8.37
2020 Demand Scenario	5.61	4.13	9.74
2040 Demand Scenario	6.95	3.73	10.68

4.3.3 Groundwater Model Results - VAHydro Virginia Coastal Plain Model

This section provides the groundwater modeling results for the VAHydro Coastal Plain model, which covers the area in the Eastern Virginia Groundwater Management Area. These scenarios are based on current and projected demand information submitted by localities in water supply plans. Results for each of the above scenarios are included for the Potomac, Aquia, and Piney Point Aquifers. These aquifers are the primary sources for the majority of groundwater demands in the Coastal Plain, including for large users covered under groundwater permits such as municipal and community water systems, as well as for unpermitted uses such as residential/domestic use, or small SSUs. The Potomac Aquifer is the primary source for groundwater demands for large users as well as domestic/residential use, although use of the Piney Point and Aquia aquifers is also very common for domestic use in portions of the Coastal Plain.

Results for the Potomac, Aquia, and Piney Point are provided below. Discussion of the overall trends can be found in the conclusion section below the results for each regional model.

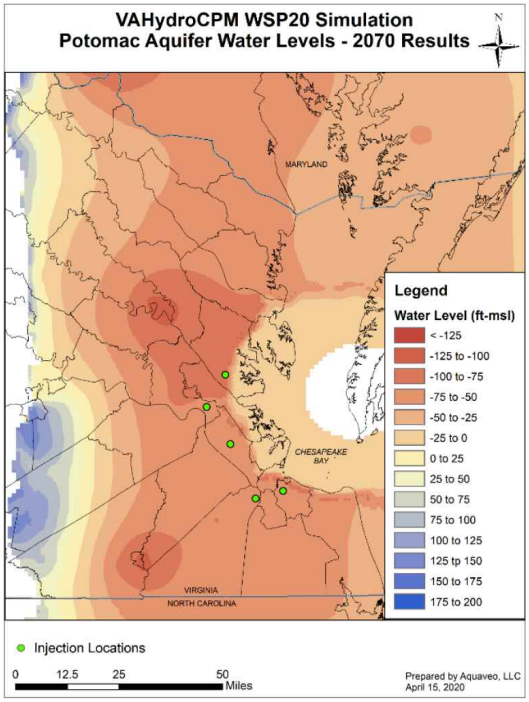


Figure 53: Simulated Potomac Aquifer Water Levels in 2070 using 2020 Water Supply Plan Demands

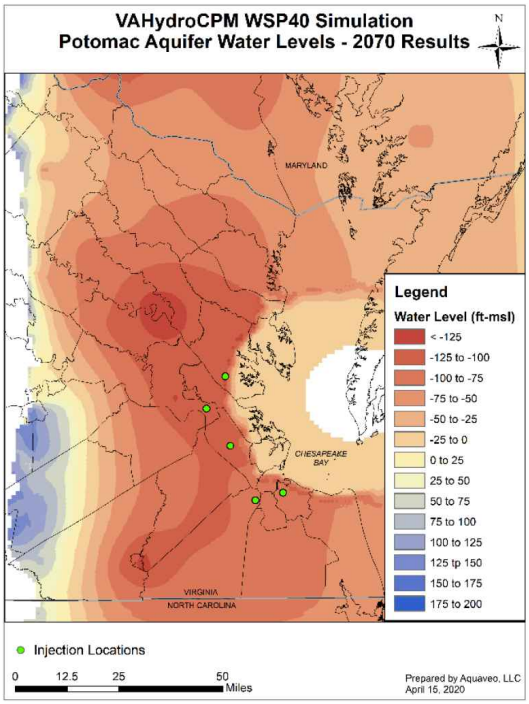


Figure 54: Simulated Potomac Aquifer Water Levels in 2070 using 2040 Water Supply Plan Demands

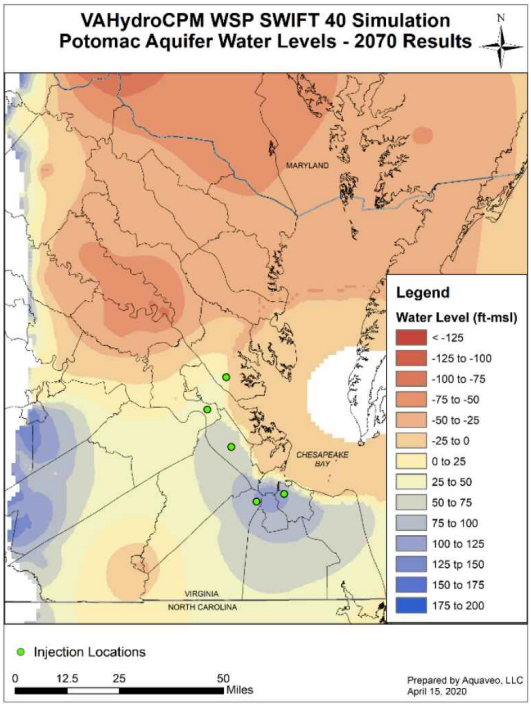


Figure 55: Simulated Potomac Aquifer Water Levels in 2070 using 2040 Water Supply Plan Demands and SWIFT Injections

Potomac Aquifer Results: Figure 53 shows the simulated water levels relative to mean sea level in the Potomac Aquifer after a fifty year simulation running from 2020 to 2070 using the 2020 groundwater demands from water supply plans. Figure 54, in comparison, shows simulated water levels after 50 years using 2040 demands. Lastly, Figure 55 shows simulated water levels after 50 years using 2040 demands with the addition of injections into the Potomac Aquifer at the identified SWIFT injection sites. The green circles represent the proposed injection sites.

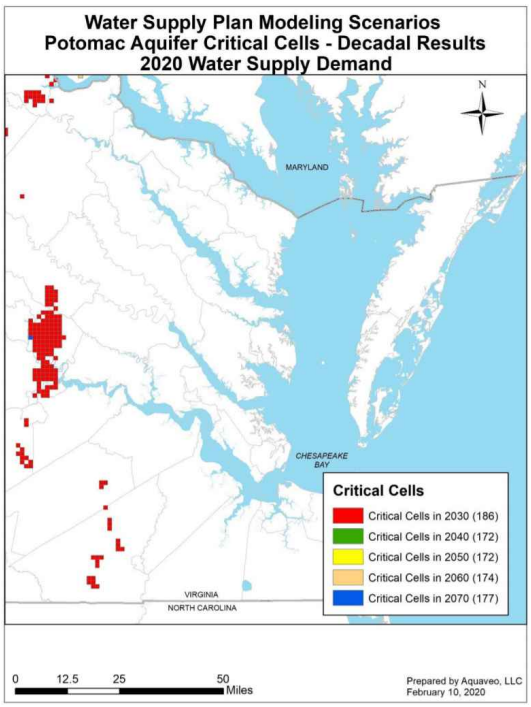


Figure 56: Simulated Critical Cells by Decade in the Potomac Aquifer using 2020 Water Supply Plan Demands

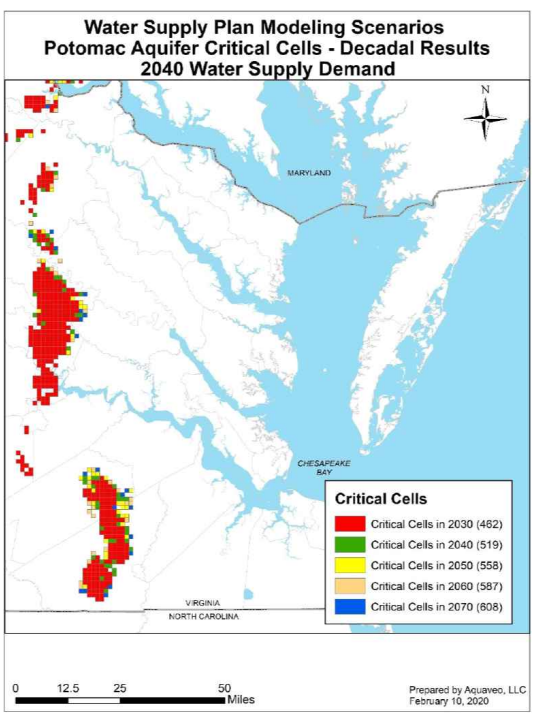


Figure 57: Simulated Critical Cells by Decade in the Potomac Aquifer using 2040 Water Supply Plan Demands

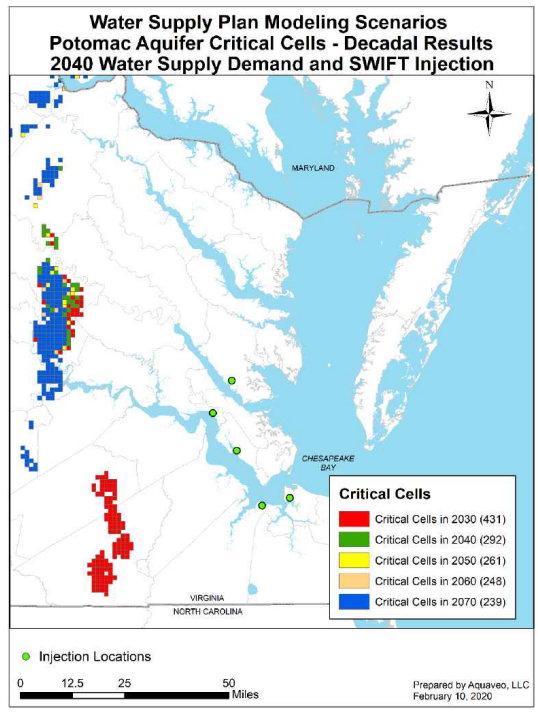


Figure 58: Simulated Critical Cells by Decade in the Potomac Aquifer using 2040 Water Supply Plan Demands and SWIFT Injections

Potomac Aquifer Critical Cells: The next series of figures displays the number of simulated critical cells for each decade for each scenario in the Potomac Aquifer. A critical cell indicates a cell in the groundwater model where the simulated water level falls below the critical surface within the simulation period. The critical surface is defined in the Groundwater Withdrawal Regulations[51] as the point that represents 80% of the distance between the land surface and the top of the aquifer. Evaluating whether an existing or proposed withdrawal creates critical cells is a key part of the technical evaluation process for all groundwater withdrawal applications. Ensuring water levels do not fall below the critical surface is intended as a protective limit designed to prevent water levels from falling below the top of a confined aquifer, the point at which impacts such as land subsidence and loss of aquifer storage can occur.

The number in parenthesis next to each decade in the legend is the number of critical cells present in that decade during the simulation. Examining these values in series indicates whether the number of critical cells are increasing or decreasing in each decade. Figure 56 shows the number of simulated critical cells for each decade based on 2020 demands, while Figure 57 shows the same using 2040 demands. Figure 58 shows the number of critical cells using 2040 demands with the addition of injections into the Potomac Aquifer at the identified SWIFT injection sites.

[51] 9VAC25-610-110

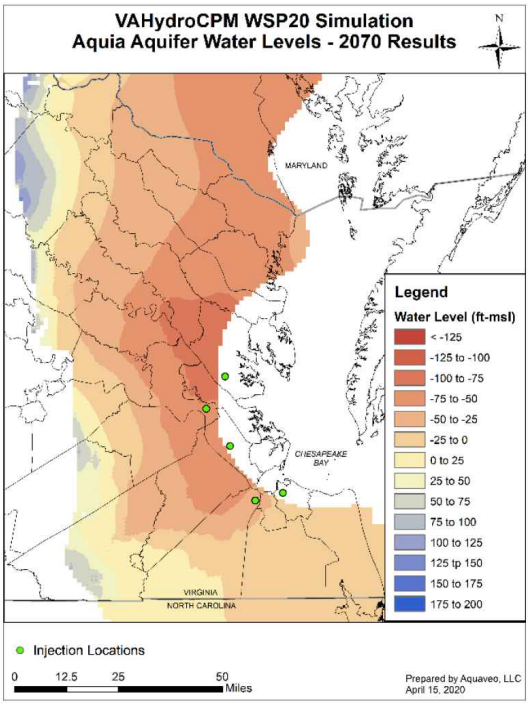


Figure 59: Simulated Aquia Aquifer Water Levels in 2070 using 2020 Water Supply Plan Demands

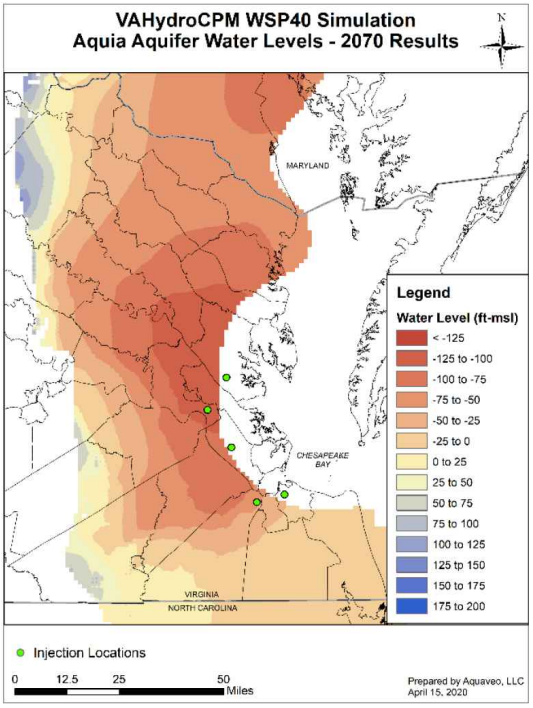


Figure 60: Simulated Aquia Aquifer Water Levels in 2070 using 2040 Water Supply Plan Demands

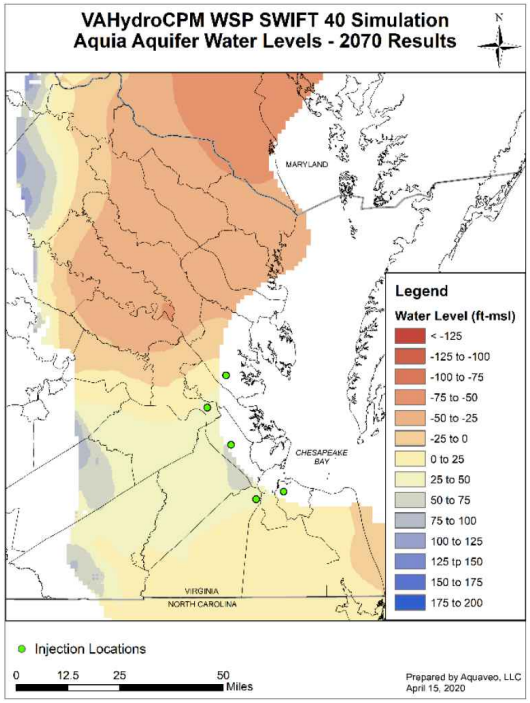


Figure 61: Simulated Aquia Aquifer Water Levels in 2070 using 2040 Water Supply Plan Demands and SWIFT Injections

Aquia Aquifer Results: Figure 59 shows the simulated water levels relative to mean sea level in the Aquia Aquifer after a fifty year simulation running from 2020 to 2070 using the 2020 groundwater demands from water supply plans. Figure 60, in comparison, shows simulated water levels after 50 years using 2040 demands. Lastly, Figure 61 shows simulated water levels after 50 years using 2040 demands with the addition of injections into the Potomac Aquifer at the identified SWIFT injection sites.

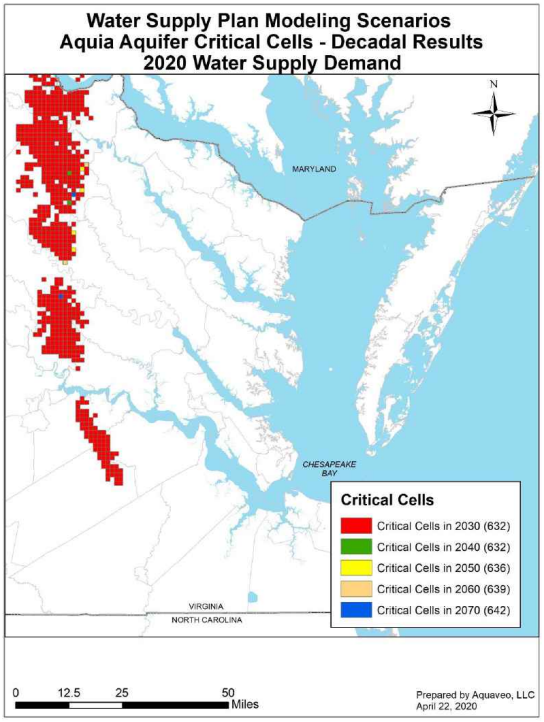


Figure 62: Simulated Critical Cells by Decade in the Aquia Aquifer using 2020 Water Supply Plan Demands

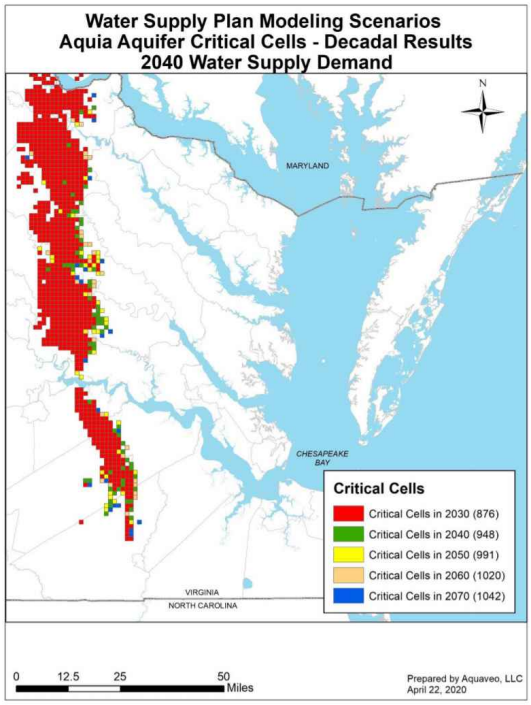


Figure 63: Simulated Critical Cells by Decade in the Aquia Aquifer using 2040 Water Supply Plan Demands

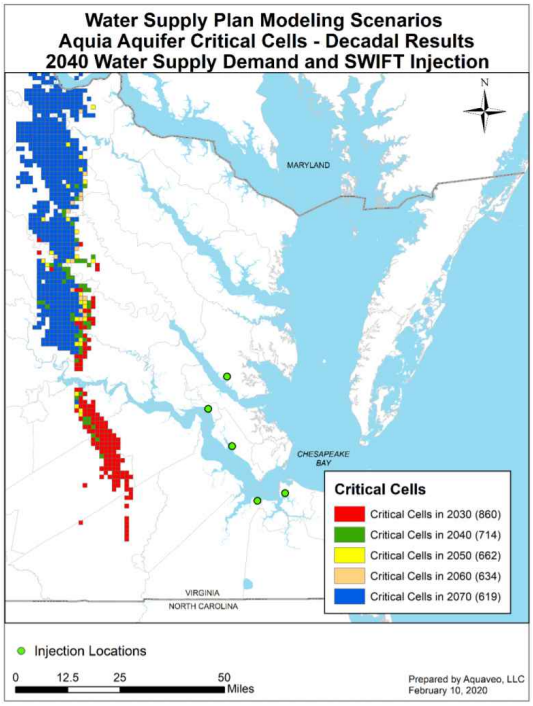


Figure 64: Simulated Critical Cells by Decade in the Aquia Aquifer using 2040 Water Supply Plan Demands and SWIFT Injections

Aquia Aquifer Critical Cell Results: The next series of figures displays the number of simulated critical cells for each decade for each scenario in the Aquia Aquifer. The number in parenthesis next to each decade in the legend is the number of critical cells present in that decade during the simulation. Examining these values in series indicates whether the number of critical cells are increasing or decreasing in each decade. Figure 62 shows the number of simulated critical cells for each decade based on 2020 demands, while Figure 63 shows the same using 2040 demands. Figure 64 shows the number of critical cells using 2040 demands with the addition of injections into the Potomac Aquifer at the identified SWIFT injection sites.

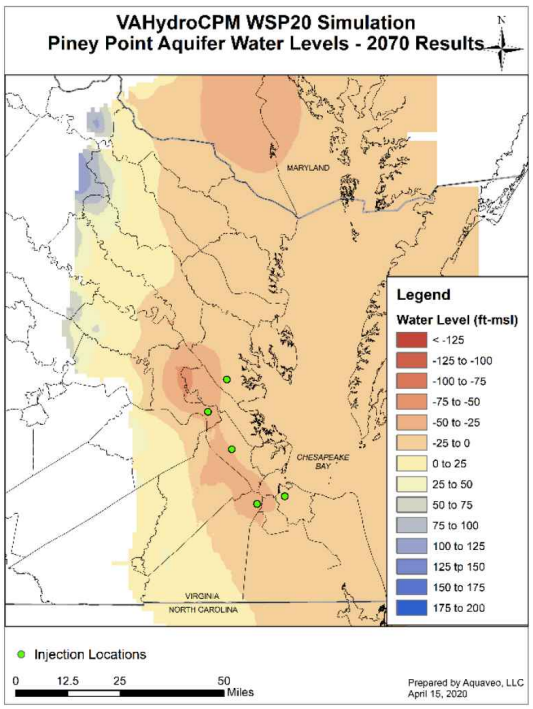


Figure 65: Simulated Piney Point Aquifer Water Levels in 2070 using 2020 Water Supply Plan Demands

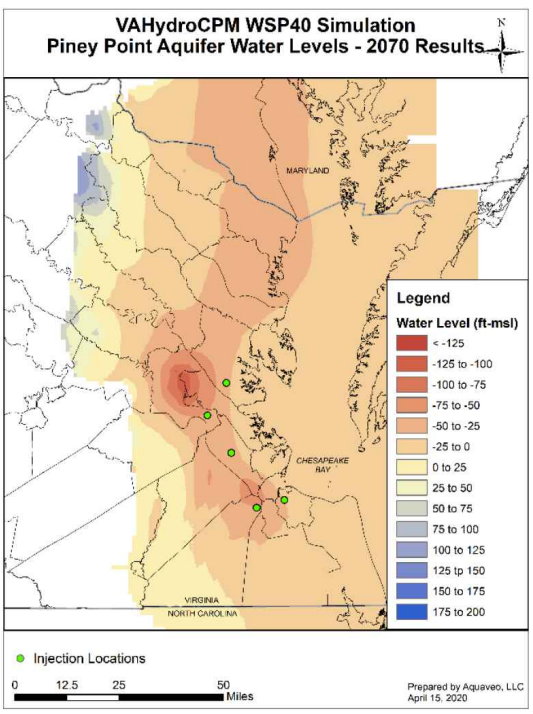


Figure 66: Simulated Piney Point Aquifer Water Levels in 2070 using 2040 Water Supply Plan Demands

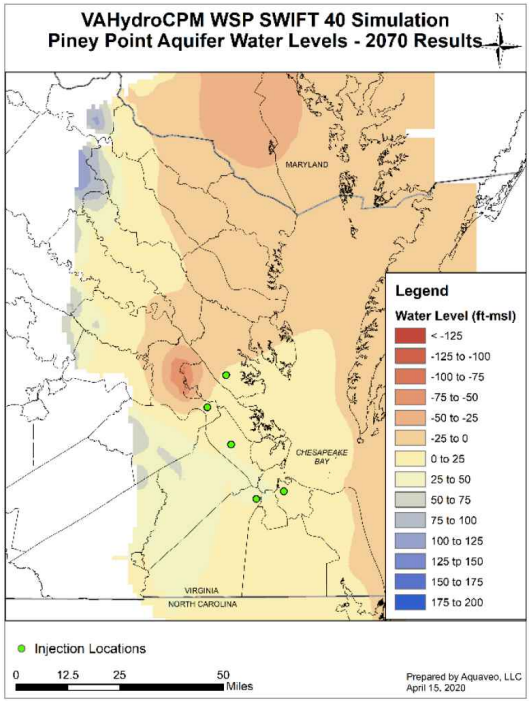


Figure 67: Simulated Piney Point Aquifer Water Levels in 2070 using 2040 Water Supply Plan Demands and SWIFT Injections

Piney Point Aquifer Results: Figure 65 shows the simulated water levels relative to mean sea level in the Piney Point Aquifer after a fifty year simulation running from 2020 to 2070 using the 2020 groundwater demands from water supply plans. Figure 66, in comparison, shows simulated water levels after 50 years using 2040 demands. Lastly, Figure 67 shows simulated water levels after 50 years using 2040 demands with the addition of injections into the Potomac Aquifer at the identified SWIFT injection sites.

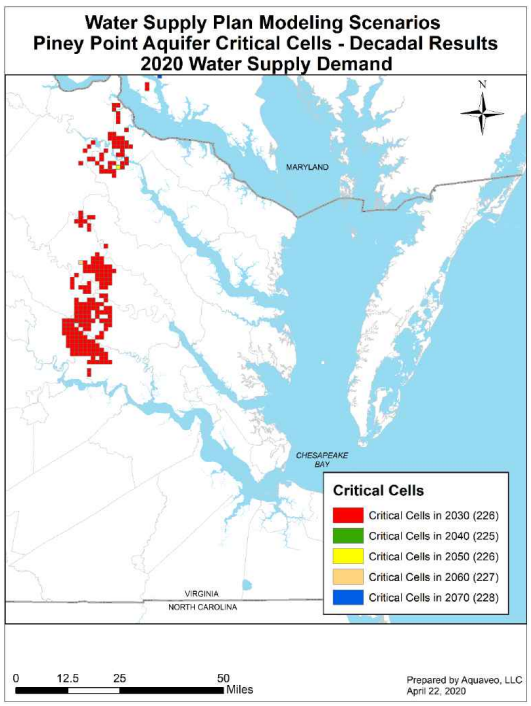


Figure 68: Simulated Critical Cells by Decade in the Piney Point Aquifer using 2020 Water Supply Plan Demands

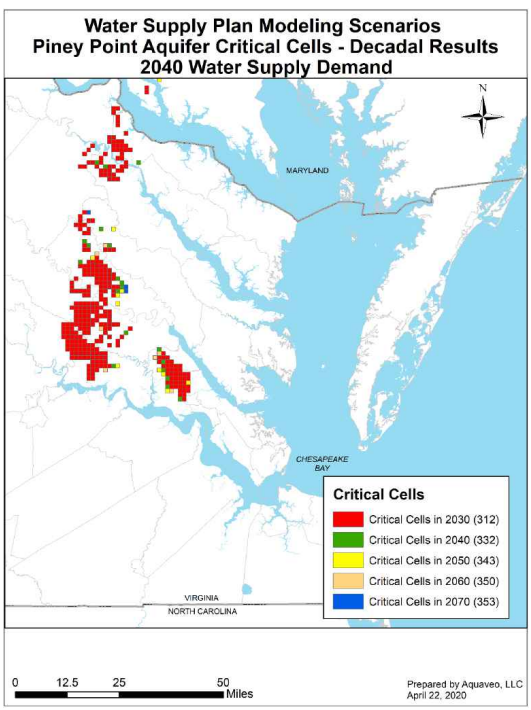


Figure 69: Simulated Critical Cells by Decade in the Piney Point Aquifer using 2040 Water Supply Plan Demands

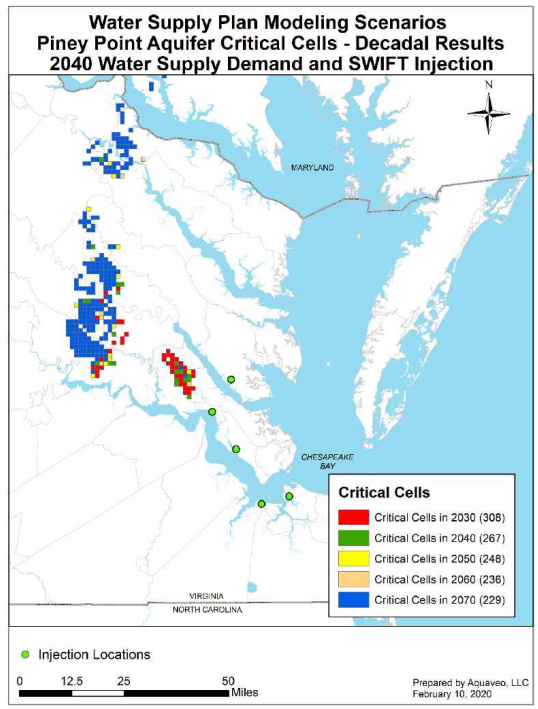


Figure 70: Simulated Critical Cells by Decade in the Piney Point Aquifer using 2040 Water Supply Plan Demands and SWIFT Injections

Piney Point Aquifer Critical Cell Results: The next series of figures displays the number of simulated critical cells for each decade for each scenario in the Piney Point Aquifer. The number in parenthesis next to each decade in the legend is the number of critical cells present in that decade during the simulation. Examining these values in series indicates whether the number of critical cells are increasing or decreasing in each decade. Figure 68 shows the number of simulated critical cells for each decade based on 2020 demands, while Figure 69 shows the same using 2040 demands. Figure 70 shows the number of critical cells using 2040 demands with the addition of injections into the Potomac Aquifer at the identified SWIFT injection sites.

4.3.4 Conclusions - VAHydro Virginia Coastal Plain Model

The overall trends related to the 2020 and 2040 demand scenarios in the Virginia Coastal Plain regional model are driven by both the regional hydrogeology as well as historic/future demands. The Coastal Plain aquifer system is a highly complex aquifer system made up of strata of unconsolidated and partly consolidated sediment that thicken moving eastward towards the Chesapeake Bay and Atlantic Ocean. This aquifer system is characterized in detail in the Virginia Coastal Plain Hydrogeologic Framework.[52] For the purpose of the State Plan, it is important to understand that the thickness and elevation of the aquifers in the system can vary and the aquifers become increasingly shallow and thin towards the fall-line. In these areas pumping has a greater impact on water levels due to the thinness of the aquifers, and generally more critical cells are seen along fall-line across all model scenarios. This trend is evident in the scenarios results provided above.

The 2020 and 2040 demand scenarios are intended to address how ongoing increases in water demands on the aquifer system for the next fifty years may impact long-term sustainability of the aquifer. As discussed above, demand in each scenario is composed of both "permitted" and "domestic" demands. One particular focus of these simulations is to better understand the potential impact of growing groundwater demands associated with domestic use from individual home owners or neighborhoods constructed with a well for each house. These scenarios use small SSU projections provided by localities for this type of use as a basis for these demands in 2020 and 2040, and in general domestic use is a larger component of these scenarios than in the 2019 Total Permitted as a result.

In the last decade, DEQ and groundwater users have worked successfully to make significant reductions in permitted groundwater use to address declining water levels in the Potomac Aquifer.

> The 2040 demand scenario indicates that **projected increases in domestic groundwater demands**, in combination with existing permitted demands, may result in continued decline in water levels in parts of the Coastal Plain Aquifer System.

As seen in Table 18, although in the 2040 scenario permitted demands are lower (88.1 MGD) than in the 2019 total permitted (94.6 MGD), the total pumping rate in the 2040 scenario is 15 MGD higher than in the 2019 total permitted due to increased projected domestic use. This is reflected in the 2040 demand scenario results which show simulated water levels lower than in the 2019 Total Permitted scenario across all aquifers; likewise more critical cells are created over the course of the fifty year simulation in the 2040 demand scenario than in the 2019 Total Permitted simulation. In contrast, the 2020 demand scenario shows simulated water levels recovering through 2050 before beginning to decline marginally through 2070, signifying that at current demand levels and estimates of domestic use water levels would likely recover. At the end of the fifty year simulation period for the 2020 demand scenario, the number of critical cells falls from 186 to 177 in the Potomac Aquifer. In the 2040 demand scenario, more than three times that number are simulated (608) by the end of the simulation (see Figure 57).

This is consistent with results in the Aquia and Piney Point Aquifers which show increasing numbers of critical cells each decade between 2020 and 2070 in the 2040 demand scenario. The increasing number of critical cells signifies an increasing areal extent of the portion of the aquifer system where water levels are simulated below the critical surface. For example, in the 2040 scenario, critical cells in the Potomac Aquifer are simulated further from the fall-line and occur in counties such as King William and Caroline, where few or no critical cells are simulated in the 2020 scenario. Areas of critical cells in the Potomac Aquifer in the 2019 total permitted and 2020 demand scenarios in Southampton and Sussex counties are significantly increased in extent and cover a greater portion of these localities in the 2040 demand scenario.

In the Piney Point Aquifer, critical cells are simulated in the 2040 demand scenario North of the James River in Charles City, New Kent, King William, Essex, and Westmoreland Counties (see Figure 69). In the Aquia Aquifer, the 2040 demand scenario results in more critical cells than any other aquifer, with water levels simulated below the critical surface along the entire fall-line North of the James with cells simulated further west than seen in the Potomac Aquifer

[52] McFarland, E.R., and Bruce, T.S., 2006, The Virginia Coastal Plain Hydrogeologic Framework: U.S. Geological Survey Professional Paper 1731, 118 p., 25 pls. (available online at http://pubs.water.usgs.gov/pp1731/

(see Figure 63). Many of these cells are also present in the 2020 demand scenario however.

The 2040 scenario suggests that the combined projected groundwater demands for permitted and estimates of domestic use for 2040 would result in an increasing number of critical cells, and therefore increasing challenges in permitting existing and new groundwater withdrawals in and around the regions where these cells are simulated.

Challenges in meeting the **regulatory criteria for permit issuance** are already present in areas of the Coastal Plain, particularly along the fall-line and in areas with existing high demands on the aquifers.

The 2040 demand scenario suggests the potential for exacerbation of existing permitting challenges as a result of increasing permitted and unpermitted demands should these demands be realized absent alternatives source and/or other mitigation strategies.

One such mitigation strategy that was evaluated in the State Plan through an additional groundwater modeling scenario was the HRSD SWIFT injection project. This project proposes to inject treated water into the Potomac Aquifer at five locations symbolized in the figures provided previously by the green circles. The simulation was based on the proposed phased approach where additional injection facilities will be constructed at intervals, and therefore the rate and extent of injection increases in phases between 2025 and 2032 with a final total injection rate of 81.45 MGD across the five injection sites in the Coastal Plain region of Virginia.

These injections were simulated in conjunction with the 2040 demands as included in the 2040 demand scenario. As seen in Figure 58, the number of critical cells in the Potomac Aquifer is comparable to the 2040 demand scenario beginning in 2030, but whereas the 2040 demand scenario indicates increasing critical cells each decade, the addition of SWIFT injections to the simulation results in decreases in the number of critical cells each decade as additional injection sites are constructed. The total number of simulated critical cells in the Potomac Aquifer by 2070 for the 2040 demand scenario is 608, while the SWIFT scenario results in 239 simulated critical cells.

The SWIFT scenario eliminates nearly all cells in the counties of Southampton and Sussex, as well as the majority of cells located away from the fall-line. The remaining critical cells in this simulation are primarily located along the fall-line in Hanover, Caroline, and Chesterfield Counties. This is the result of increased simulated water levels across the majority of the Coastal Plain, with significant recovery seen in the two existing major cones of depression and water levels above sea level simulated in the Tidewater area.

Although the injections are proposed in the Potomac Aquifer, the variably consolidated geology of the aquifer system permits both withdrawals and injections from an aquifer to impact adjacent aquifers. As such, the results in the Potomac Aquifer are generally consistent with the results in the Aquia Aquifer as well, although the SWIFT injections do not significantly impact critical cells in the Aquia Aquifer located North of the James River in the simulations. Substantial areas with with simulated water levels below the critical surface remain in the SWIFT scenario, particularly along the fall-line in Caroline, King George, Hanover, and other localities.

Across all scenarios the majority of simulated critical cells in the Piney Point Aquifer are located north of the James River. The SWIFT injections are not simulated to have as significant an impact on Piney Point water levels north of the James River and the majority of critical cells simulated in the 2040 demand scenario remain in the SWIFT scenario. Critical cells in the Piney Point Aquifer are concentrated in Charles City, New Kent, King William, and other localities located north of the James River, including portions of the Northern Neck.

While the results in the SWIFT scenario are promising, particularly in the Potomac Aquifer and in areas south of the James River, there remains many unknowns regarding the rate and extent that injections will impact water levels in the aquifer system. A pilot injection well at HRSD's SWIFT Research Center is providing field data on how the injections impact pressure in the Potomac and overlying aquifers.[53] The center currently collects data from observation wells and from an extensometer operated by USGS which measures minute changes in land elevation in response to the injection. These data are critical to evaluating model results and calibrating the model with respect to the simulation of the proposed injections.

[53] https://www.hrsd.com/swift/about

At this stage in the project, only limited data has been collected on the single pilot well, and it is too soon to know if the promising results seen in the SWIFT simulation are likely, as preliminary data indicates changes in aquifer pressure, and therefore water levels, may not be as substantial in rate or extent as simulated in the model currently. The SWIFT project may be an important mitigation strategy in addressing the impacts to the confined aquifer system in the Coastal Plain, but it must be complimented by other strategies. Individual localities with high groundwater demands will likely need to pursue alternatives such as surface water to meet their demands, particularly in those areas with a high potential of current or future challenges in meeting the regulatory criteria for permit issuance, andor meeting the cumulative demands off all groundwater demands.

4.3.5 Groundwater Model Results - VAHydro Virginia Eastern Shore Model

This section provides the groundwater modeling results for the VAHydro Virginia Eastern Shore model, which covers the area in the Eastern Shore Groundwater Management Area. These scenarios are based on current and projected demand information submitted by localities in water supply plans. Hydrogeology on the Eastern Shore is often characterized through the analogy of a freshwater lens, representing the freshwater aquifers like the Yorktown-Eastover and the water table, that sit atop groundwater that is substantially higher in chlorides, due to the proximity to the Chesapeake Bay to the west and the Atlantic Ocean to the east. A recent update to the Hydrogeologic Framework of the Virginia Eastern Shore, a joint effort between USGS and DEQ, is the primary source for understanding the aquifer systems on the Eastern Shore.[54]

Results for the 2020 demand and 2040 demand scenarios are provided for the Upper Yorktown-Eastover, Middle Yorktown-Eastover, and Lower Yorktown-Eastover aquifers. These three aquifers are the primary sources for all demands on the Eastern Shore. The three sections of the Yorktown-Eastover are considered separate aquifers but are interconnected such that withdrawals from one can and do impact the others. There is limited fresh surface water available and outside of agricultural ponds, the Eastern Shore is entirely reliant on groundwater for meeting demands at present. The three Yorktown-Eastover aquifers supply the majority of large users covered under groundwater permits such as municipal and community water systems, as well as most residential/domestic use, or small SSUs. The surficial aquifer, or the unconfined water table, is used largely to meet a portion of agricultural demands and is not commonly used for domestic or other uses. Therefore, evaluating the sustainability of water resources on the Eastern Shore is in large part an evaluation of the sustainability of the Yorktown-Eastover aquifer system.

In addition to evaluating simulated water levels, changes in chloride concentration were also simulated. As the Yorktown-Eastover aquifer system is largely freshwater with increasing salinity as depth increases, one concern regarding additional demand is salt-water intrusion, an effect where pressures related to withdrawals result in saltier water migrating either horizontally or vertically. Results from these simulations are also provided below.

[54] McFarland, E.R., and Beach, T.A., 2019, Hydrogeologic framework of the Virginia Eastern Shore: U.S. Geological Survey Scientific Investigations Report 2019–5093, 26 p., 13 pl., https://doi.org/10.3133/sir20195093.

Upper Yorktown-Eastover Results: Figure 71 shows the simulated water levels relative to mean sea level in the Upper Yorktown-Eastover Aquifer after a fifty year simulation running from 2020 to 2070 using the 2020 groundwater demands from water supply plans. Figure 72, in comparison, shows simulated water levels relative to mean sea level after 50 years using 2040 demands.

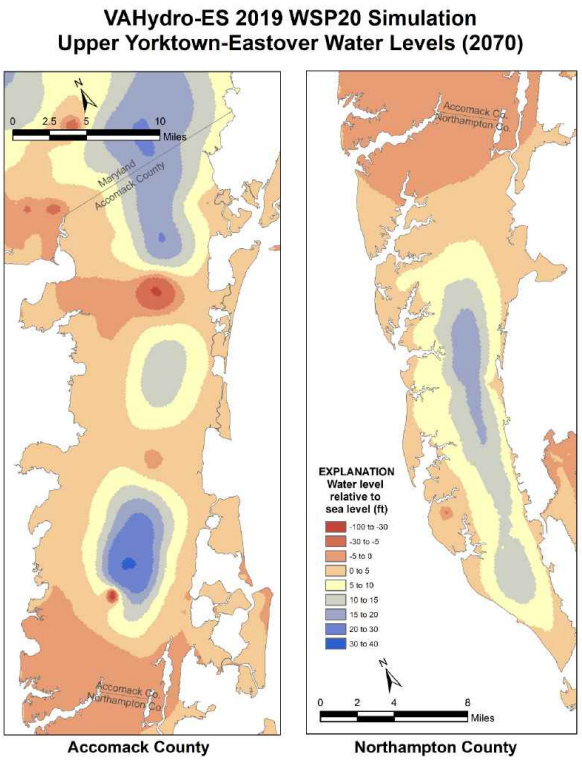


Figure 71: Simulated Upper Yorktown-Eastover Aquifer Water Levels in 2070 using 2020 Water Supply Plan Demands

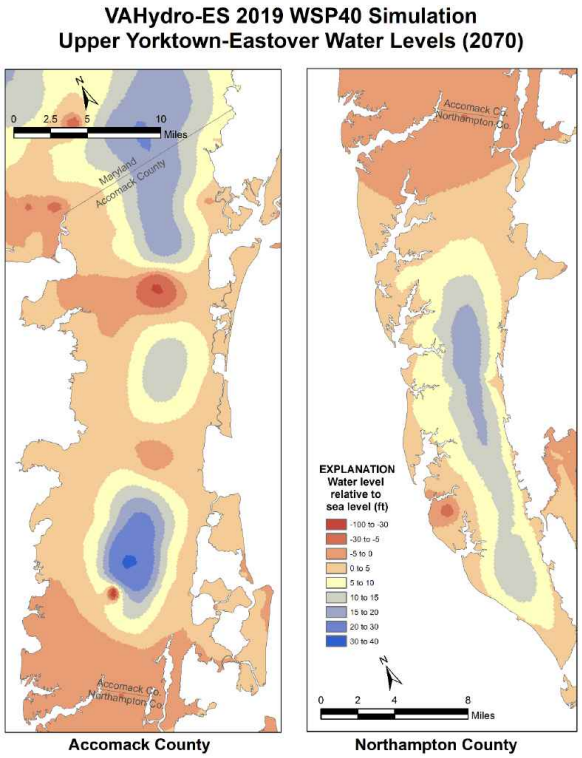


Figure 72: Simulated Upper Yorktown-Eastover Aquifer Water Levels in 2070 using 2040 Water Supply Plan Demands

Middle Yorktown-Eastover Results: Figure 73 shows the simulated water levels relative to mean sea level in the Middle Yorktown-Eastover Aquifer after a fifty year simulation running from 2020 to 2070 using the 2020 groundwater demands from water supply plans. Figure 74, in comparison, shows simulated water levels relative to mean sea level after 50 years using 2040 demands.

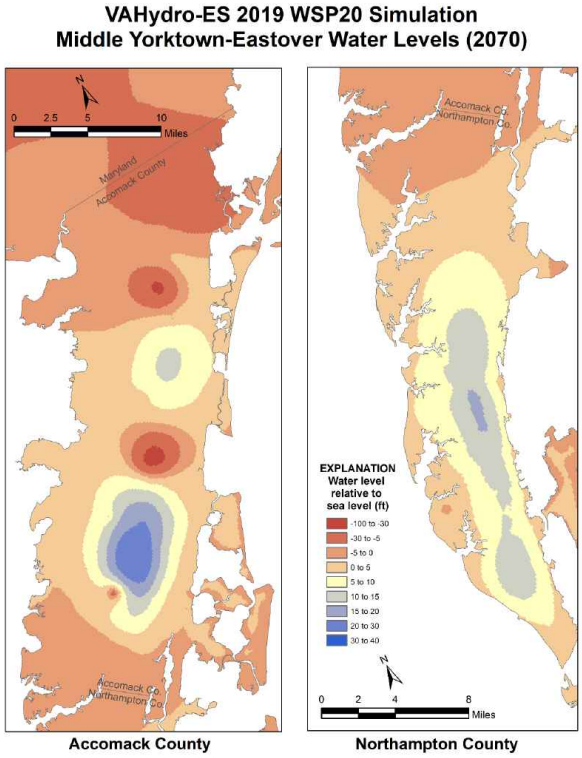


Figure 73: Simulated Middle Yorktown-Eastover Aquifer Water Levels in 2070 using 2020 Water Supply Plan Demands

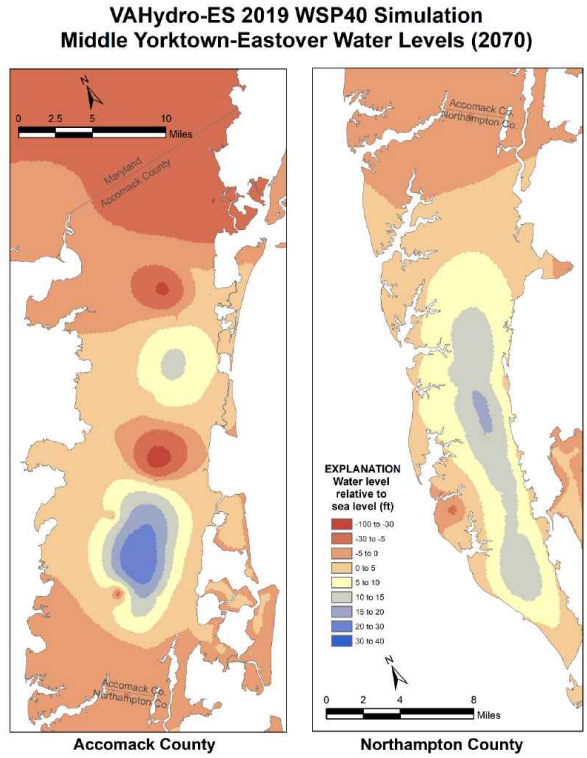


Figure 74: Simulated Middle Yorktown-Eastover Aquifer Water Levels in 2070 using 2040 Water Supply Plan Demands

Lower Yorktown-Eastover Results: Figure 75 shows the simulated water levels relative to mean sea level in the Lower Yorktown-Eastover Aquifer after a fifty year simulation running from 2020 to 2070 using the 2020 groundwater demands from water supply plans. Figure 76, in comparison, shows simulated water levels relative to mean sea level after 50 years using 2040 demands.

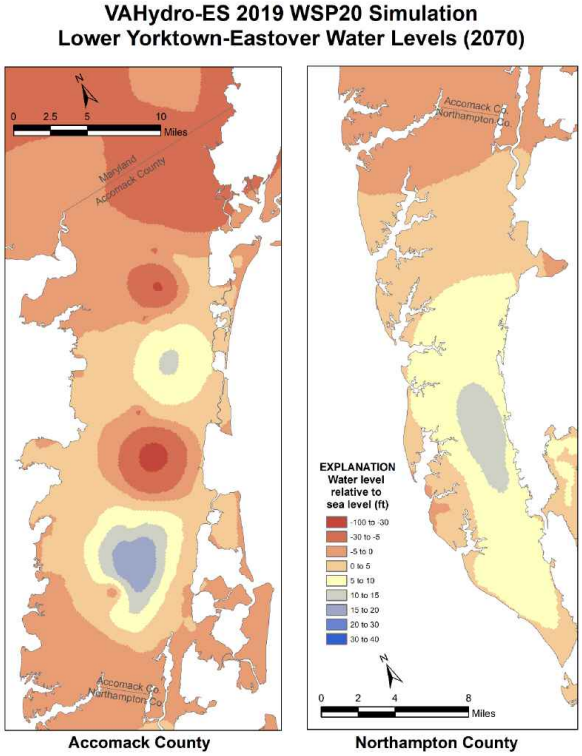


Figure 75: Simulated Lower Yorktown-Eastover Aquifer Water Levels in 2070 using 2020 Water Supply Plan Demands

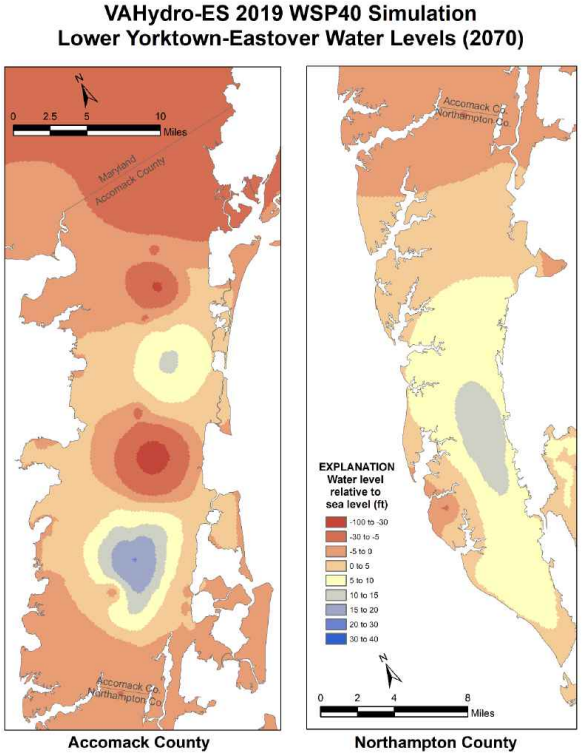


Figure 76: Simulated Lower Yorktown-Eastover Aquifer Water Levels in 2070 using 2040 Water Supply Plan Demands

Critical Cell Results: As with the VCPM model, evaluation of the critical surface was also completed in the VESM model for all three aquifers for the 2020 demand and 2040 demand scenario. Neither scenario resulted in model cells with simulated water levels below the critical surface, or critical cells, for any aquifer. The most recent 2019 Total Permitted simulation, which includes the highest overall pumping rate of all scenarios, also did not result in any critical cells as simulated water levels remain above the critical surface throughout the Eastern Shore.

Chloride Simulation Results: The VESM regional model is also capable of simulating changes in chloride concentrations. The 2040 demand scenario was run for fifty years and chloride concentrations in mg/L were compared to the 2019 Total Permitted chloride concentrations in mg/L. The results of these comparisons are provided in Figures 77, 78, and 79 for the Upper, Middle, and Lower Yorktown-Eastover Aquifers respectively. Areas showing a reduction in chloride concentration in mg/L are areas where simulated chloride concentrations are higher in the 2019 total permitted scenario than in the 2040 demand scenario. Areas showing an increase in chloride concentrations in mg/L are where simulated chloride concentration are higher in the 2040 demand scenario. The majority of the Eastern Shore remains green, showing no significant change in chloride concentration between the two scenarios.

Historically, simulations of chloride concentrations have shown minimal increases in chlorides inland, with the majority of simulated changes occurring offshore and in specific areas along the coastline near the Town of Cape Charles in Northampton, or near the Captain's Cove development in Northern Accomack County. These are areas with existing issues with elevated chlorides that can be exacerbated by increasing withdrawals. Similarly, the two areas which are simulated to see higher concentrations in the 2040 demand scenario compared to the 2019 total permitted are the Cape Charles area and the area around Captain's Cove in the Middle Yorktown-Eastover and Lower Yorktown-Eastover aquifers. This is largely driven by the increased demands that are projected for these areas in the 2040 demand scenario.

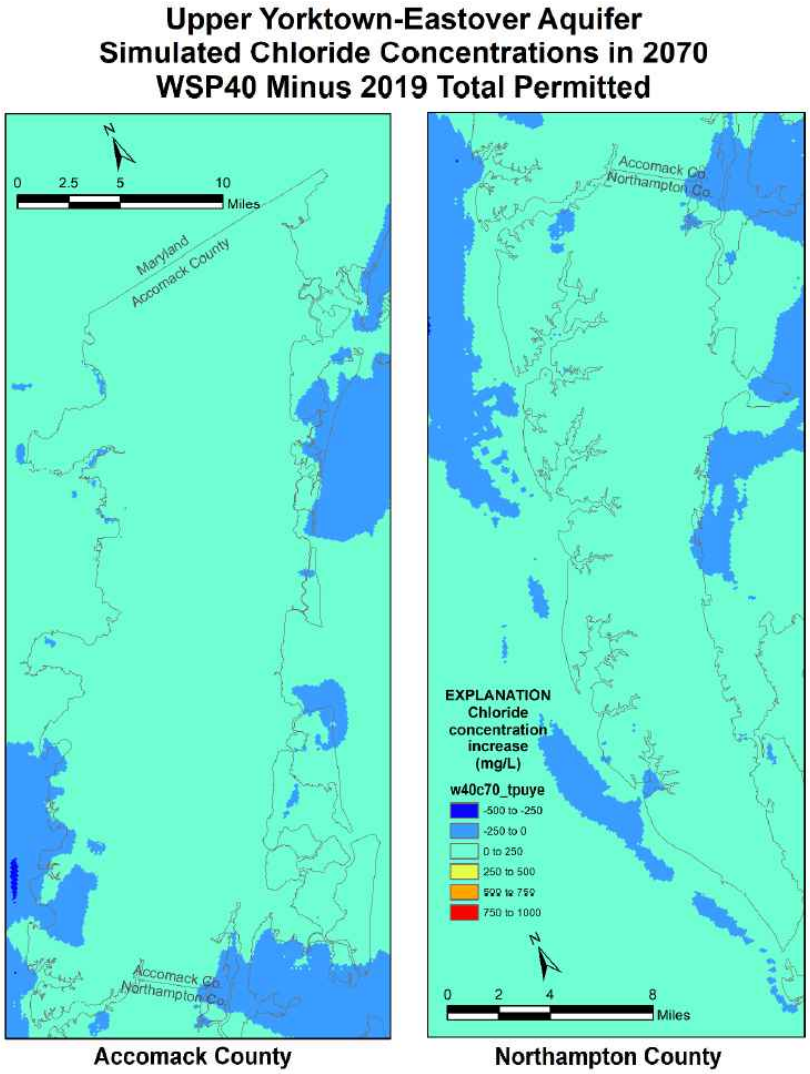


Figure 77: Comparison of Simulated Chloride Concentrations in mg/L between 2020 Water Supply Plan Demand Scenario and 2019 Total Permitted scenario in the Upper Yorktown-Eastover Aquifer

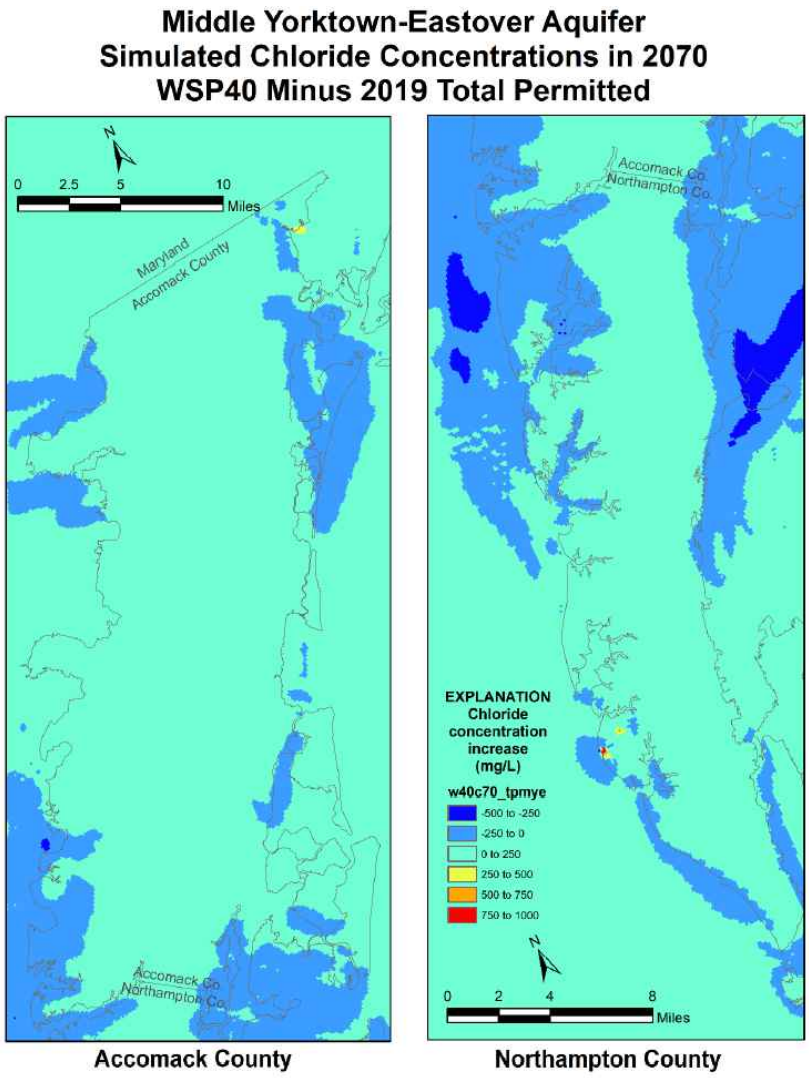


Figure 78: Comparison of Simulated Chloride Concentrations in mg/L between 2020 Water Supply Plan Demand Scenario and 2019 Total Permitted scenario in the Middle Yorktown-Eastover Aquifer

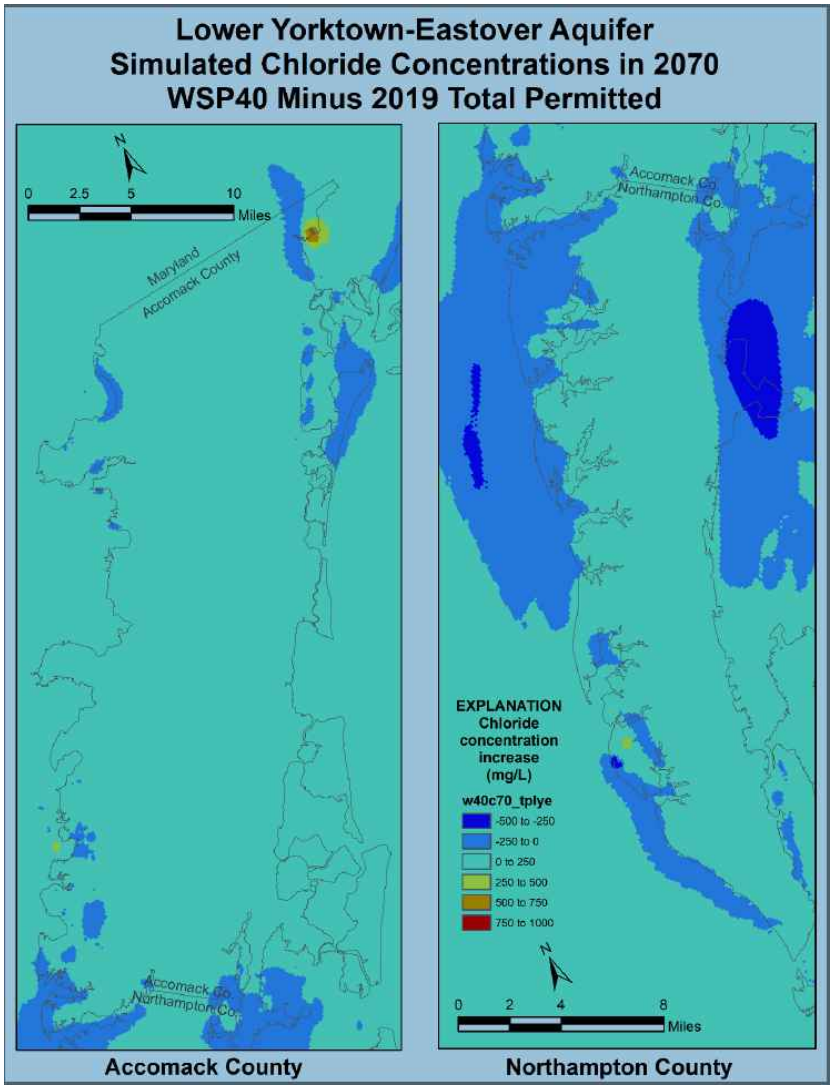


Figure 79: Comparison of Simulated Chloride Concentrations in mg/L between 2020 Water Supply Plan Demand Scenario and 2019 Total Permitted scenario in the Lower Yorktown-Eastover Aquifer

4.3.6 Conclusions - VAHydro Virginia Eastern Shore Model

The overall trends related to the 2020 and 2040 demand scenarios in the Virginia Eastern Shore Model are driven by both the regional hydrogeology as well as historic/future demands. As all potable water demands and the majority of non-potable demands on the Eastern Shore come from groundwater, particularly the three confined Yorktown-Eastover aquifers, ensuring the sustainability of the aquifer system is critical. The two primary concerns related to groundwater withdrawals are impacts to water levels and the potential for salt-water intrusion due to the Eastern Shore's unique hydrogeology. This section will cover the trends related to these two concerns.

A detailed discussion of existing and projected future demands on the Eastern Shore is provided in the Eastern Shore Appendix. In summary, the Eastern Shore is projected to see moderate increases in groundwater demand between 2020 and 2040. However, the majority of that demand is projected for municipal (CWS) facilities. Accomack and Northampton Counties are projected to decrease in population by 20% and 15% respectively. As a result, demand for small SSU, or domestic groundwater use, is projected to decrease by around 10% by 2040, and this can be seen in the decreased domestic pumping rate in the 2040 demand scenario in Table 19 when compared to the 2020 demand scenario. In total, groundwater demands are projected to increase around 1 MGD on the Eastern Shore, with those demands primarily associated with permitted facilities in areas of existing demand concentration rather than dispersed more generally through domestic demand increases.

As **2040 demand projections are not significantly higher** than 2020 demands on the Eastern Shore, the simulated water levels in the 2040 scenario are not substantially different from the 2020 demand scenarios.

Water levels are not simulated to fall below the critical surface in either the 2020 or 2040 demand scenario in the Upper, Middle, or Lower Yorktown-Eastover Aquifers. However, recent total permitted evaluations completed for groundwater withdrawal permit applications on the Eastern Shore have shown simulated water levels nearing the critical surface in the vicinity of the two poultry processing plants - which are the largest withdrawals in the region.

Simulations of chloride concentration changes in the 2040 scenario compared to the 2019 Total Permitted showed the potential for increasing chlorides in areas with existing elevated chloride concentrations, primarily near the Town of Cape Charles and Captain's Cove. This reflects the potential for increasing chloride concentrations in these areas if growth were to align with the projections in the regional water supply plan. Agricultural use is also growing - driven in part by increasing poultry farms. This growth is not fully captured in the water supply plans at this point and is therefore not fully captured in these scenarios.

As a whole, this analysis suggests that developing alternatives to the Yorktown-Eastover aquifer system is necessary on the Eastern Shore, although the options are limited. Use of the surficial aquifer as a supplement or replacement to withdrawal from the confined aquifer is a promising potential, particularly for agricultural use, and is being incorporated into the withdrawal permitting program. The surficial aquifer recharges from precipitation at a much higher rate than do the confined aquifers below it, and therefore any use that can be placed on the surficial will be more sustainable long-term. Desalinization may be a viable option for larger systems, although that would likely require a regional partnership of some kind due to cost. Surface water from dug ponds and other types of surface water impoundments can be an effective alternative to groundwater for agricultural water use. The location and extent of demand growth will ultimately determine where these kinds of measures may be most necessary.

4.4 Assessing Virginia's Water Resources - Conclusions and Areas of Further Analysis

Assessing the long-term sustainability of water resources in Virginia is an ongoing iterative process. This analysis provides new insight into how current and future demands, a changing climate, and other factors may impact water supply, aquatic life, and other beneficial uses. It identifies areas of concern that may warrant additional attention in the planning or permitting process. It offers some answers, but also questions, that may be useful in furthering the ongoing dialogue between all stakeholders on this crucial subject.

The following is a summary and restating of the key trends from the surface water and groundwater cumulative impact analyses. This process has driven significant advances in the science and modeling that underpin this work - but is has also made clear several areas where further analysis or model refinement will be necessary. Those are addressed here as well:

4.4.1 Summary

Surface Water Demand Scenarios: Total water demands excluding power generation are projected to increase 21% statewide from around 1.58 billion gallons to 1.91 billion gallons between 2020 and 2040. However, the 2040 demand scenario results in only minor to moderate reductions in critical drought flows in the majority of river basins. Significant reductions are simulated in some areas, particularly headwater watersheds and areas with large demands and limited reservoir storage. Examples include portions of the Shenandoah and Roanoke River Basins.

> The **2040 Demand Scenario** does not suggest major reductions in streamflow driven by demand increases for most of Virginia. However, drought flows in the 2020 demand scenario are already sufficiently low to impact water supply and other beneficial uses in some parts of the state.

The limited impacts when comparing the 2040 and 2020 demand scenarios is in some part due to the success of planning and resource management, particularly as it relates to developing storage and diverse sources. Areas with the most projected growth in demands also tend to be those areas that have taken a regional approach to planning and source development. Pump storage projects such as Cobb's Creek, or interconnected networks of reservoirs in the Rivanna System demonstrate that increasing demands can be met through adequate storage while limiting impacts to streamflows. The 2018 WSP compliance and review process also resulted in revised projections for some localities, and in many cases projections were revised to a lower amount than originally submitted. Each year also brings new VWP permits, which increases the amount of demands that are withdrawn through permits that include instream flow requirements.

In comparison to the demand scenarios completed in the 2020 State Plan, the 2015 State Plan actually used a longer planning period, since it began with use projections from 2008 (which in many cases were the most up to date available at the time), and compared those to 2040 projections. For the 2020 State Plan, only the demand increase from current (2020) demands through projected 2040 demands is being evaluated. While this could lead to lesser impacts when evaluating changes in demand between the two analyses, the effect is likely minimal as for many localities the change in demand between the original WSP submission and recent submissions is not substantial.

However, it is important to recognize that streamflows during critical drought periods are already impacting beneficial uses including water supply in some parts of Virginia, particularly in headwaters of streams and rivers and in areas with limited storage. The 2020 State Plan includes a new metric called "Potential Unmet Demand" that is calculated for each facility during a modeling scenario. This metric is discussed in more detail in Chapter 4. In short, nearly 10% of facilities modeled statewide have unmet demand of some amount in the 2020 demand scenario. The total potential unmet demand is more than 160 MGD statewide in the 2020 demand scenario, increasing to 229 MGD in the 2040 demand scenario. It is critical to understand where demands are not being met in these simulations, as this will be helpful in understanding where challenges may occur in reality.

To that end, a summary of potential unmet demand is provided for each minor basin in Appendix A. However, the 2020 State Plan also includes as an appendix

all of the data used in CIA modeling and analysis, which allows evaluation of the raw streamflow results for each metric and scenario for any non-tidal river segment in Virginia. This data will be critical for localities that are interested in evaluating these data as they take the next steps in developing local and regional water supply plans. These data can also be used in project scale evaluations. Detailed results on the surface water demand scenarios can be found in Chapter 4, Section 4.2.8.1.

> DEQ is planning to offer **outreach opportunities to interested stakeholders** that would like to use the State Plan and the results of the cumulative impact analysis to better understand and address their own local and regional planning challenges.

Surface Water Climate Change Scenarios: Global climate models nearly unanimously project Virginia to have continued increases in temperature over the next century, depending on the magnitude of greenhouse gas emissions. Temperature changes observed over the last 30 years have already resulted in substantial increases in potential evaporation throughout Virginia. While some evidence suggests a small increase in overall flow for streams and rivers in the Northern U.S., this relationship has not been documented for Virginia streams. Therefore historical data thus far gives no assurance that Virginia can count on a future of less severe droughts.

> Increased evaporation means that **future planning efforts** must factor in the potential of an extreme drought that is of greater severity than in years past.

Future climate modeling for Virginia may benefit from adding geographic trends as a screening criteria in order to have an improved understanding of how trends may vary by physiographic province and latitude. Also, since currently available climate models are unable to predict whether the timing of rainfall (seasonal or annual) will change, these model predictions cannot assess the likelihood, or potential impacts of shifting rainfall patterns.

That said, the temperature and rainfall changes that were simulated in the climate change scenarios used for the 2020 State Plan are all within a reasonable bound based on the predictions of the best available global climate models of increasing atmospheric CO_2. These analyses show what may happen to streamflows should these conditions occur. These are not predictions that a given river segment or facility will be impacted in this way, but the data suggests such impacts are real possibilities. These three scenarios should also not be considered the best and worst-case models in terms of drought flow. They were selected by the CBP modeling team to "define the range of uncertainty in projected future."

All stakeholders including state and local government, water authorities, and individual water users will need to take steps to incorporate these kinds of analyses into resource planning efforts. At minimum, climate change suggests that Virginia has the potential to experience droughts that are more severe than those experienced in the past. Even if such events are rare, it will become increasingly important that water supply planning occur at a scale that facilitates a regional evaluation of sources and demands, as well as evaluating regional opportunities for diversifying sources, developing storage, and building interconnections and redundancy where possible among neighboring systems.

Surface Water Exempt Users: Unpermitted use makes up nearly 75% of all surface water demands. For the most part, unpermitted surface water use represents users who are exempt from the requirement to obtain a VWP permit. Yet these withdrawals still have a very real impact on surface water. The exempt user scenario is the first attempt to quantify this impact cumulatively.

> The results of the **exempt user scenario** suggest that the cumulative potential withdrawals from exempt surface water users exceed the water budget in many of Virginia's streams and rivers.

Were all exempt user demands to be acted upon, many surface water users, exempt or not, would not be able to meet their demands as streamflows would be reduced or eliminated. Substantial impacts to other beneficial uses, such as aquatic life, waste assimilative capacity, and even recreation, are also likely based on the simulated reductions in streamflow.

This scenario does not suggest that any specific exempt user is proposing to operate at the maximum

possible exempt demand, but provides a necessary reference point to understand the potential impacts of these demands. As a whole, it underscores the importance of evaluating exempt demands cumulatively and in the context of the regional water resources.

Surface Water Impacts to Aquatic Life: The 2020 State Plan introduced two new metrics that will be important to evaluating impacts to aquatic life in the future: the overall change in flow (consumptive use) metric, and the elfgen framework, which together can be used to evaluate potential impacts to species richness as a result of flow reductions. Statewide evaluation using the elfgen framework showed that the 2040 demand scenario resulted in only a few areas with significant risks to species richness. In general, consumptive use was highest below impoundments which regulate releases downstream of the dam. Other areas of concern include smaller headwater streams which also showed an elevated risk of species loss. The exempt user scenario results in higher consumptive use due to the higher total withdrawals associated with the withdrawal demands, and this increases the extent of the risk to species richness.

Applying the **elfgen framework** with the 2040 demand scenario resulted in only a few areas with significant risks to species richness; however, the exempt user scenario results in greater risks to species richness across Virginia due to the increases in consumptive use.

This represents the initial implementation of this framework for evaluating the potential for impacts to aquatic life. More work is needed to define and implement procedures for evaluating the potential for changes in species richness in a resource management context.

Groundwater - EVGMA: Groundwater modeling was completed in the Eastern Virginia Groundwater Management Area and Eastern Shore Groundwater Management Area. For each management area, 2020 and 2040 demand scenarios were developed based on demand projections submitted by localities in water supply plans. These scenarios took a novel approach of estimating domestic groundwater use using small self-supplied use demand projections and existing information on the distribution of domestic wells.

In the **Eastern Virginia Groundwater Management Area**, the 2040 Demand Scenario results in widespread increases in the number and extent of critical cells in areas with existing critical cells.

Where the 2040 demand scenario predicts an increase in critical cells, this may mean increasing challenges in meeting the regulatory criteria for groundwater withdrawal permit issuance in these areas - and generally for large withdrawals anywhere in the Coastal Plain. An additional scenario that included injections from the SWIFT project shows promise in increasing water levels, but more data is needed to evaluate how the actual rate of recovery compares to the model. It remains critical that groundwater users in the Coastal Plain continue to take a regional planning approach, evaluate and implement alternative sources, and continue to improve water conservation to reduce demands overall.

Groundwater - ESGMA: On the Eastern Shore, while agricultural demands have grown over the last five years, decreases in domestic/residential groundwater use are expected and may balance that growth. 2040 demand projections on the Eastern Shore are not significantly higher than 2020 demands, and therefore the impacts to water levels in the 2040 scenario are not substantially different in comparison to current demands.

In the **Eastern Shore Groundwater Management Area**, water levels are not simulated to fall below the critical surface in either the 2020 or 2040 demand scenario in the Upper, Middle, or Lower Yorktown-Eastover Aquifers.

Despite the minimal impacts seen in the 2040 Demand Scenario, the Total Permitted scenario completed for groundwater withdrawal permit applications on the Eastern Shore has shown simulated water levels nearing the critical surface in the vicinity of the two poultry processing plants - which are the largest withdrawals in the region. Agricultural use is also growing - driven in part by increases in the poultry farming industry in Accomack County.

This suggests that developing alternatives is equally important on the Eastern Shore, although the options are limited. Investigation of the surficial aquifer as

a supplement to the Yorktown-Eastover aquifer system is a potential, particularly for agricultural use. The surficial aquifer recharges from precipitation at a much higher rate than do the confined aquifers below it, and therefore any use that can be placed on the surficial will be more sustainable long-term. Desalinization may be a viable option for larger systems, although that would likely require a regional partnership of some kind due to cost. The location and extent of demand growth in the next twenty years will ultimately determine where these kinds of measures may be most necessary.

4.4.2 Areas for Future Analysis

A reoccurring theme in the State Plan is that investment in the science and data that informs resource management is critical. One intended goal of the State Plan is to support adaptive management strategies through analysis. That analysis also provides opportunities to identify strengths and weaknesses in these tools. DEQ identified several areas that would benefit from refined analysis, improvements to water supply plan data, drought assessment/response procedure improvements, and optimized watershed monitoring approaches. A number of these potential refinements are identified here, although resources do not necessarily allow DEQ to pursue them all currently.

Groundwater Return Flows: Groundwater withdrawals from fractured rock aquifers, as modeled, currently results in a net increase in streamflow when groundwater is returned to a river through wastewater treatment. While this is a welcome outcome in terms of drought flows both in a model and in reality, it will be important to better understand whether pumping from these wells results in any decrease in base flow during drought times that might offset the benefits that are currently estimated.

This is particularly challenging to study and model in fractured rock aquifers because the hydrogeology for each well can differ significantly in response to the quantity and quality of the fractures it intersects. DEQ and USGS have completed, and are currently working on regional studies that provide some insight here, but they are resource intensive and their geographic scope is very limited in comparison to similar work in the Coastal Plain. Modeling efforts in Clarke County and Bedford county are underway and may help to give insight about the utility of performing this analysis, and the potential variability that might be encountered.

Unaccounted water/transmission losses in Coastal Plain: For both surface water and groundwater based systems, transmission losses during distribution result in the need for extra withdrawals to meet user demand, and therefore wasted treatment capacity. For surface water based systems, losses from wastewater collection systems result in a reduction of potential in-stream flows (i.e. more consumptive use), although this is generally only a concern during drought. Some of what is lost in transmission does eventually end up back in rivers and streams.

In confined aquifer systems, transmission losses through the distribution system are potentially a greater concern. In confined aquifer systems, transmission losses do not readily return to the groundwater aquifer of origin due to the overlying confining layers. In the coastal plain where groundwater predominates as a source of water, efforts to reduce transmission losses can have an immediate and direct benefit to slowing aquifer depletion, and therefore provide for future demands. A more thorough accounting of unaccounted water, particularly related to transmission, would be essential to understanding the extent to which reduction of transmission losses in the coastal plain may aid in the recovery of aquifer levels. Many localities provided estimates of "unaccounted water" in water supply plans, but many did not. Improving the quality and extent of these estimates is important statewide, but particularly in the two groundwater management areas.

Improving Agricultural Use Estimates: One of the largest challenges for localities in developing water supply plans was identifying and collecting agricultural water use estimates, both for current and future use. DEQ is currently collaborating with Virginia Tech on a project to develop more refined estimates of unreported agricultural water use (see Chapter 5, Section 5.2). This will provide one method of improving analysis that likely underestimates agricultural water use. This project will also develop methods of estimating how high temperatures and low rainfalls may influence agricultural water use patterns in order to create more accurate assessments of the impacts to streams during drought, and the potential for future climate changes to affect use patterns. Additionally, improving the estimates of current and future agricultural water use in water supply plans is also a critical need in ensuring that future cumulative impact analyses accurately reflect agricultural water use in Virginia.

Modeling Exempt Impoundments: This plan showed that impoundments that are unpermitted or

exempt from VWP permit requirements do not have required minimum releases, and can have the greatest impacts to downstream flows in the face of large demand increases. Many of these impoundments are also in small headwaters, and it is these small watersheds that have been shown in this analysis to be most vulnerable to stream flow changes. DEQ's current representation of these impoundments in the VAHydro watershed model is incomplete, and future efforts to incorporate all managed water supply impoundments into the model should be prioritized. By incorporating these impoundments into the VAHydro model, simulations can be performed to help recommend management strategies that can minimize the types of aquatic impacts that have been seen in this report, and to enhance the reliability of these systems for the provision of human water use.

Modeling Complex and Conjunctive Systems: As staffing allows, DEQ also intends to refine models in high use areas, particularly in systems with significant interconnections between sources, and conjunctive use systems (groundwater and surface water). The rules governing how such systems are operated are typically complex - and often requires simultaneous modeling of potentially interconnected systems that provide redundancy to one another.

Refining Point Source and Withdrawal Connections: The consumptive use project discussed in Chapter 4 developed some connections between point source discharges and withdrawals. This work needs to be built upon with further refinement of connections for point sources in non-municipal sectors of highest variability and/or highest consumptive use as identified in the statewide analysis.

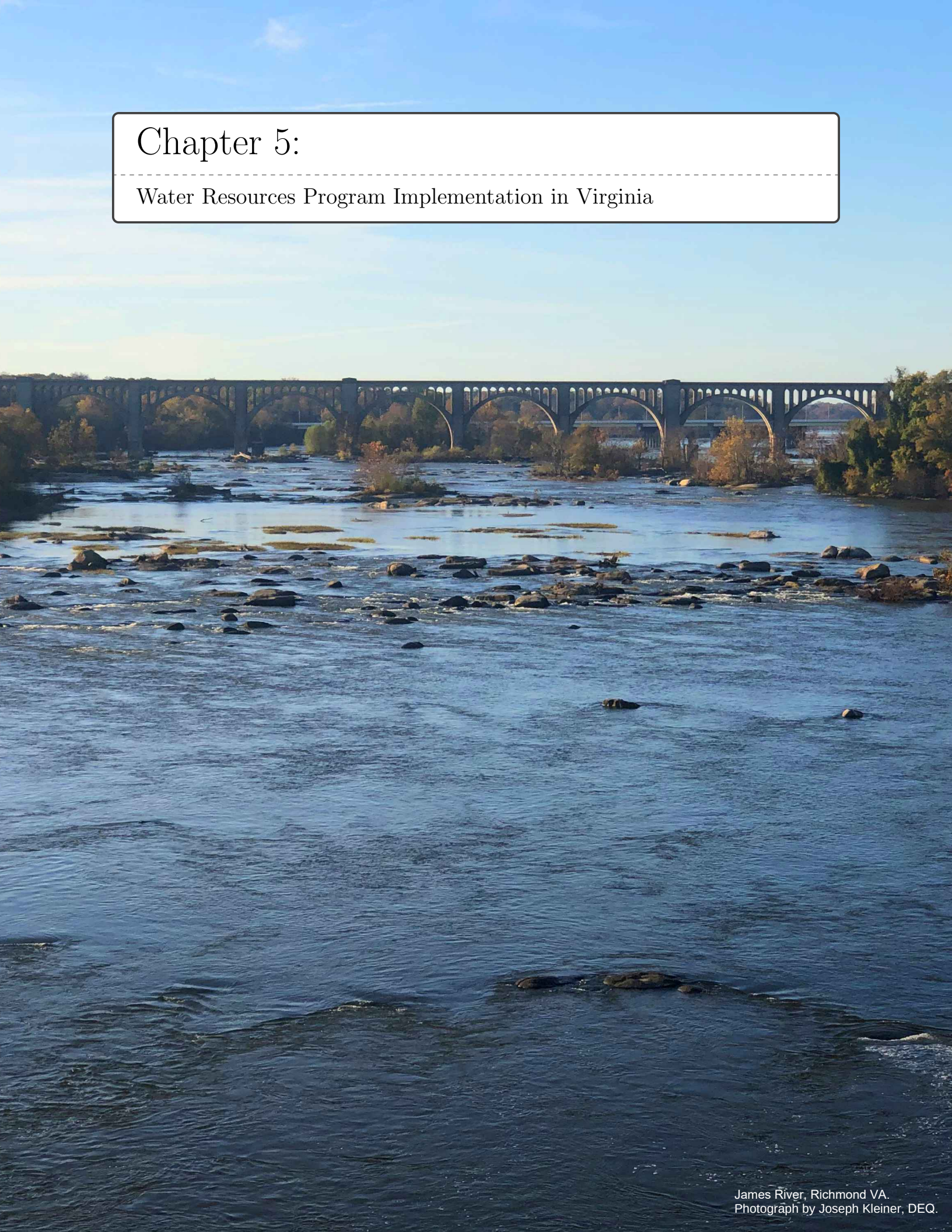
Expanding Climate Change Simulation period and Spatial Area: The evidence of increased temperatures and evaporative losses since 1984, and lack of strong evidence of an overall trend towards increasing rainfall in Virginia provides strong motivation for expanded modeling and analysis of rainfall and temperature trends in Virginia. Because current climate change models in Virginia run from only 1990-2000, at minimum it is recommend to expand climate change models over the 1984-2014 period to allow evaluation of potential impacts to 7Q10, and a more precise comparison of climate change effects on historical extreme droughts from the 1980s and in 2002. Recent record rainfalls and flash droughts suggest the necessity of developing a process of updating model meteorologic time series from 2015 to present, and thereafter updated annually. This expansion of climate inputs moving forward will be an essential part of adaptive management strategies to allow assessment of the ongoing effects of increasing temperature, changing land use and water system demands, evaporation, and the effects of emerging trends in rainfall timing and base flow recharge.

Developing climate change models for the southern rivers (outside the Chesapeake Bay Drainage) portion of Virginia is critical to providing this important analysis to the entire Commonwealth.

Analyzing Historic Winter Recharge: Analyzing winter recharge patterns over the last 100 years may identify trends that inform future summer extreme drought probabilities [Austin, 2014]. Combining this analysis with an expanded modeling time period would further enable analysis of trends in winter recharge in response to climate change.

Chapter 5:

Water Resources Program Implementation in Virginia



James River, Richmond VA.
Photograph by Joseph Kleiner, DEQ.

5 Water Resources Program Implementation in Virginia

5.1 Water Resources Program Implementation - 2015 to Present

This section is intended as a summary of major water resource management initiatives and focuses during the period from 2015 to present. A detailed overview of core resource management activities, for example the number of permits issued or withdrawal reports received, as well as the most recent reported water use data for each year is provided in the annual publication of the "Annual Report on the Status of Virginia's Water Resources." Previous year's copies of the Annual Report are available upon request.

This section is broken into several main focuses: Groundwater Management, Surface Water Management, and Water Supply Planning and Annual Reporting.

5.1.1 Groundwater Management

Groundwater is a major source both inside and outside the groundwater management areas. Challenges in ensuring the long-term sustainability of the resource exist both in the fractured rock aquifers located west of Interstate 95, as well as in the Coastal Plain and Eastern Shore aquifer systems. In the last five years, DEQ has worked to manage groundwater through a variety of program initiatives:

VCPGWI: In the Eastern Virginia Groundwater Management Area (EVGMA), historic demands on the aquifers have often exceeded the rate of recharge in the aquifers. For decades, water levels in the major aquifers, particularly in the Potomac Aquifer, the primary source for groundwater in the Coastal Plain, have been declining. Declining water levels have driven higher rates of land subsidence, which can lead to a loss of aquifer storage, and increased salt-water intrusion. In areas where water levels have fallen or are nearing the critical surface, new or existing groundwater withdrawals are unable to meet the regulatory criteria for issuance of a groundwater withdrawal permit.

The Virginia Coastal Plain Groundwater Initiative (VCPGWI) began in 2014 and was designed to address this issue directly. In order to achieve the goals of protecting the aquifer system and providing current and future water needs for the Commonwealth, DEQ negotiated reductions in permitted withdrawal limits with the largest groundwater users in the EVGMA. Combined, these users represented approximately 80% of all permitted groundwater withdrawals within the EVGMA. Between 2015-2016, DEQ issued new permits to each of these facilities resulting in a reduction of their combined maximum annual permitted withdrawal volumes of approximately 52%. Many of these permits included a tiered reduction schedule for withdrawal limits which provides a period of time for permittees to develop alternative water sources or to increase the capacity of existing alternative water sources.

In addition, most of the permits require evaluations and ultimately, pursuit of an alternative water source, with reports submitted to DEQ on progress towards that objective. These alternative water source requirements have since become more common in groundwater withdrawal permits as a tool to assist groundwater users in areas with the potential for supply challenges in investing time and resources towards developing alternative water sources. Many of the largest groundwater users have begun working to develop alternatives water sources such as surface water withdrawals, wells in shallow aquifers, and water reuse proposals. Continuing these efforts to diversify beyond groundwater is one of the most effective tools in both protecting the aquifers and ensuring sustainable and reliable water supply for Virginians.

EVGWMA Expansion: In response to declining water levels in the Coastal Plain Aquifer system, the SWCB expanded the EVGMA[55] to include all of the portions of the Coastal Plain east of Interstate 95 that were not already included in the management area. This included the Northern Neck, the Middle Peninsula, and parts of Northern Virginia east of Interstate 95. Modifications to the Groundwater Withdrawal Regulations[56] went into effect in 2014 and provided for the issuance of groundwater withdrawal permits to existing users in the expanded management area. Permit applications were received from 122 existing users during 2014 as a result of the expansion. Through 2020, 107 existing user permits have been issued with the remainder either not ultimately requiring a permit or not eligible for the existing user pro-

[55] 9VAC25-600-20
[56] 9VAC25-610-10 et seq.

cess. Three existing user applications remain pending. The total maximum annual groundwater withdrawal volume authorized for the 107 issued existing user permits is approximately 2.54 billion gallons per year (BGY), which equates to an annualized average daily withdrawal rate of 6.95 MGD.

On the whole, this expansion allows for more comprehensive management of the Virginia Coastal Plain aquifers. Neither aquifers, nor the impacts from groundwater withdrawals, are limited by political or regulatory boundaries. Management depends on cumulative evaluation of regional impacts, and this expansion allows for a more accurate and inclusive assessment of impacts to the Potomac and other coastal plain aquifers in Virginia.

Additionally, permit requirements are one of the major mechanisms through which geotechnical investigations of Virginia's aquifers are completed. The hydrogeology in the expanded area is far less understood than in the original management area because few geophysical logs, monitoring wells, and other hydrogeological evaluations have been completed in these areas. The majority of the existing user permits require collection of geophysical logs that will greatly expand the available information about the hydrogeology of the Northern Neck and Middle Peninsula. New real-time water level monitoring wells have also been required since the expansion. These kinds of data can be used to inform refinements to the Virginia Coastal Plain Hydrogeologic Framework [57], and also form the basis for management decisions, as well as model calibration and development.

Compliance Assistance Framework: In 2017, DEQ implemented a compliance assistance framework that involved outreach in both the EVGMA and Eastern Shore Groundwater Management Area (ESGMA) aimed at groundwater users that may require a groundwater withdrawal permit but are not currently aware or otherwise not in compliance with the permit requirement. This process was intended to assist such users in applying for and receiving a groundwater withdrawal permit. As a result of this initiative, DEQ received over 60 applications from unpermitted groundwater users seeking to obtain groundwater withdrawal permits. The majority of these applications were from poultry facilities on the Eastern Shore, while the remainder were from schools and other small agricultural operations. Forty-five draft permits for poultry farms on the Eastern Shore were reviewed and approved by the SWCB on December 13, 2019, and issued on December 18, 2019. Addressing unpermitted groundwater use is an ongoing objective for DEQ and while this effort was successful in bringing unpermitted use associated with poultry farming into compliance on the Eastern Shore, efforts to identify unpermitted groundwater use within management areas will continue as resources allow.

Eastern Shore General Permit: One of the byproducts of the efforts to permit poultry farms on the Eastern Shore was increased interest by the public and other stakeholders in the evaluation of the surficial aquifer, or Columbia Aquifer, as an alternative to the confined Yorktown-Eastover Aquifer. Given the importance of the Yorktown-Eastover aquifer system as a sole source aquifer, the SWCB required inclusion of a special condition in each of the groundwater withdrawal permits for poultry facilities issued as a result of the previously discussed Compliance Assistance Framework to conduct an alternative source investigation of the surficial aquifer to evaluate whether it can provide all or part of the water supply needs for the permitted facility in the future. However, these requirements applied only to those permitted farms.

Legislation enacted following the 2019 General Assembly Session (2019 Va. Acts Ch. 755) directed the SWCB to adopt regulations providing incentives, such as an expedited general permit process, for the withdrawal of groundwater from the surficial aquifer, rather than the confined aquifer, in the Eastern Shore Groundwater Management Area. In 2019, DEQ published a Notice of Intended Regulatory Action (NOIRA) to establish the framework for the issuance of a general permit for withdrawals from the surficial aquifer in the ESGMA. DEQ convened and completed a Regulatory Advisory Panel (RAP) in 2020. The proposed draft revisions to the groundwater withdrawal permitting regulation and general permit were approved by the SWCB.

A public comment period and public hearing will be held in early 2021. The SWCB will then review the final regulation. If approved, the new general permit regulation will provide a quick and efficient path for a groundwater withdrawal permit for those users with groundwater needs that can be met using the surficial aquifer on the Eastern Shore. This is significant as it will be the first general permit regulation for groundwater withdrawals in Virginia. However, the

[57] McFarland, E.R., and Bruce, T.S., 2006, The Virginia Coastal Plain Hydrogeologic Framework: U.S. Geological Survey Professional Paper 1731

general permit will still include permit terms, withdrawal limits, reporting requirements, and other elements found in an individual groundwater withdrawal permit.

Eastern Virginia Groundwater Advisory Committee (EVGWAC): The EVGWAC was created by the General Assembly in response to recognition of the current and future challenges in ensuring sustainability of the Potomac and other aquifers in the EVGMA. Based on a series of whole committee and workgroup meetings, the EVGWAC produced a Final Report in August of 2017.

The report identified 12 recommendations: 1) Commonwealth should support storage, recovery, and recharge projects (such as SWIFT), 2) Commonwealth should promote the development of the list of alternative water sources and solutions included in the report, 3) lengthening the maximum groundwater permit term to 15 years, 4) General Assembly should establish additional incentives for voluntary regional planning, 5) General Assembly should create incentives for local governments and well owners to connect to surface water sources, 6) General Assembly should require new non-agricultural irrigation wells be screened in water table where able, 7) General Assembly should develop a statement of regulatory intent to encourage use of ponds and stormwater ponds for irrigation/agriculture, 8) DEQ should establish an annual "State of the Water Resources" forum, 9) General Assembly should authorize DEQ to develop a groundwater banking system, 10) General Assembly should direct DEQ with a timeline and resources to create a framework for groundwater trading, 11) General Assembly should provide funding to ensure a robust groundwater management program (see report for identified priorities), and 12) General Assembly should fund essential operation costs for DEQ to manage groundwater.

Many of these recommendations have been acted on by DEQ or the General Assembly as described in the 2020 State Plan and in the annual publication of the Annual Water Resources Report. The EVGWAC was reestablished by the General Assembly effective July 1, 2020 and will provide annual reports on these recommendations and other topics covered by the committee. More information and the latest annual report issued by the EVGWAC can be found on the DEQ Website.

Groundwater Science: In order for science based or evidence based decision-making to be valid, the science and data that drives resource management decision making must remain current and relevant. Significant staff and financial resources are invested in this area.

> **Evidence Based Decision-Making** is a process for making decisions that is grounded in the best available research evidence and informed by evidence or data from the field. DEQ prioritizes advancing the state of available research and evidence on which to base management decisions.

Below are several examples of projects related to groundwater and hydrogeology science/data undertaken by DEQ and its partners:

- A two year cooperative effort with the USGS to characterize the hydrogeology of Virginia's Eastern Shore was completed in 2019. The "Hydrogeologic Framework of the Virginia Eastern Shore"[58] is a major revision of the hydrostratigraphy, permeability, and regional groundwater chloride distribution of the Virginia Eastern Shore. Information in the new framework will be used to revise an existing regional groundwater flow model, and to assist with groundwater withdrawal and management decisions pertaining to agricultural and municipal groundwater demands.

  A large component of the research associated with describing the hydrogeology of the Eastern Shore is the delineation and hydrologic description of ancient paleochannels (remnants of ancient river beds) that transect the subsurface of the Eastern Shore. These paleochannels are important because they are thought to significantly influence storage and movement within the regional groundwater system. In addition, collection of well cutting and geophysical logs were required as a result of the groundwater withdrawal permit process for 45 poultry facilities on the Eastern Shore. DEQ geologists oversaw and interpreted these data, which were then incorporated into this significant revision of the Eastern Shore Hydrogeologic Framework.

[58] McFarland, E.R., and Beach, T.A., 2019, Hydrogeologic Framework of the Virginia Eastern Shore: U.S. Geological Survey Scientific Investigations Report 2019–5093

[59] McFarland, E.R., and Bruce, T.S., 2006, The Virginia Coastal Plain Hydrogeologic Framework: U.S. Geological Survey Professional Paper 1731

- A similar effort is also underway to revise the "The Virginia Coastal Plain Hydrogeologic Framework"[59] using geophysical logs and other data collected as a result of groundwater withdrawal permits in the southern portions of the EVGMA. This revision will focus on refining the delineation of the unconfined and confined aquifers in the area south of the James River and is expected to be published by the end of 2021.

- DEQ has implemented a schedule for calibrating both the VAHydro Eastern Shore Model and VAHydro Coastal Plain Model on a regular basis. Working with technical contractor Aquaveo, each model is evaluated by comparing simulated water levels to observed water levels in monitoring wells. Updates to the hydrogeologic frameworks described above are also evaluated. This periodic task results in continuous improvement and is a critical quality assurance process for any model.

- Between 2015-2020, DEQ geologists continued to maintain and expand the State Observation Well Network as resources allowed and as observation well installations were required by groundwater withdrawal permits. The observation well network is critical to evaluating the short and long-term impacts of withdrawals on water levels in aquifers and calibrating groundwater models. DEQ is one of the few states that has been certified to collect and report groundwater data directly to USGS, and all monitoring data is stored in the USGS National Water Information System (NWIS). There are currently 270 monitoring wells in the network, many of which are real-time, which means they report water levels directly to the web at 15 minutes intervals.

  DEQ has added several new real-time observations wells in the last five years including a nest of wells near the Town of Smithfield, an area with significant groundwater demands. Several wells near West Rock's West Point Paper Mill were converted to real-time state monitoring wells between 2019-2020. In upcoming years, several additional observation well installations are planned including installations near the International Paper Franklin Mill, near Courtland, Virginia, and in Middlesex County. These installations will provide critical data for evaluating aquifer response in areas with significant existing or increasing groundwater demands.

  At the same time, financial and staff resources are limited and the size of the network is constrained by these limitations. In addition to collecting water levels and water quality samples, DEQ staff must also maintain each of the wells in the network. DEQ has begun an initiative to evaluate all wells in the state network to identify wells that require repair, as well as those that may warrant abandonment and removal from the network. Reducing the size of the network is one goal of this initiative as resources are currently not sufficient to maintain all wells while maintaining the capacity for new installations that may be required by groundwater withdrawal permits.

- In 2013, an Ambient Groundwater Quality Program was established to characterize the quality of groundwater throughout the Commonwealth of Virginia. This involved collecting groundwater quality data as resources allow. DEQ resources currently allow for the collection and analysis of no more than 40 groundwater samples statewide each year. As described in the Ambient Groundwater Quality Monitoring Strategy, which is available upon request, the program establishes a groundwater quality baseline across the state, identifies areas of potential groundwater quality concern, and monitors the changes in groundwater quality over time as resources allow.

  Between 2015-2020, the Ambient Groundwater Quality Program continued to focus on the collection of groundwater samples from wells in the trend well network. Trend wells were selected for sampling on a quarterly basis to monitor both for saltwater "upconing" and the more regional phenomena known as salt water intrusion, both occurrences where groundwater with a higher chloride concentration moves into areas with lower chloride concentrations, which can be driven by groundwater withdrawals.

- DEQ geologists also worked to advance understanding of the fractured rock aquifer systems located west of Interstate 95. Groundwater use in these areas of the state is also significant, but it is far more difficult to evaluate the sustainability of the resource in comparison to the Coastal Plain Aquifer System which can be evaluated on a regional scale. The quality and quantity of groundwater from fractured rock aquifers can vary significantly over short distances due to the interconnectivity, or

lack thereof, of the fractures. Evaluating these aquifers must be done on a more localized scale, and is resource intensive. However, particularly in areas with dense groundwater demands and the potential for resource conflicts, these kinds of evaluations are necessary.

DEQ worked with the USGS on a 2015 publication which characterized the hydrogeology and simulated groundwater flow in the Piedmont and Blue Ridge Physiographic Provinces, specifically in Bedford County.[60] DEQ is also cooperating with the USGS on an ongoing study to characterize the groundwater resources in Fauqiuer County. DEQ collected and analyzed borehole data from the Culpeper Mesozoic Basin in Fauquier County in support of this study. A better understanding of groundwater storage and availability in these complex geologic settings is needed to sustainably manage the resource and to help ensure water availability for these systems. Such studies are resource intensive and their conclusions are often local rather than regional. As groundwater demands continue to increase in these fractured rock aquifers, resources must be allocated to better understanding the hydrogeology of these systems. DEQ staff and other resources are often constrained, limiting the work that can be completed in these areas.

- DEQ also provides a leadership role in the Potomac Aquifer Recharge Oversight Committee (PAROC), and has coordinated closely with HRSD related to the SWIFT injection pilot project. DEQ has reviewed and evaluated underground injection control (UIC) proposals for James River Plant, reviewed well cuttings and characterized formations at the pilot site, and coordinated with HRSD during its efforts to fund, construct, and implement monitoring with a new extensometer that will allow fine measurement of land surface changes in response to injection. DEQ will continue to work with HRSD to provide expertise and feedback as the SWIFT project is implemented.

- Over the last five years, DEQ geologists completed a compilation of legacy and modern data on the characteristics of natural spring resources throughout the Commonwealth of Virginia. A final geodatabase was developed containing approximately 1,640 springs with roughly 5,900 field measurement events, and 2,900 laboratory water quality sampling events. A publication about the spatial and temporal characteristics of groundwater discharges from springs throughout the state is in process.

5.1.2 Surface Water Management

Surface water is used to meet the majority of demand in Virginia. Although groundwater demand is projected to grow more quickly than surface water demand, areas where surface water demand is increasing are often also areas where existing demands on the resource are already high, such as highly developed urban and suburban areas. DEQ is tasked with managing surface water such that impacts to beneficial uses are minimized; permitting and planning provide the foundation for this task. However, DEQ has invested significant staff resources to advance the tools and science that add to that foundation. The following are the major efforts that DEQ has undertaken in the last five years related to surface water management:

Surface Water Withdrawal Permitting: DEQ continues to permit surface water withdrawals for projects small and large across Virginia. In recent years, permits have been issued for existing or new projects that range from pump storage reservoirs to small surface water intakes, each requiring modeling of potential impacts, significant coordination with resource agencies, and public outreach. Permit applications for previously novel projects are becoming more common. For example, DEQ has permitted several freshwater tidal intakes for large municipalities in recent years and has received several more requests for similar projects. As part of the Federal Energy Regulatory Commission (FERC) relicensure process, DEQ will need to process VWP permits for 10 hydroelectric power facilities in Virginia in the next five years. In summary, the number of applications for surface water withdrawals has increased over time, but the types of projects under review are becoming more diverse and in the case of the FERC hydroelectric projects, are increasingly complex.

Surface Water Modeling: DEQ's surface water model has been improved both in capability and efficiency in the last five years. DEQ recently integrated

[60] McCoy, K.J., White, B.A., Yager, R.M., and Harlow, G.E., Jr., 2015, Hydrogeology and simulation of groundwater flow in fractured-rock aquifers of the Piedmont and Blue Ridge Physiographic Provinces, Bedford County, Virginia: U.S. Geological Survey Scientific Investigations Report 2015–5113

the surface water model into the VAHydro information management system. Integration into VAHydro makes the model more accessible, allowing permit writers and other staff to use it more effectively. It has also facilitated an ongoing effort to develop automated visualizations and analysis products that are auto-generated each time the model is run. This effort is being worked on in partnership with Virginia Tech. The DEQ partnership with Virginia Tech also developed an automated "hydrologic analysis toolkit" to perform model error analysis (MEA), and complete Cumulative Impact Analysis (CIA) for use in permitting and water supply planning throughout Virginia. This toolkit was instrumental in completing the CIA's for the State Plan. This work on the "back-end" may appear to primarily impact DEQ staff, but the goal of these efforts is to increase efficiency and consistency when modeling is being completed for the regulated community or the general public.

The surface water model itself has also been updated in a variety of ways. The 2020 model is built on a rainfall-evaporation-runoff (RER) time-series which runs from January 1, 1984 to December 31, 2014 in the Chesapeake Bay watershed drainage area, a significant advancement over the previous model time span of January 1, 1984 to December 31, 2005. Extensive efforts by DEQ staff were undertaken over the past year to integrate water supply planning datasets with annual reporting and permitting components in VAHydro. This resulted in improved spatial accuracy of withdrawal locations, which allows DEQ to analyze current and projected impacts in HUC10 sub-watersheds, a 10 fold increase in resolution over analyses in the 2015 State Plan. These efforts also facilitated modeling monthly use patterns based on historical reported data.

The Chesapeake Bay Program released the Phase 6 watershed model in early 2018, and this was incorporated into the VAHydro model in preparation for the modeling completed for the State Plan. DEQ and Virginia Tech also worked together to update land use in the Southern Rivers, or the area outside the Chesapeake Bay Basin, to contain the 2016 VGIN aerial imagery and land cover data sets. Finally, as discussed in detail in Chapter 4, several new scenarios were developed to broaden the kinds of analysis that can be done using the model. These include climate scenarios, an exempt user scenario, and some new metrics including a facility level metric (potential unmet demand).

Advancing the model is supportive of the statewide modeling required for the State Plan, but also builds capabilities for better and more efficient permit modeling. That feedback goes both ways; as new surface water withdrawal applications are submitted, project scale models are developed and incorporated into the overall statewide model. This ensures that permitted withdrawals, whether direct intakes or complex pump storage projects, are accurately reflected in future cumulative evaluations. Models are intended to be evaluated and updated over-time as new data is collected. DEQ has invested considerable resources in recent years in model development, both for surface water and groundwater.

Surface Water Science: DEQ has developed a strong cooperative relationship with USGS and the Virginia Tech Department of Biological Systems Engineering, which has led to several significant publications. 2020 marked the completion of a long-term project to develop a method to relate widely available hydrologic and ecological monitoring data. The approach combines state planning and reporting databases, multiple river and habitat models, and biometric assessment of fish and benthic monitoring data to develop a more geo-spatially specific understanding of the relative risk to aquatic life resulting from surface water withdrawals in Virginia. Two professional papers outlining project methods, results and potential management implications were published in the Journal of the American Water Resources Association in late 2020.[61][62] As detailed in Chapter 4, Section 4.2.8.4, these results were incorporated into the State Plan as the primary means to evaluate impacts to aquatic life from withdrawals. More work remains to be done in this area and DEQ expects to work closely with resource agencies and others stakeholders to determine how to build upon these efforts going forward.

In 2020, Virginia Tech and DEQ also completed a long-term project to improve estimates of consumptive use in Virginia, as well as to develop a suite of tools to transfer data on water withdrawals, discharges, and consumptive use between

[61] Kleiner, J., E. Passero, R. Burgholzer, J. Rapp, and D. Scott. 2020. "elfgen: A New Instream Flow Framework for Rapid Generation and Optimization of Flow-Ecology Relations." Journal of the American Water Resources Association 56 (6): 949–966.

[62] Rapp, J.L., R. Burgholzer, J. Kleiner, D. Scott, and E. Passero. 2020. "Application of a New Species-Richness Based Flow Ecology Framework for Assessing Flow Reduction Effects on Aquatic Communities." Journal of the American Water Resources Association 56 (6):967–980.

the National Pollutant Discharge Elimination System, VAHydro, and USGS National Water Information System (NWIS) databases. This project was funded by a USGS WUDR grant and a paper summarizing the results is currently pending publication in the "Journal of Water Resources Planning and Management." This research was also integrated into the cumulative impact modeling associated with the 2020 State Plan to better account for consumptive use, as described in Chapter 4. Evaluating consumptive use is critical for creating an accurate surface water budget and determining water availability in different locations across the Commonwealth.

A USGS WUDR grant award was also received by DEQ in 2020 based on a proposal to develop better estimates of agricultural water use. This project is also being completed in cooperation with the Virginia Tech Department of Biological Systems Engineering. One of the major challenges localities had when preparing water supply plans was collecting information on water use from agricultural water users, and the majority of the plans have limited estimates for agricultural water use. Agricultural water use is also under reported, although DEQ continues to work to engage with agricultural communities to improve awareness of reporting requirements annually. That remains a long-term process. This project helps address these gaps by improving estimates of water used for irrigation at the county level using USDA Agricultural Census data and DEQ water withdrawal reporting data. Ultimately these data could be useful both in a planning perspective as well as for informing modeling. While this project is still in the beginning phases, it is another example of where focused research can actively support management of the resource.

DEQ is also part of the Virginia Drought Monitoring Task Force (DMTF), which is the organization responsible for making drought declarations. DEQ monitors and evaluates hydrologic and water supply conditions based on guidance in the Virginia Drought Assessment and Response Plan. Resources have also been invested in the science of predicting droughts. DEQ worked with USGS on a project to develop methods for estimating drought probabilities, the results of which were published in 2014[63]. This work showed the majority of summer time base flows are the result of "recharge" rainfall from prior winters; therefore, extreme droughts are most likely to occur in the summer/fall following an extremely dry winter. Each spring, DEQ completes an analysis of winter-time recharge to produce an estimate of the likelihood of moderate to extreme drought conditions in the upcoming summer. These assessments identify watersheds and regions of the state with elevated likelihood of drought in order to prioritize monitoring, analysis, and potential for permit support needs.

5.1.3 Water Supply Planning and Annual Reporting

Water Supply Plan Updates: Between 2015 and 2020, DEQ has continued to work closely with localities and planning programs in support of their planning efforts. For the 2018 five year review cycle, all localities in Virginia reviewed their contributions to regional or local water supply plans and addressed compliance conditions by the required deadline. This was a significant administrative effort by the program which began after the publication of the 2015 State Plan. DEQ organized meetings with each planning program to cover the results of the 2015 State Plan and to identify compliance items that were required for the water supply plan review. All plans were determined to be in compliance prior to the deadline. More importantly, this effort resulted in numerous updates to locality water use information and demand projections which were incorporated into the 2020 State Plan.

In preparation for the 2020 State Plan, DEQ also completed a comprehensive quality control evaluation of existing sources and demand information, demand projections, withdrawal reporting, and overall database accuracy. This effort involved developing a series of scripted automated checks to flag potential issues, as well as significant staff time to identify and correct issues where found. This is an effort that will be completed on a reoccurring cycle as each year a large amount of new data is submitted to VAHydro and must be checked.

VAHydro Development: The development and upkeep of the VAHydro system is ongoing. This system is described in more detail previously, but in summary it is a web based system that links modules pertaining to water withdrawal permitting, water supply planning, water withdrawal reporting, GW-2 well registration, and drought monitoring/modeling of both surface water and groundwater. The water supply planning module was developed over several years and launched in 2017. The module allows localities to access their plan information, submit new

[63] Austin, S.H., 2014, Methods for estimating drought streamflow probabilities for Virginia streams: U.S. Geological Survey Scientific Investigations Report 2014–5145

information, and see other information that may be relevant to their facilities, whether that be annual reporting or permits. The intention is that this tool will facilitate a planning process that is iterative, with updates occurring at more frequent intervals than the regulatory deadlines.

DEQ developed a module that allows direct entry of well construction information by well drillers statewide. This database is currently being used by well driller's constructing small private wells as well as larger permitted wells. Drillers can login to VAHydro and enter information from a GW-2 (Water Well Completion Report), which both VDH and DEQ can then access. Driller's can also review their previous submittals and keep track of their well construction information over time. This module has proven successful with the number of drillers participating increasing annually. Once entered, this data is readily available to incorporate into analysis and can be easily exported when a request for well information is received. Well construction information for more than 8,000 wells has been submitted through VAHydro to date.

DEQ is also developing a pilot to allow groundwater withdrawal permittees to enter their quarterly reporting online. This module will cut down on DEQ staff time required to enter groundwater withdrawal reporting into the database and will be quicker for permittees than the current submittal process. This new module is expected to launch in 2021. Permittees will still be allowed to submit via paper reports if preferred.

Annual Withdrawal Reporting: DEQ also administers the annual withdrawal reporting program. Over 1,500 facilities have historically reported their annual water use. Each year, staff resources are required to address facilities that fail to report on time. In addition, as resources allow, staff conduct outreach and contact new facilities that may meet the permitting thresholds.

A new requirement in the reporting regulation this year is that facilities must provide the location of their withdrawal. Historically this was not required and therefore many facilities lacked spatial data for their intakes or wells. DEQ will contact facilities that lack location info and work with them to update their facility information in the database.

5.2 Future Priorities in Water Resource Management

Managing water resources is a complex task. Developing the programmatic, technical, and scientific foundations for management requires continuous investment of time and resources. Complexity also comes from the diverse group of stakeholders that are brought together through their use of water resources. These stakeholders often have differing interests, although the overarching goal of managing resources sustainably is generally shared. The following section discusses several priorities identified through the development of the State Plan. Addressing these priorities may require input and effort from the full range of stakeholders: state and local government, private companies and corporations, water authorities, planning districts, citizens, and more.

5.2.1 Amendments to the Local and Regional Water Supply Planning Regulation:

One of the objectives of the Local and Regional Water Supply Planning program is to establish a process that facilitates cross-jurisdictional planning that takes into consideration a cumulative understanding of shared water resources within a given region. In practice, the extent to which cross-jurisdictional planning for water supply has been implemented has varied across the state and from locality to locality. One of the primary challenges identified in the Joint Legislative Audit and Review Commission's 2016 report on the Effectiveness of Virginia's Water Resource Planning and Management was that water supply planning programs were not sufficiently regional and that planning programs did not always align with common sources of water.

Cross-jurisdictional planning can help address disparities in access to water and enable collaboration on large water supply projects that may otherwise be too costly without a regional approach.

Legislation enacted following the 2020 General Assembly Session (2020 Va. Acts Ch. 1105) addresses this challenge directly by requiring the SWCB to adopt regulations designating regional planning areas based primarily on river basins, to encourage the development of cross-jurisdictional water supply projects, and to estimate the risk that each locality and region in the Commonwealth will experience water supply shortfalls. This law also directs localities to participate in cross-jurisdictional, coordinated water resource planning, and to develop a single water supply plan for each regional planning area. A Notice of Intended Regulatory Action (NOIRA) was published in June, 2021. A Regulatory Advisory Panel (RAP) made up of a variety of stakeholders will be used to develop recommended regulation amendments for SWCB consideration through the collaborative approach of regulatory negotiation and consensus

5.2.2 Evaluating Impacts from Exempt and Unpermitted Water Users:

Evaluating and addressing impacts from water users that are statutorily exempt from the requirement to obtain a withdrawal permit, or otherwise unpermitted, continues to be a challenge in managing both surface water and groundwater. Exempt and unpermitted surface water withdrawals made up approximately 75% of total reported surface water withdrawals in 2019.[64] Exempt in this context means a surface water facility that is exempt pursuant to the criteria in Va. Code § 62.1-44.15:22B or 9VAC25-210-310. One of the challenges in evaluating impacts from exempt surface water users is the multiple types of data cited to support exempt demand amounts ranging from the capacity of the intake to the safe yield of the source. There is considerable variation across these values for any given facility, and this variation only increases when evaluating the cumulative impact of a stream with multiple exempt users.

As noted previously, in order to effectively manage surface water resources and address the uncertainty related to these demands, DEQ determined the most conservative, or maximum possible, demand should be evaluated in this scenario. However, DEQ does not agree that the maximum values used in this scenario represent an allocation for, or the expectation of, a future withdrawal of that volume; nor does DEQ concede that any particular exempt user is necessarily entitled to withdraw any particular maximum value used in this scenario.

To summarize the results from this analysis, when evaluated cumulatively, and even in some cases indi-

[64] "2019 Annual Report on the Status of Virginia's Water Resources."

vidually, the maximum possible exempt demands are not sustainable during drought conditions regularly experienced in Virginia today; the potential for worsening droughts in response to climate change would only exacerbate this issue. If facilities were to operate at the maximum possible exempt demand, issuance of VWP applications for new withdrawals would be unlikely or even impossible in portions of every major river basin in Virginia due to unacceptable impacts to downstream beneficial uses which includes existing water users, aquatic life, and the maintenance of water quality.

A process to incorporate the evaluation of potential exempt user demands into the VWP permit application review process needs to be developed. One other existing tool for addressing impacts from exempt surface water use is to establish a Surface Water Management Area.[65] However, this tool is focused primarily around periods of low flow or drought. Therefore it may not be an effective tool for managing impacts to aquatic life, as critical life cycle stages such as spawning can occur in times of the year when droughts are not common. Any approach to address this issue must consider the full range of beneficial uses DEQ is tasked with protecting.

The proportion of groundwater use that is exempt from permitting, or otherwise unpermitted, although smaller in absolute terms than exempt surface water demands, is more difficult to estimate since much of it comes from domestic wells with no requirement to report withdrawals. There are few exemptions from the requirement to obtain a permit for groundwater withdrawals in a declared groundwater management area, and therefore those that are considered unpermitted are generally either very small users such as domestic/residential wells, or facilities that do withdraw enough groundwater to require a permit but have not obtained one. Additionally, groundwater use outside of declared groundwater management areas is unpermitted. Particularly in the groundwater management areas, continuing to improve estimates of domestic use remains a key goal given the increasing demands on the aquifer system by the growing population of homeowners with individual wells.

DEQ has worked with USGS to improve estimates of historic domestic groundwater use and these estimates contribute to the total pumping used for groundwater modeling. DEQ continues to make incremental progress on this need as resources and authority allow. The groundwater scenarios completed for the 2020 State Plan represent an additional approach in estimating domestic use based on water supply plan projections that account for the local expectations of growth (see Chapter 4, Section 4.3). DEQ also continues to collect private well construction information that provides important context for domestic groundwater use trends statewide. Continuing to refine estimates of domestic use in groundwater management areas is critical to understanding how unpermitted groundwater use, in conjunction with permitted use, will impact long-term water levels in aquifers like the Potomac Aquifer. This is an area that will require ongoing investment of resources for DEQ and other stakeholders.

In contrast to residential or small groundwater users that are under the permit threshold, DEQ identifies unpermitted groundwater users that do meet the permit threshold on a frequent basis and brings such facilities into compliance. Addressing groundwater withdrawn without a permit within a groundwater management area by facilities in this category continues to be a DEQ priority.

5.2.3 Climate Change and Resource Planning:

Climate change is an important emerging issue that is expected to significantly affect future water availability. For the first time, the surface water modeling completed for the 2020 State Plan also features three climate change scenarios that use a range of meteorological inputs. The three climate scenarios in the State Plan are covered in more detail in Chapter 4, 4.2.4, but in short these three scenarios can be characterized as the "wet", "median", and "dry", representing the 90th, 50th, and 10th percentiles in temperature and precipitation respectively. The simulated meteorological conditions for each scenario are within the range of outcomes from climate ensemble models in Virginia. The dry climate scenario presents the most significant challenges with regards to water supply, as detailed in Chapter 4, Section 4.2.8.2, for it suggests the potential for droughts to become more severe, even if they remain uncommon. Planning at regional and local levels should begin to evaluate how that may impact water supply reliability long-term. State level management must also consider the potential for impacts to other beneficial uses, aquatic life in particular.

[65] see 9VAC25-220

Given the **potential for future droughts** to be more severe than those experienced in the past, the development of processes to incorporate climate change evaluation into existing management actions including water withdrawal permitting and water supply plan review is increasingly necessary.

Currently, DEQ's climate scenarios cover the Chesapeake Bay watershed portions of Virginia, which is where climate change data is available. Expanding the scenarios to cover the river basins in the "Southern Rivers" portion of Virginia outside the Chesapeake Bay watershed area is a high priority, although this task is dependent on available financial and staff resources. As the discussion in Chapter 4 makes clear, one trend in the climate models appears to be that Southern Virginia may be drier on average than areas further North. Therefore it is important that the capability to model how climate change impacts streamflows in this area is developed to better document this trend, and to ensure consistent statewide coverage of this kind of analysis. Additionally, given that much of the demand in the eastern portions of Southern Virginia Coastal Plain relies on a limited supply of groundwater, it will be critical to understand how surface water resources in this region may be impacted by climate change as they are increasingly evaluated as an alternative to groundwater.

5.2.4 Evaluating Tidal Fresh Surface Water Withdrawals

Groundwater limitations in the Coastal Plain have led water users to consider alternatives that they previously considered to be cost prohibitive. Recently, several applications for the construction of tidal fresh surface water withdrawal intakes have been received and are under review by DEQ. Examples have been proposed in the Rappahannock, Pamunkey, Chickahominy, and Appomattox rivers. These intakes would be constructed in a tidally influenced section of a river that is nonetheless still primarily freshwater, with relatively low salinity compared to stretches closer to the Chesapeake Bay.

The water quality in a tidal system is dynamic and the amount of available freshwater can improve or reduce local water quality. Reducing freshwater inflows into a tidal system can shift the gradient where low salinity and high salinity water combine further upstream. Even a moderate increase in salinity can impact the viability of a withdrawal designed to treat primarily freshwater, but it can also impact aquatic species sensitive to changes in salinity during critical periods such as spawning. Sea level rise that drives increases in salinity concentrations further upstream is a compounding factor as well.

DEQ's non-tidal model was not designed to model water quality changes in a tidal system. Given the growing interest in tidal fresh withdrawals, developing an in-house model to evaluate water quality impacts from upstream withdrawals would allow evaluations comparable to those completed for non-tidal projects. Additional funding would be required to support this development. In addition, developing procedures for both modeling and evaluating tidal fresh withdrawal projects will be necessary to ensure a consistent and clear application review process.

5.2.5 Eastern Virginia Groundwater Management Area - Long-term Supply

One of the long running challenges that DEQ has worked to address is the historic over allocation of groundwater from the Coastal Plain aquifer system, particularly from the Potomac Aquifer. A long-term decline in water levels required DEQ to take the actions described earlier, including negotiating an average reduction of 52% in permit withdrawal limits for the largest groundwater users in the Eastern Virginia Groundwater Management Area. As actual use has dropped as well, water levels in the Potomac Aquifer have begun to stabilize in some areas of the Coastal Plain. Yet even with reductions in permit limits, increasing domestic and other unpermitted use still results in areas of the Potomac Aquifer where water levels are simulated to fall below the critical surface[66] in the Total Permitted Scenario[67]. In practical terms, DEQ expects continued challenges in issuing both new and existing permits in some parts of the EVGMA. The scenarios completed using the WSP demand projections for the 2020 State Plan suggest that increasing domestic use in combination

[66] The critical surface is defined as 80% of the distance between the land surface and the top of the aquifer.

[67] The Total Permitted scenario is a cumulative impact analysis groundwater simulation completed annually to predict the future impacts of all permitted withdrawals on confined aquifer water levels within a groundwater management area. DEQ maintains a Total Permitted scenario for both the Eastern Virginia and Eastern Shore groundwater management areas for the purpose of evaluating groundwater withdrawal applications. The Total Permitted scenario is updated each year to reflect changes in permit limits; the scenario also includes demands for domestic/exempt groundwater use and out-of-state use based on USGS/DEQ estimates.

with existing permitted use could increase the extent of where those challenges occur.

Managing the Coastal Plain Aquifer System will require an adaptive approach that regularly reviews existing management strategies, incorporates new data, and where necessary revises and implements new strategies.

There is evidence to suggest that when considering existing surface water capacity in conjunction with aquifer capacity, Virginia could potentially meet long-term needs in the EVGMA, if existing sources were managed more regionally and efficiently. A 2014 report on Coastal Plain aquifer depletion completed for DEQ by Virginia Tech[68] suggests that per capita and total water use in the Hampton Roads region is decreasing. The report concludes that existing surface water sources alone in this region could be sufficient to meet future demands. The limiting factors are the cost of creating efficient interconnected distribution systems across localities and encouraging regional cost sharing of these projects.

Emphasizing regional planning as a means to take better advantage of existing and potential sources is one of the major goals of the upcoming regulatory changes to the water supply planning regulation. The Hampton Roads Planning District Commission (HRPDC), which covers much of the southern portion of the Coastal Plain, is one of the largest and most complex examples of the regional water supply planning process, and shows the potential in such processes. The reconvening of the Eastern Virginia Groundwater Management Advisory Committee[69] provides a forum to continue to investigate ways to improve management of groundwater in Eastern Virginia. Recent successes in reducing water use and the SWIFT pilot program offer good reasons for cautious optimism, but there is more work ahead for DEQ and the many stakeholders that are invested in solving this issue.

5.2.6 Funding Challenges

DEQ commits significant staffing and financial resources to ensure the programs discussed throughout the State Plan are supported by current data and science. Over time, these programs have grown more complex as regulations have changed and new responsibilities have been added. Often programs have had to find ways to manage new responsibilities without additional funding for staffing or technical services. Additional staffing and funding remains a critical need.

5.2.7 Continuing the Work of the State Water Resources Plan

The 2020 State Plan, which is the second iteration of this ongoing process, remains very much a work in progress. The ultimate intention of the State Plan is that it be less a large document published at five year intervals, and more of a reflection of an ongoing process to ensure that the waters of the state continue to provide adequate water supply and other beneficial uses for all Virginians, even in the face of changing conditions. DEQ believes that the work that provides the foundation for this State Plan supports efforts by all stakeholders to realize this goal.

DEQ has developed new ways to simulate the complex inputs and outputs in Virginia's surface and groundwater resource systems, visualize effects on these systems, make trade-offs among beneficial water uses more transparent, and provide the underlying data to those that want to build on the analysis. At the same time, greater local government use of VAHydro as a tool for planning can mean reduced overall costs to planning programs, and provides a means to keep data sets more current than in the past. Each of these aspects brings the State Plan closer to being the tool it is intended to be, and DEQ looks forward to continuing this work well after publication.

[68] Stephenson, S. K. (2014). An Economic Investigation of the Economic Impacts of Coastal Plain Aquifer Depletion and Actions That May Be Needed to Maintain Longterm Availability and Productivity.
[69] Eastern Virginia Groundwater Management Advisory Committee - DEQ Website

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A Minor Basin Focuses

Appendix A includes 20 distinct analyses focusing on each of the minor basins listed below. Minor Basins are further subdivisions of the major river basins in Virginia, and vary in size from around 900 mi2 to 6,000 mi2 and contain roughly 1-3 HUC8 units. For each minor basin the following is included: an overview of current and projected demands for the basin, results of the surface water and groundwater cumulative impact analysis (as applicable), and an overview of the major trends or results identified in that analysis. These summaries are intended as a resource for a range of stakeholders: localities, water users, and the public. It provides information that may be useful for, among other things, resource planning, managing a water system, or learning more about water use and impacts in an area of interest. In addition, the underlying data that informs these sections is included as an appendix to the State Plan, with an accompanying data dictionary that explains what the data is and means.

Click on the blue links beside each minor basin to view that section:

- Big Sandy - A.1
- Eastern Shore - A.2
- James Appomattox - A.3
- Upper James - A.4
- Middle James - A.5
- Lower James - A.6
- Meherrin Nottoway - A.7
- New River - A.8
- Roanoke Dan - A.9
- Roanoke River - A.10
- Potomac Shenandoah - A.11
- Upper Potomac - A.12
- Middle Potomac - A.13
- Lower Potomac - A.14
- Upper Rappahannock - A.15
- Lower Rappahannock - A.16
- Upper Tennessee - A.17
- York Mattoponi - A.18
- York Pamunkey - A.19
- Lower York - A.20

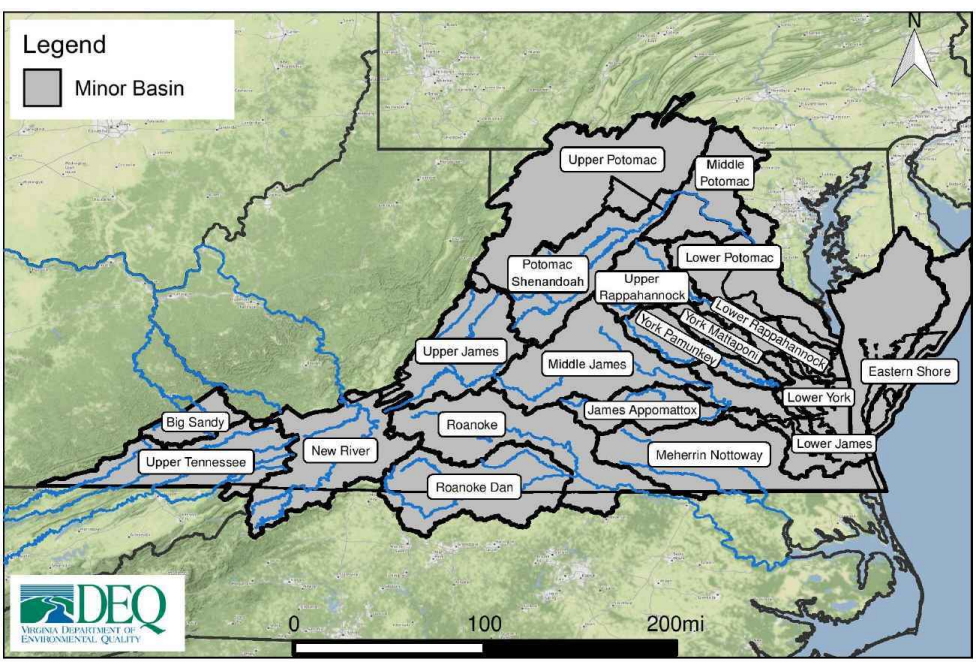

Figure 80: Minor Basin Overview

A.1 Big Sandy Minor Basin

A.1.1 Watershed Overview

The Big Sandy Minor Basin is located in southwest Virginia and is located fully or partially within the localities listed in Table 20. Buchanan and Dickenson counties contain the greatest drainage area of the basin and are located along the southern West Virginia border. The basin flows northwest with the Pound and Russell Fork rivers draining the Appalachian Plateau before crossing into Kentucky where it forms the Levisa Fork river. The Levisa and Tug Fork rivers eventually join to form the Big Sandy draining into the Ohio River. Land use and cover in the basin is almost entirely forested plateaus, steep mountainous terrain, and has very limited urban development.

The total drainage area in the Big Sandy Basin covers 952.73 square miles, making it one of the smallest basins in Virginia. The Big Sandy basin includes five rural localities with limited population centers in the basin; these small, rural towns include Clintwood, Grundy, and others.

Table 20: Population Trend by Locality in Big Sandy Basin

Localities	20 Year % Change
Buchanan	-31.30
Dickenson	-17.95
Russell	-16.86
Tazewell	-10.60
Wise	-8.72

A.1.2 Existing Water Sources

Major surface water sources within the basin include the John Flannagan Reservoir, Caney Creek, and the Dismal & Levisa Rivers. The John Flannagan Reservoir in Dickenson County supplies the greatest volume of water throughout the basin as a major public water supply source. Groundwater within the basin is primarily withdrawn from bedrock aquifers by small self-supplied users for residential water supplies. Both surface and groundwater sources are used throughout the basin, with surface water providing the greatest available supply.

Withdrawals within the basin are used primarily for public water supply, mining, and manufacturing operations. The location of wells and surface water intakes identified by DEQ within the basin are shown in Figure 81, which shows the limited number of wells reported to DEQ in the basin in comparison to surface water sources. This number does not include private or domestic wells.

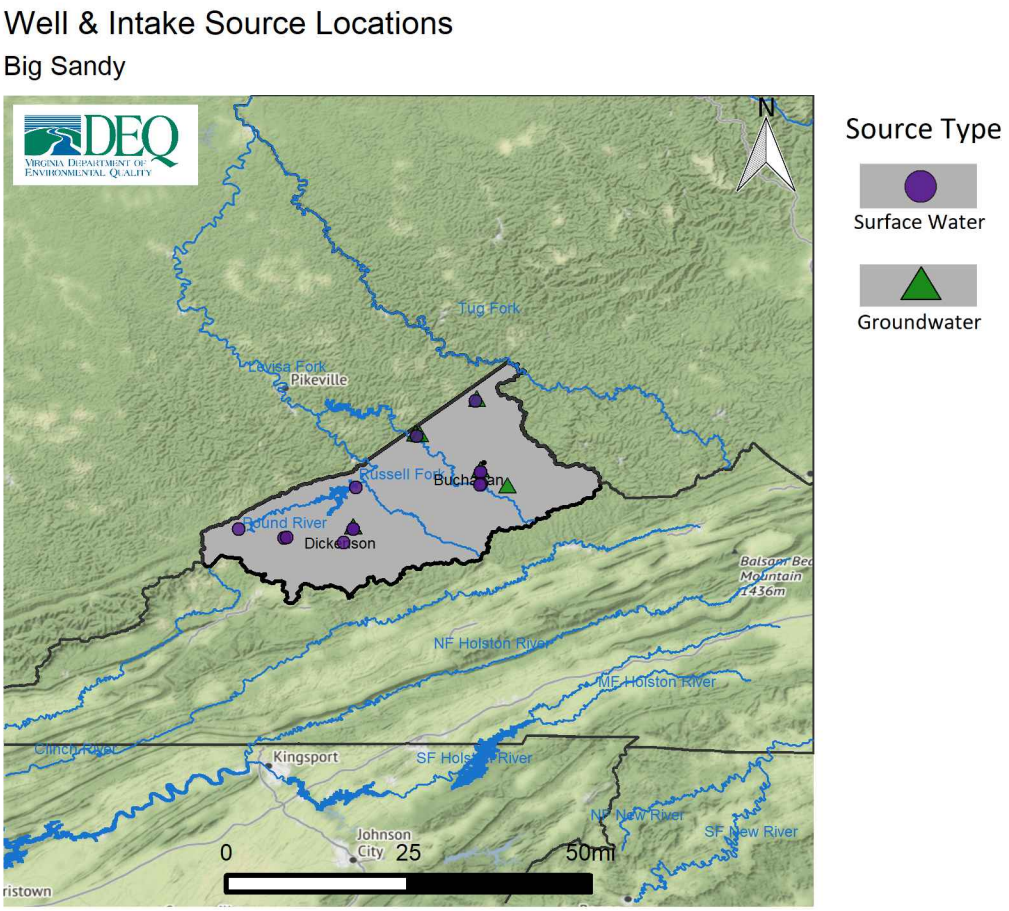

Figure 81: Spatial distribution of groundwater wells and intakes in the Big Sandy Basin

A.1.3 Existing Water Use

The following section discusses existing (current) water use within the basin, which is based on existing demand information submitted to DEQ in the water supply plans. The Big Sandy basin does not include any power generation associated withdrawals. Table 21 includes demands for all use categories in the basin.

Table 21: Summary of Big Sandy Minor Basin Water Demand by Source Type and System Type

System Type	Source Count	2020 Demand (MGD)	2030 Demand (MGD)	2040 Demand (MGD)	20 Year Percent Change
Surface Water					
Agriculture	0	0.00	0.00	0.00	0.00
CWS	2	5.58	5.82	6.06	8.53
Large SSU	7	2.41	2.51	2.62	8.65
Small SSU	N/A	0.00	0.00	0.00	0.00
Total SW	**9**	**7.99**	**8.33**	**8.68**	**8.64**
Groundwater					
Agriculture	0	0.00	0.00	0.00	0.00
CWS	1	0.36	0.38	0.41	14.03
Large SSU	4	0.25	0.30	0.34	35.75
Small SSU	N/A	0.64	0.38	0.11	-82.60
Total GW	**5**	**1.25**	**1.06**	**0.86**	**-31.20**
Total (SW + GW)					
Agriculture	0	0.00	0.00	0.00	0.00
CWS	3	5.94	6.20	6.47	8.86
Large SSU	11	2.66	2.81	2.96	11.23
Small SSU	N/A	0.64	0.38	0.11	-82.60
Minor Basin Total	**14**	**9.24**	**9.39**	**9.54**	**3.25**

* Small SSU demands are county-wide estimates of private well usage below 300,000 gallons a month. The number of private wells is not known.

The total existing demand from all surface and groundwater sources is approximately 9.24 MGD, with groundwater supplying approximately 1.25 MGD or 13.5% of total water demands. Surface water demand within the basin totals approximately 7.99 MGD, or 86.5% of current demands. Groundwater demands are primarily driven by Small Self-Supplied Users (Small SSUs), Community Water System (CWS) facilities, and limited Large Self-Supplied Users (Large SSUs). Approximately 51% of current groundwater demands are from Small SSUs, mostly private individual well owners. Surface water demands are driven from CWS and Large SSUs. CWS facilities represent approximately 69.8% of current surface water demands in the basin. Agricultural demands from surface and groundwater sources in the basin are currently unknown, with no current demands reported for this category.

The five largest withdrawals for each source type are provided in Table 22. Limited reliance on groundwater is present in the basin, with only three facilities reporting groundwater withdrawals including the Buchanan County Public Service Authority, Big Rock, and Luke mining preparation plants. Surface water demands are more significant in the basin with the largest demand occurring from the John Flannagan Reservoir for public water supplies, and from mining operations such as the Big Rock and Vansant Prep Plants. The John Flannagan Water Authority is the largest withdrawal in the basin, supplying approximately 4.86 MGD of drinking water throughout Buchanan and Dickenson counties. Currently approximately 62% of all surface water demands are from the John Flannagan Water Authority.

Table 22: Top 5 Users in 2040 by Source Type in the Big Sandy Minor Basin

Facility Name	System Type	Locality	2020 Demand (MGD)	2030 Demand (MGD)	2040 Demand (MGD)	20 Year Percent Change	% of Total Surface Water
Surface Water							
John Flannagan Water Auth WTP	CWS	Dickenson	4.86	5.16	5.45	12.14	62.79
Mcclure #1 Mine & Prep Plant	Large SSU	Dickenson	0.83	0.83	0.83	0.00	9.56
Big Rock No. 8 Prep Plant	Large SSU	Buchanan	0.5	0.61	0.71	42	8.18
Coke Ovens	Large SSU	Buchanan	0.43	0.43	0.43	0.00	4.95
Vansant No. 2 Prep Plant	Large SSU	Buchanan	0.36	0.36	0.36	0.00	4.15
Total SW			6.98	7.39	7.78	11.46	89.63
Groundwater							**% of Total Groundwater**
Buchanan Co Psa Service Area	CWS	Dickenson	0.36	0.38	0.41	13.89	47.67
Big Rock No. 8 Prep Plant	Large SSU	Buchanan	0.22	0.26	0.31	40.91	36.05
Luke Preparation Plant	Large SSU	Buchanan	0.03	0.03	0.03	0.00	3.49
Big Rock No. 7 Prep Plant	Large SSU	Buchanan	0.00	0.00	0.00	0.00	0.00
Total GW			0.61	0.67	0.75	22.95	87.21

Table 21 also provides the proportion of each use category that is supplied by either surface water or groundwater. Use categories include Community Water System (CWS), Large Self-Supplied User (Large SSU), Small Self-Supplied User (Small SSU), and Agricultural Self-Supplied User (AG). These categories are defined below. Surface water demand is primarily comprised of CWS and Large SSUs. Groundwater demand is primarily comprised of Small SSU demands. There is limited groundwater demand from CWS and Large SSUs.

The CWS category includes any public and private waterworks that serve at least 15 service connections used by year-round residents or regularly serve at least 25 year-round residents, and are regulated under the Virginia Department of Health's Waterworks Regulation (12VAC5-590). In the Big Sandy Basin, approximately 0.36 MGD of groundwater demand and 5.58 MGD of surface water demand is from CWS. The Buchanan County Public Service Authority is currently the only CWS withdrawing groundwater in the basin. Significant surface water users from this category include the John Flannagan and Pound Reservoirs. The John Flannagan Water Authority is the largest public water supplier in the basin, serving Buchanan, Dickenson, and the Town of Clintwood. The Pound Reservoir is located in Wise County and serves the Town of Pound service area with approximately 0.44 MGD.

Large SSUs include any non-CWS or AG who withdraw more than 300,000 gallons per month from a well or surface water intake. In the Big Sandy Basin, approximately 0.25 MGD of groundwater demand and 2.41 MGD of surface water demand is from Large SSUs. Both of the significant groundwater and surface water users are limited to mining operations. Significant groundwater users within this category are the Big Rock and Luke Mining operations, and are the only known Large SSUs withdrawing groundwater in the basin. The McClure mine and prep plant is the largest Large SSU user withdrawing surface water in the basin, with approximately 0.83 MGD used for mining operations. Additional surface water withdrawals from the Big Rock, Vansant, and Luke Preparation Plant mining operations comprise the remaining surface

water demands. Currently, no Large SSU irrigation, agriculture, or commercial withdrawals are known in the basin.

Small SSUs include any users who withdraw less than 300,000 gallons per month from wells. Small SSUs generally consist of residential or domestic use for those who live outside service areas and provide their own water. In the Big Sandy Basin, approximately 0.64 MGD of groundwater demand is from Small SSUs. The basin is primarily rural with most residential homeowners reliant on a private well for water supply. Localities within the basin with the greatest contribution from Small SSUs include Buchanan and Dickenson counties. Small SSUs are currently the greatest use category for groundwater in the basin.

The AG category includes crop farms, livestock operations, aquaculture and other agricultural facilities. In the Big Sandy Basin, no groundwater or surface water demand is currently demanded or projected from AG. Agricultural estimates for the basin are limited with no facilities currently reporting water demands.

A.1.4 Projected Population and Water Use

Projected Population: Trends in water use are generally driven by trends in population change or economic development. Increasing population within an area generally means increased connections for community water systems or additional demands from homeowners that construct private wells. Increasing population in an area provides an incentive for both new and expanded industrial and commercial water use. Alternatively, the addition of new economic opportunities, such as a large employer, may include additional water withdrawals for operational needs. Reviewing short and long term population projections can inform water supply planning efforts.

Table 20 shows the projected change in population by percent between 2020 and 2040 for each locality located partly or wholly within this minor basin. Population trends show dramatic reductions throughout all localities fully or partially within the basin. Buchanan County has the greatest projected population decrease with approximately 31.30% decrease in expected by 2040. Dickenson County is also projected to decrease by approximately 17.95% over the planning period. With significant reductions in population expected throughout the planning period, water demand projections show minimal growth. This is best shown in a more than 80% decrease in projected demands from small self-supplied users, as individuals are expected to move out of the basin.

Projected Water Use: The following section discusses projected water use through 2040 within the Big Sandy basin, based on projections provided in local and regional water supply plans. Table 21, included in the existing demand section above, is the basis for information discussed in this section.

Total demand within the basin is projected to slightly increase from 9.24 MGD in 2020 to 9.54 MGD in 2040. Growth is focused within surface and groundwater demands from community water systems and large self-supplied users. The greatest driver of water demand in the basin is projected population reductions expected throughout the basin. As residential homeowners move out of the basin, demands from small self-supplied users are projected to decrease by more than 80%. Minimal increases in surface water demands and significant reductions in groundwater demands are expected by 2040. Limited economic development and outward migration of individuals are driving water demands in the basin.

The largest contributors to trends in total projected demand include increased demands from the John Flannagan Water Authority and numerous mining operations. However, decreased demands from small self-supplied users greatly reduce projected groundwater demands throughout the planning period.

Demand from CWS users within the basin is projected to increase by 8.86% by 2040. Within this category, surface water use is projected to increase by 8.53%, while groundwater use is projected to increase by 14.03%. Surface water demands are driven by the John Flanagan Water Authority; groundwater demands are driven by the Buchanan County Public Service Authority. As population is expected to decrease over the planning period, increases in CWS demand will likely be minimal.

Demands from Large SSUs users within the basin is projected to increase by 11.23% by 2040, from 2.66 MGD to 2.96 MGD in 2040. Within this category, surface water use is projected to increase by 8.65%, while groundwater use is projected to increase by 35.75%. Surface and groundwater demands are driven by increases from numerous mining operations in the basin. No other large self-supplied users are known in the basin.

Demands from Small SSUs within the basin is projected to decrease by 82.6% by 2040. Projected population declines throughout the basin are responsible for the projected water demand decrease. Minimal economic opportunity and increasing age of individuals in the basin continues to drive reduced population and residential water demand trends over the planning period.

Demands from Agriculture Users within the basin are not currently reported within the water supply plan. With limited agricultural information for the basin, no water demands are projected for the category over the planning period.

A.1.5 Cumulative Impact Analysis

The following section provides a brief summary of the Cumulative Impact Analysis (CIA) modeling results in the Big Sandy Minor Basin. Discussion of these results will primarily be found in the "Trends and Goals" section of this appendix. However a brief overview of the VAHydro model and the scenarios and metrics is provided below.

The VAHydro surface water model simulates streamflow using inputs such as precipitation, climate, land use, and topography, combined with data on all known withdrawals and discharges, and operational rules of major hydrologic features such as reservoirs. Each minor basin is broken into smaller hydrologic subsections, or river segments. The model simulates the water balance on a daily basis for each individual river segment, with each downstream segment being affected by the "cumulative impact" of streamflow changes occurring in upstream segments. The following figures help analyze this cumulative impact within the Big Sandy Minor Basin (model results summarized by river segment). Note that this section is not intended to document in detail the methods and assumptions for the VAHydro model or for the scenarios and metrics discussed. Detailed documentation of the model and assumptions can be found in Chapter 4.

The VAHydro surface water model was used to simulate streamflow under a variety of scenarios. Demand scenarios examine how streamflow is impacted under 2030 or 2040 demands as compared to current (2020) demands. Demands were calculated based on current and future demand information submitted through local and regional water supply plans. Climate change scenarios examine how streamflow is impacted when 2040 demands are simulated in conjunction with a range of precipitation and temperature conditions that may occur in the future due to changing climate (Dry, Median, Wet scenarios). Finally, the exempt user scenario examines impacts from users excluded, or exempt, from VWP permit requirements per Va. Code § 62.1-44.15:22 B. Exempt users were simulated at the maximum possible demand identified through a review of demand justification values commonly asserted by exempt users, including but not limited to VDH pump capacity, maximum pre-1989 withdrawal, and maximum intake capacity. In order to effectively manage surface water resources and address the uncertainty related to these demands, DEQ determined the most conservative, or maximum possible, demand should be evaluated in this scenario. However, DEQ does not agree that the maximum values used in this scenario represent an allocation for, or the expectation of, a future withdrawal of that volume; nor does DEQ concede that any particular exempt user is necessarily entitled to withdraw any particular maximum value used in this scenario. The methods and assumptions for each of these modeling scenarios are discussed in more detail in Chapter 4.

For each scenario described above, different metrics can be used to evaluate the simulated streamflow. A metric is a method for measuring or evaluating a given set of data; different metrics can be evaluated to answer different questions. Within this section the following metrics will be discussed: the lowest 30 day flow (L30), the lowest 90 day flow (L90), 7Q10, and overall change in flow. The L30 describes the lowest consecutive 30 day average daily streamflow over the simulation period. This metric is a representation of a short-term, or acute drought. Similarly the lowest 90 day flow represents the lowest consecutive 90 day

average daily streamflow over the simulation period. This would represent a prolonged drought. The 7Q10 is the lowest 7-day average flow that occurs (on average) once every 10 years. 7Q10 is generally used in the evaluations of in-stream beneficial uses such as waste assimilative capacity. Overall change in flow describes the net loss of water from the riverine system as a result of off-stream use not otherwise returned through point source discharges, or losses due to evapotranspiration. This metric is discussed further below.

Demand Scenarios: 2020 demand or "current demand", 2030 demand, and 2040 demand scenarios were simulated. The following series of figures compares the 2030 and 2040 demand scenarios to the current demand scenario. The change in flow depicted on each map is the change expected when comparing two scenarios - in this case future demands compared to current demands. Each page includes two figures comparing either the 2030 or 2040 demand scenario to current demand using the L30, L90, and 7Q10 metrics. This allows for comparisons of simulated impacts between the 2030 and 2040 demand scenarios. The scenarios and metrics are identified in the paragraph below and in the figure captions.

Figures 82 and 83 compare the lowest 30 day flow simulated with the current demand scenario with the lowest 30 day flow simulated in the 2030 and 2040 demand scenarios respectively. Figures 84 and 85 compare the lowest 90 day low flow simulated with the current demand scenario with the lowest 90 day flow simulated in the 2030 and 2040 demand scenarios respectively. Figures 86 and 87 compare the 7Q10 simulated with the current demand scenario with the 7Q10 simulated in the 2030 and 2040 demand scenarios respectively.

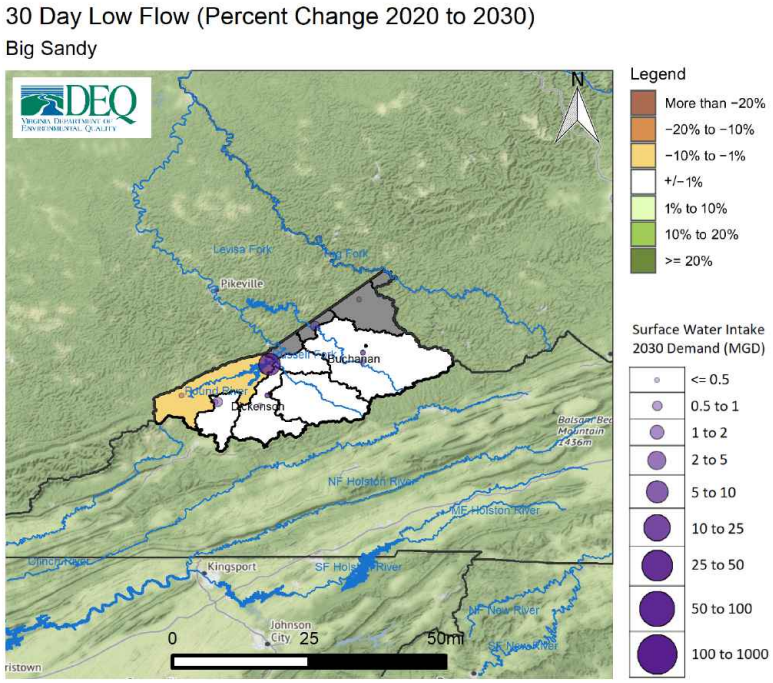

Figure 82: Change in 30 day low flow between 2020 and 2030 demand scenarios within the Big Sandy Basin

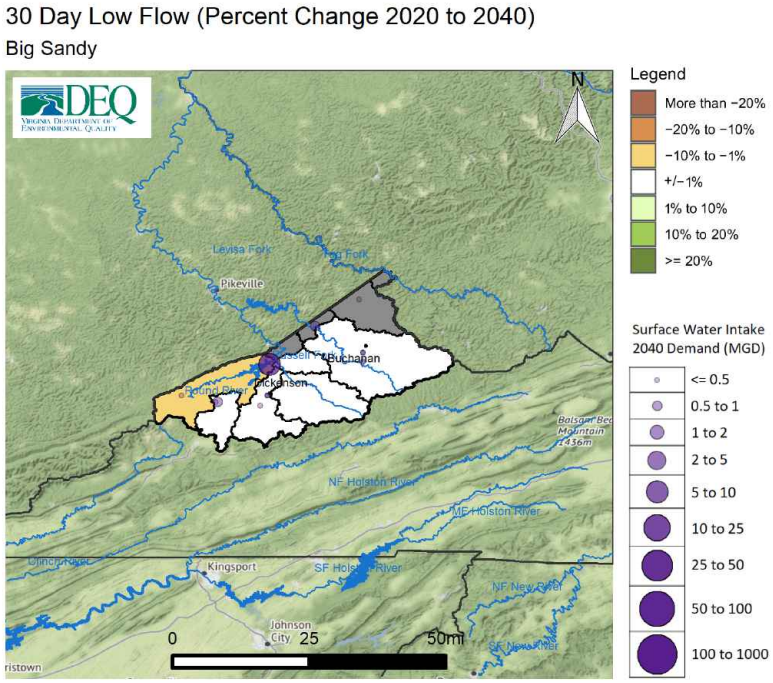

Figure 83: Change in 30 day low flow between 2020 and 2040 demand scenarios within the Big Sandy Basin

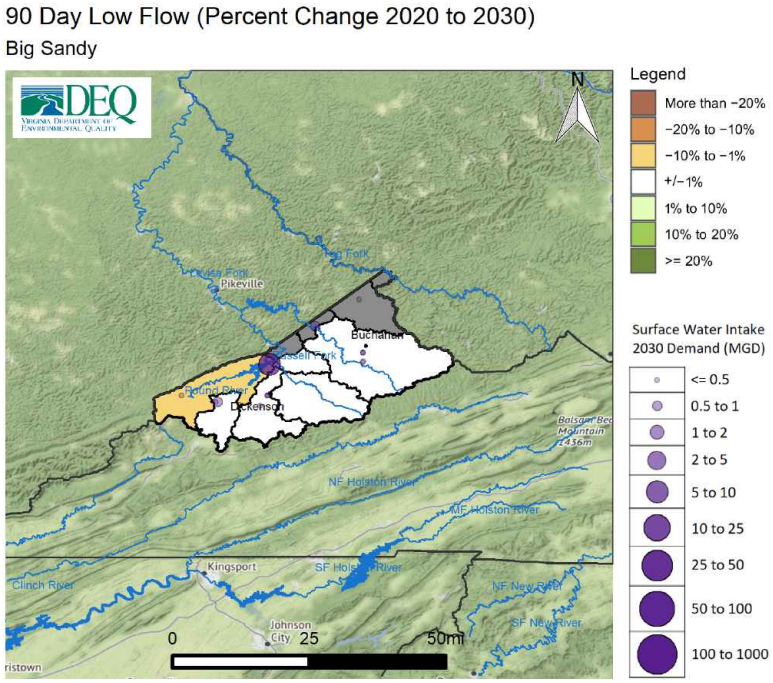

Figure 84: Change in 90 day low flow between 2020 and 2030 demand scenarios within the Big Sandy Basin

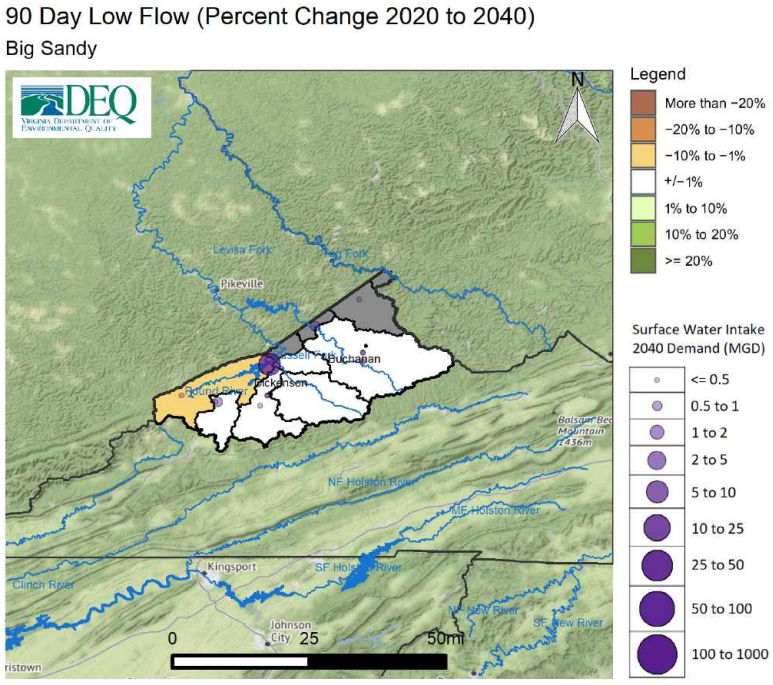

Figure 85: Change in 90 day low flow between 2020 and 2040 demand scenarios within the Big Sandy Basin

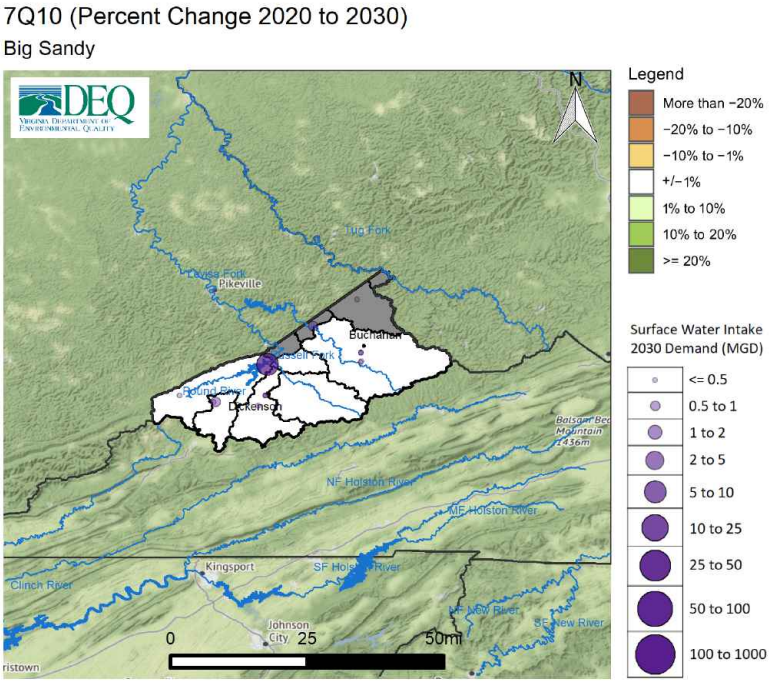

Figure 86: Change in 7Q10 between 2020 and 2030 demand scenarios within the Big Sandy Basin

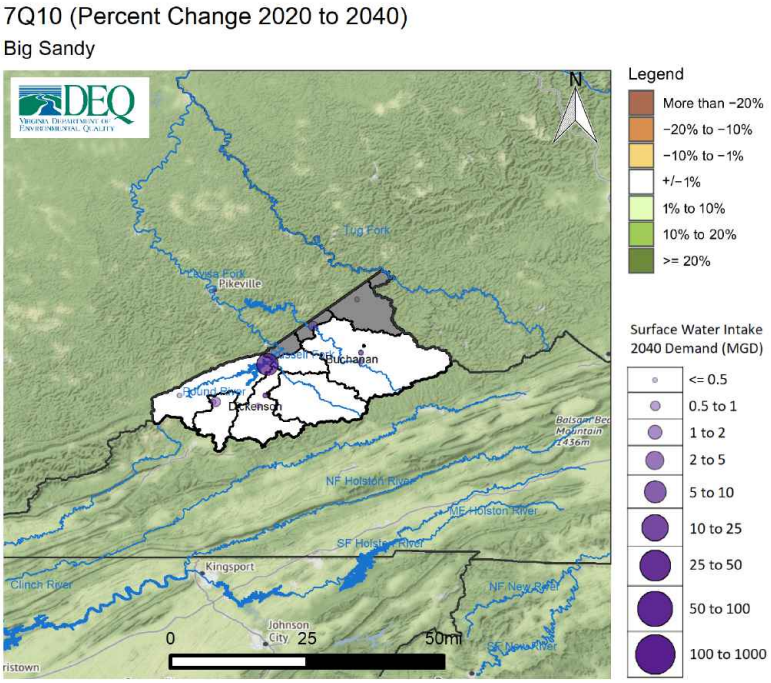

Figure 87: Change in 7Q10 between 2020 and 2040 demand scenarios within the Big Sandy Basin

The figures above show a comparison between two scenarios. An additional way to evaluate impacts to streamflow is to examine the total reduction in streamflow resulting from all withdrawals within a river segment, as well as losses due to evapotranspiration, while taking into consideration any discharges back to the source. To use a common industry term, the overall change in flow metric evaluates "consumptive use", or the amount of water removed from the river that is not returned through discharges. This can help describe potential impacts to downstream withdrawals, while also providing a basis for evaluating impacts to aquatic life. In general, total reductions in streamflow can result in a proportional reduction in aquatic biodiversity [70]. The relationship between streamflow and aquatic biodiversity is discussed in more detail in Chapter 4. Figure 88 shows the overall change in streamflow for the 2030 Demand Scenario, while figure 89 shows the overall change in streamflow for the 2040 Demand Scenario.

[70] Rapp, J.L., R. Burgholzer, J. Kleiner, D. Scott, and E. Passero. 2020. "Application of a New Species-Richness Based Flow Ecology Framework for Assessing Flow Reduction Effects on Aquatic Communities." Journal of the American Water Resources Association 1–14.https://doi.org/10.1111/1752-1688.12877.

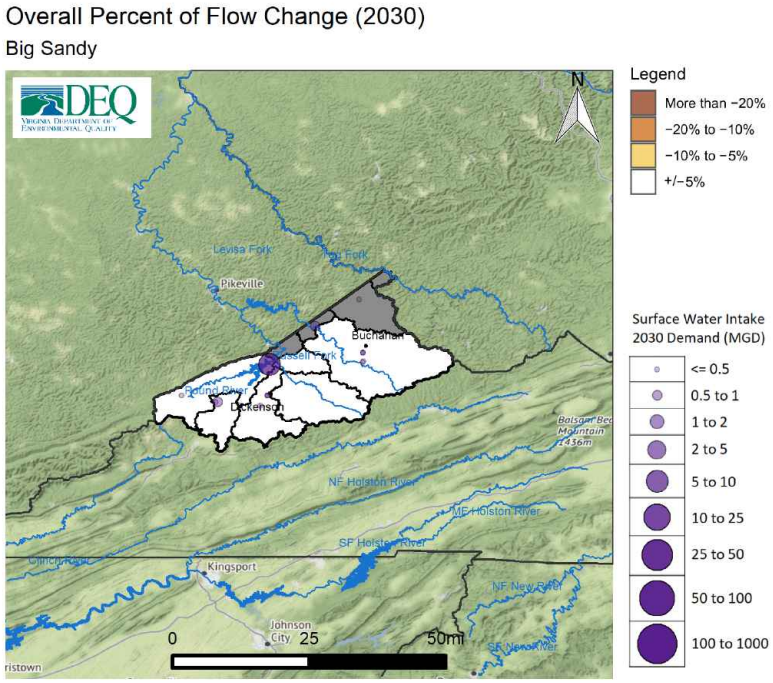

Figure 88: Overall change in flow in percent for 2030 demand scenario within the Big Sandy Basin

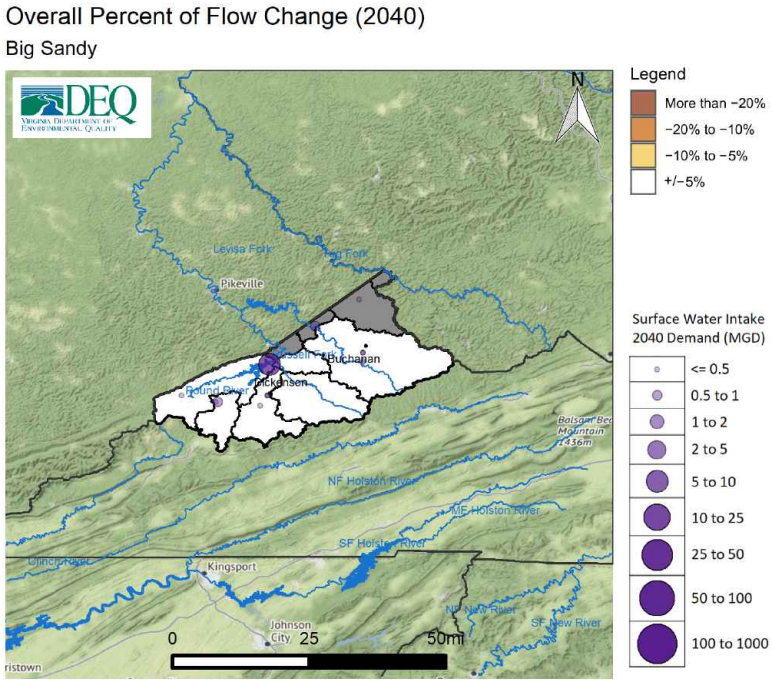

Figure 89: Overall change in flow in percent for 2040 demand scenario within the Big Sandy Basin

Climate Scenarios: Three scenarios that simulate impacts to streamflow in response to changes in temperature and climate were completed for areas in the state where climate data was available, which includes the portions of the Commonwealth located in the Chesapeake Bay watershed. Details on the methods and assumptions employed for these scenarios can be found in Chapter 4. In short, the three scenarios can be described as dry, median, and wet scenarios. Virginia is expected to experience a range of precipitation and temperature changes that may vary spatially and from year to year. The potential for both more severe and prolonged droughts as well as for higher intensity and more frequent rain events must be considered. These three scenarios are not intended as predictions of future climate conditions, but as representations of several possibilities that climate change models indicate could occur. Should they occur, these results provide an evaluation of how streamflows may be impacted. Their purpose is to build upon existing climate modeling to provide a foundation for state and local government, as well as other stakeholders, to better evaluate what practical water resource challenges may be associated with the range of climate conditions Virginia could experience. Note that this Basin is located outside of the Chesapeake Bay watershed and therefore climate scenarios were not completed at this time. DEQ is working to expand these climate scenarios to cover the entire state for future planning efforts.

Exempt User Scenario: The exempt user scenario simulates the maximum possible exempt demand for users excluded from Virginia Water Protection permitting requirements per Va. Code § 62.1-44.15:22 B, in combination with the permitted withdrawal limits for those users that are permitted. A more detailed discussion of the data and assumptions used in this scenario can be found in Appendix B. Note that this scenario uses current climate conditions. Figure 90 depicts the percent change in the Lowest 30 Day Flow between the exempt user scenario and current (2020) demand. Figure 91 depicts the percent change in the Lowest 90 Day Flow between the exempt user scenario and current (2020) demand. Figure 92 depicts the percent change in the 7Q10 between the exempt user scenario and current (2020) demand. Finally, figure 93 depicts the overall change in flow in percent (consumptive use) for the exempt user scenario.

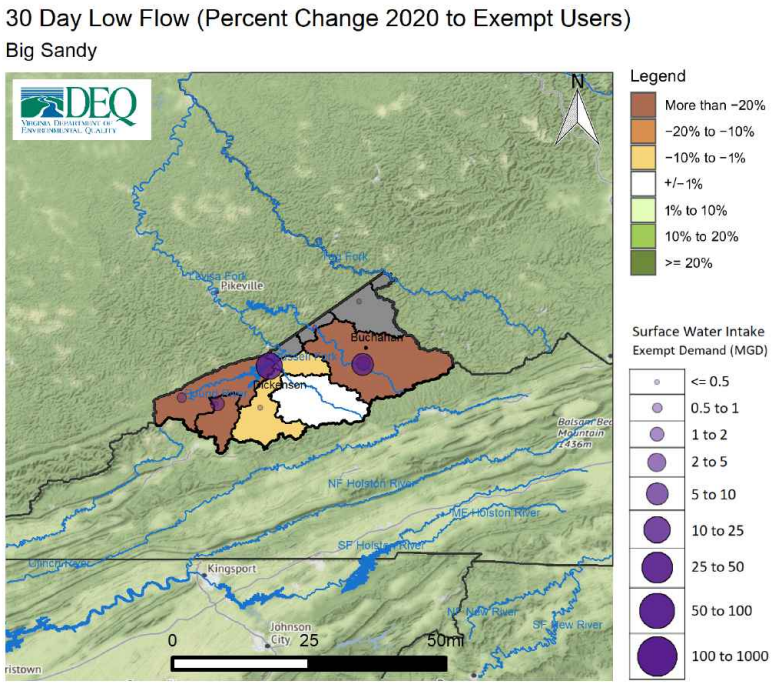

Figure 90: Change in 30 day low flow between current demand scenario and exempt user scenario within the Big Sandy Basin

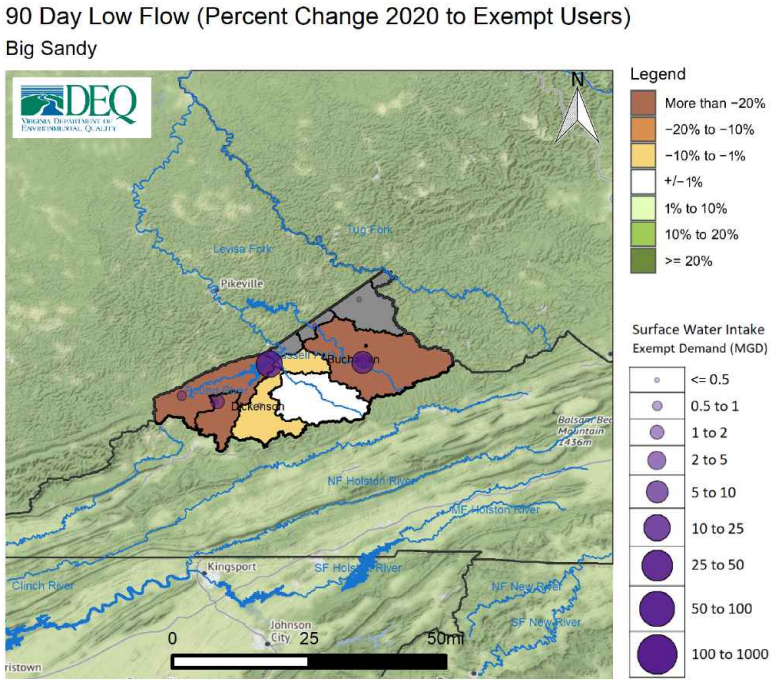

Figure 91: Change in 90 day low flow between current demand scenario and exempt user scenario within the Big Sandy Basin

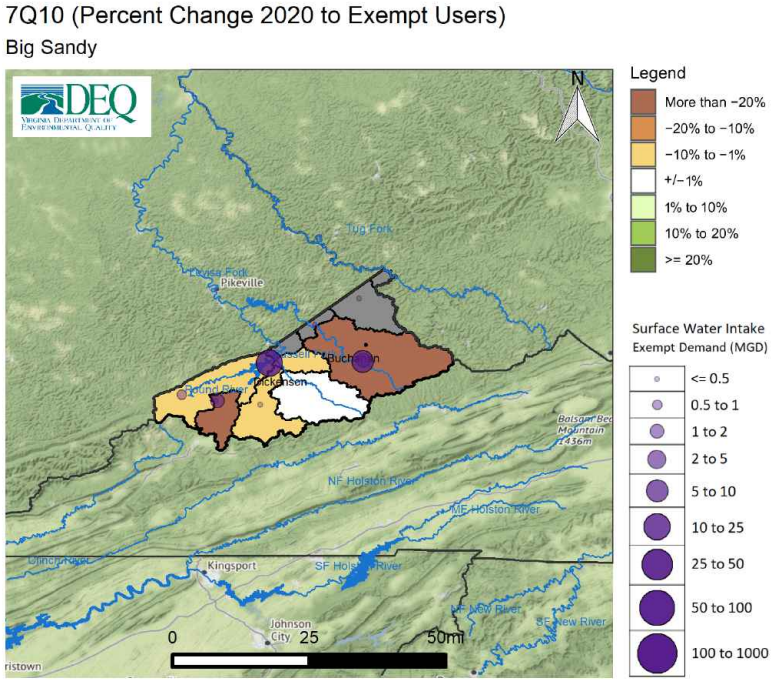

Figure 92: Change in 7Q10 between current demand scenario and exempt user scenario within the Big Sandy Basin

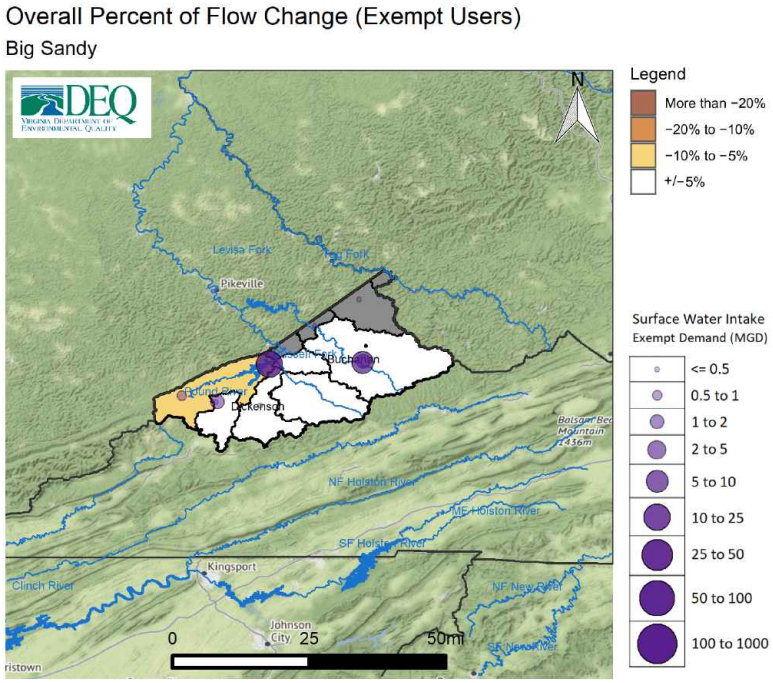

Figure 93: Overall change in flow in percent for exempt user scenario within the Big Sandy Basin

Potential Unmet Demand: Potential unmet demand was evaluated for all facilities within the basin for each scenario. Potential unmet demand is the portion of surface water demand for a specific facility that is limited by available streamflow as simulated in a given model scenario, including any known operational limits such as flow-by requirements. This unmet demand, if realized, could be managed through water conservation, through alternative sources, operational changes, or from available storage. Absent of these or other options, this portion of demand could remain unmet. As with all scenarios, demand requirements were determined using demand projections provided in the water supply plans. In the case of the exempt user scenario, the highest possible withdrawal amount was used for users exempt from VWP permitting requirements.

This metric is useful for evaluating where the results seen in the above figures may result in challenges in meeting future demands under a variety of conditions including increasing demands in the basin, changing climate, or withdrawals from users exempt from permitting requirements. Table 23 provides for each facility the highest average daily potential unmet demand over a 30 day period over the course of the simulation for the following scenarios: 2020 demand, 2030 demand, 2040 demand, and exempt user. Only facilities showing potential unmet demand in at least one scenario appear on this table. Additional information on the potential unmet demand metric can be found in Chapter 4 and Appendix B.

Table 23: Change in Highest 30 Day Potential Unmet Demand (MGD) in Big Sandy Minor Basin

Facility	**2020 Demand**	**2030 Demand**	**2040 Demand**	**Dry Climate**	**Exempt User**
John Flannagan Water Auth WTP	0.91	1.04	1.19	-	10.66
Coke Ovens	0.06	0.06	0.06	-	6.37
Vansant No. 2 Prep Plant	0.04	0.04	0.04	-	0.83
Mcclure #1 Mine & Prep Plant	0.07	0.07	0.07	-	0.41
Moss No. 1 Preparation Plant	0.00	0.00	0.00	-	0.15
Rockhouse Preparation Plant	0.00	0.00	0.00	-	0.01
Paramont Coal Co Va Llc - Deep Mine No 41	0.00	0.00	0.00	-	0.01

* Climate scenarios were not completed in areas located outside of the Chesapeake Bay Basin

Note: Potential unmet demand is the portion of surface water demand for a specific facility that is limited by available streamflow as simulated in a given model scenario, including any known operational limits such as flow-by requirements. This unmet demand, if realized, could be managed through water conservation, alternative sources, operational changes, or from available storage.

A.1.6 Trends and Goals

The Code of Virginia mandates that the State Water Control Board should take into consideration the principle that "adequate and safe supplies shall be preserved and protected for human consumption, while conserving maximum supplies for other beneficial uses". [71] This principle is the key driver of the challenges in water resource management, which is that all beneficial uses must be adequately considered when evaluating impacts to surface water resources. The State Water Control Board is tasked with ensuring that water supply quantity needs are met at all times while also protecting Virginia's natural resources, and furthermore, ensuring equitable allocation during a time of shortage.[72] While evaluating and planning for the long-term sustainability of water supply for Virginia is the primary goal for the State Plan, evaluating and limiting impacts to in-stream beneficial uses such as aquatic habitat life is also part of DEQ's responsibility.

The primary purpose of this section is to identify where the most significant challenges to long-term sustainability of water supply and other beneficial uses are indicated based on the CIA and information collated from local water supply plans within this basin. Goals for future planning and areas for additional data collection or analysis are also suggested where appropriate.

The CIAs were completed using the best available data and methods known to DEQ. This discussion focuses on the evaluation of trends - in other words the prevailing tendency or inclination. This means evaluating whether streamflow is simulated to increase or decrease in a given scenario, and by how much. A relative trend indicating reductions of greater than or equal to 10% in streamflow, whether driven by demand increases, changing climate conditions, or exempt user demands was considered a threshold for potential impacts to beneficial uses. The following summarize the key trends or goals for this basin:

- **Demand Scenarios:** Surface water demands in the Big Sandy Minor Basin are projected to increase by approximately 8% driven primarily by CWS and Large SSU categories. Comparisons of the 2020 and 2040 demand scenarios show no river segments with simulated reductions of more than 10% in short term (L30) drought, long term (L90) drought, or in the overall percent of flow change. Streamflow in the John Flannagan Reservoir segment are simulated to fall between 5-10% when comparing 2020 to 2040 demand scenarios, however reservoir operations are not yet simulated in this basin. The extent to which reservoir storage would be impacted in these scenarios could not be evaluated at this time. Potential unmet demands are greatest with the John Flannagan WTP simulated with just over 1 MGD in unmet demands by 2040, however given the reservoir is not currently modeled these unmet demands could likely be met through existing storage.

- **Climate Scenarios:** As climate change data was not available in this basin, climate change scenarios were not completed for this basin. The overall trend in climate change simulations statewide suggests the potential for higher average temperatures and higher average precipitation totals. However, the simulations also suggest the potential for more significant droughts than have been historically experienced in Virginia. Simulations completed elsewhere in the Commonwealth show short-term and long-term droughts with 20-50% reductions in streamflow compared to previous droughts. The potential for more severe droughts must be considered by localities and users when evaluating existing sources and alternatives, as well as for broader planning and resource management efforts by all stakeholders whether state or local.

- **Exempt User Scenario:** Compared to the demand scenarios, the exempt user scenario shows significant reductions in short term drought, long term drought, 7q10, and overall percent of stream flow change. The most significant reductions occur in the John Flannagan Reservoir, the Big Sandy River at Levisa Fork, and the Cranenest River. Reductions within the Big Sandy River at Levisa Fork are driven by the maximum possible exempt demands from two mining operations in the Dismal River.

[71] § 62.1-44.36 of the Code of Virginia
[72] 9VAC25-390-20.1

The withdrawals result in more than a 10% simulated reduction in flow downstream of the intakes. Additionally, reductions of more than 10% within the Cranenest River upstream of the John Flannagan Reservoir are also simulated in the exempt user scenario driven by two mining operation intakes from Caney Creek and Lick Fork. Downstream the Cranenest River flows into the John Flannagan Reservoir that operates as a public water supply source and power generation facility. Releases from the dam are coordinated with the Army Corps of Engineers and a continuous 50 cfs is released when actively generating power. Reductions in downstream flow are possible when not generating, as only 10 cfs released during those periods, although this is not currently simulated in the model. With minimal releases from the reservoir, a more than 20% reduction in overall flow occurs which could result in impacts to aquatic life and other beneficial uses. The Big Sandy watershed has increased biodiversity compared to many other basins in Virginia, so managing overall streamflow to protect aquatic life is critical.

A.2 Eastern Shore Minor Basin

A.2.1 Watershed Overview

The Eastern Shore of Virginia is part of the Delmarva Peninsula, so named as the peninsula stretches across the states of Delaware, Maryland, and Virginia. The Virginia portion of the Eastern Shore is separated from the rest of Virginia by the Chesapeake Bay. It is made up of two counties: Accomack and Northampton. The Eastern Shore is very flat with the maximum elevation above sea level not much more than 60 feet. Route 13 is an approximate indication of the watershed divide, which is to say areas east of Route 13 drain to the Atlantic Ocean, while areas west drain to the Chesapeake Bay. For purposes of the State Plan, these two drainage areas have been combined into a single Eastern Shore basin. Due to the flat terrain, there are few significant non-tidal streams, meaning very limited fresh surface water availability. Groundwater is the primary source on the Eastern Shore. Land use on the Eastern Shore is primarily agricultural, with a mix of field crops, tomatoes, and livestock operations. The Eastern Shore does not have any large cities or urban areas, but the area does attract significant tourism in the summer, particularly in and around towns such as Cape Charles and Chincoteague.

A.2.2 Existing Water Sources

Groundwater within the basin is primarily withdrawn from the Yorktown-Eastover Aquifer system, a series of three confined aquifers called the Upper, Middle, and Lower Yorktown-Eastover aquifers. The Yorktown-Eastover system is known as a "sole source aquifer" as it is the majority source across the Eastern Shore and there are no readily available alternatives for meeting public water supply needs. The water table aquifer, which is the unconfined aquifer known as the Columbia Aquifer, is also used but primarily for agricultural purposes. Surface water use is almost entirely for agricultural purposes on the shore, and is generally withdrawn from small agricultural impoundments. Withdrawals within the basin are used for public water supply as well as for agriculture, irrigation, commercial, and industrial/manufacturing. The location of wells and surface water intakes identified to DEQ within the basin are shown in Figure 94. This figure does not include private or domestic wells. The greatest concentration of both development and wells is along Route 13 as it runs from Northampton County through Accomack County.

Table 24: Population Trend by Locality in Eastern Shore Basin

Localities	20 Year % Change
Accomack	-21.97
Northampton	-15.03

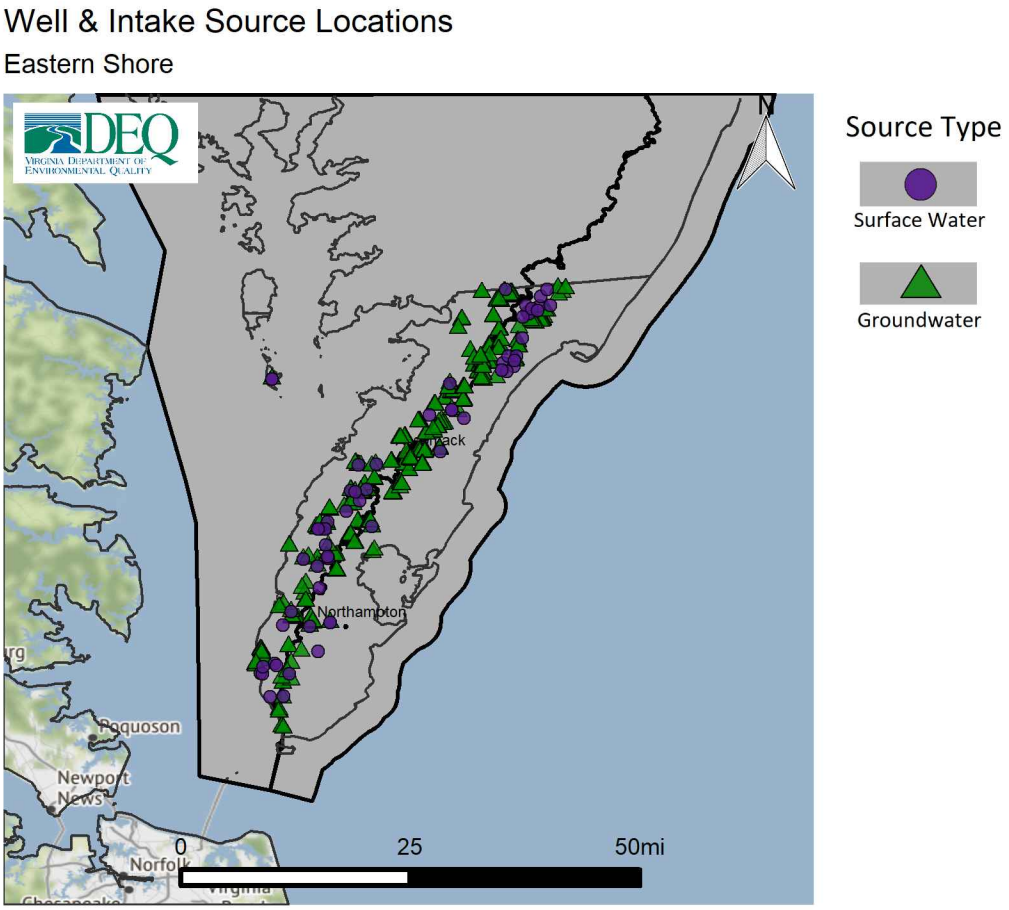

Figure 94: Spatial distribution of groundwater wells and intakes on the Eastern Shore

A.2.3 Existing Water Use

The following section discusses existing (current) water use within the basin, which is based on existing demand information submitted to DEQ in the water supply plans. Table 25 provides a summary of all demands within the basin by system type and source type including power generation. It also provides a count of surface water or groundwater sources associated with each system type. This number does not include private or domestic wells.

Table 25: Summary of Eastern Shore Minor Basin Water Demand by Source Type and System Type (including Power Generation)

System Type	Source Count	2020 Demand (MGD)	2030 Demand (MGD)	2040 Demand (MGD)	20 Year Percent Change
Surface Water					
Agriculture	87	2.81	2.81	2.81	0.00
CWS	0	0.05	0.06	0.06	5.58
Large SSU	5	0.00	0.00	0.00	0.00
Small SSU	N/A	0.00	0.00	0.00	0.00
Total SW	**92**	**2.86**	**2.87**	**2.87**	**0.35**
Groundwater					
Agriculture	368	1.04	1.04	1.04	0.56
CWS	54	1.14	1.66	2.17	91.21
Large SSU	80	3.37	3.52	3.67	8.78
Small SSU	N/A	4.03	3.82	3.62	-10.18
Total GW	**502**	**9.58**	**10.04**	**10.50**	**9.60**
Total (SW + GW)					
Agriculture	455	3.85	3.85	3.85	0.15
CWS	54	1.19	1.71	2.23	87.34
Large SSU	85	3.37	3.52	3.67	8.78
Small SSU	N/A	4.03	3.82	3.62	-10.18
Minor Basin Total	**594**	**12.44**	**12.90**	**13.37**	**7.48**

* Small SSU demands are county-wide estimates of private well usage below 300,000 gallons a month. The number of private wells is not known.

The total existing demand from all surface and groundwater sources is approximately 12.44 MGD, with groundwater supplying approximately 9.58 MGD or 77% of total water demands. Surface water demand within the basin totals approximately 2.86 MGD, or 23% of current demands. Note the significant number of groundwater sources present in the basin with more than five hundred active wells.

The five largest facility demands for each source type are provided in Table 26. As noted above, more than 75% of all demand comes from groundwater wells. The largest groundwater demands include the Perdue Poultry Processing Plant, Tyson Poultry Processing Plant, as well as the Town of Chincoteague. The largest surface water demands are all agricultural withdrawals.

Table 26: Top 5 Users in 2040 by Source Type in the Eastern Shore Minor Basin (including Power Generation)

Facility Name	System Type	Locality	2020 Demand (MGD)	2030 Demand (MGD)	2040 Demand (MGD)	20 Year Percent Change	% of Total Surface Water
Surface Water							
Dublin Farms Inc.	AG	Accomack	1.39	1.39	1.39	0.00	48.43
Yaros Farms Inc	AG	Northampton	0.73	0.73	0.73	0.00	25.44
Doughty-Drewer Complex	AG	Accomack	0.11	0.11	0.11	0.00	3.83
F.a. Holland & Sons	AG	Accomack	0.11	0.11	0.11	0.00	3.83
Eastville Farm	AG	Northampton	0.11	0.11	0.11	0.00	3.83
Total SW			2.45	2.45	2.45	0.00	85.37
Groundwater							**% of Total Groundwater**
Perdue Farms Incorporated	Large SSU	Accomack	1.81	1.93	2.05	13.26	19.52
Tyson Farms, Inc.	Large SSU	Accomack	1.28	1.3	1.31	2.34	12.48
Chincoteague Town Of	CWS	Accomack	0.52	0.6	0.67	28.85	6.38
Captain's Cove Utility Company, Inc.	CWS	Accomack	0.1	0.34	0.57	470	5.43
Exmore Town Of	CWS	Northampton	0.11	0.22	0.34	209.09	3.24
Total GW			3.82	4.39	4.94	29.32	47.05

Table 25 also provides the proportion of each use category that is supplied by either surface water or groundwater. Use categories include Community Water System (CWS), Large Self-Supplied User (Large SSU), Small Self-Supplied User (Small SSU), and Agricultural Self-Supplied User (AG). These categories are defined below. Surface water demand is almost entirely AG. Groundwater demand is used for all other categories including CWS facilities, Large SSUs, and Small SSUs.

The CWS category includes any public and private waterworks that serve at least 15 service connections used by year-round residents or regularly serve at least 25 year-round residents, and are regulated under the Virginia Department of Health's Waterworks Regulation (12VAC5-590). On the Eastern Shore, approximately 1.14 MGD of groundwater demand is from CWS facilities. Significant groundwater users within this category include the Town of Chincoteague, Captain's Cove Utility Company, and the Town of Exmore. Surface water demands for CWS are minimal and not a primary water source in the basin.

Large SSUs include any non-CWS or AG who withdraw more than 300,000 gallons per month from a well or surface water intake. On the Eastern Shore, approximately 3.37 MGD of groundwater demand is from Large SSUs. Significant groundwater users within this category include the two poultry processing plants. There is no surface water demand for Large SSUs.

Small SSUs include any users who withdraw less than 300,000 gallons per month from wells. Small SSUs generally consist of residential or domestic use for those who lives outside service areas and provide their own water. Small SSU demand is generally met with groundwater. On the Eastern Shore, approximately 4.03 MGD of groundwater demand is from Small SSUs. The majority of the population on the Eastern Shore lives outside of service areas and rely on domestic wells for water supply.

The AG category includes crop farms, livestock operations, aquaculture and other agricultural facilities. On the Eastern Shore, approximately 1.04 MGD of groundwater demand and 2.81 MGD of surface water demand is from AG. These current use estimates likely are lower than actual due to recent growth in poultry farms

and other farms not otherwise captured in these projections. Surface water is almost entirely withdrawn from ponds and is used primarily for irrigation, while groundwater is the major water source for livestock operations.

A.2.4 Projected Population and Water Use

Projected Population: Trends in water use are generally driven by trends in population change or economic development. Increasing population within an area generally means increased connections for CWSs or additional groundwater demands from homeowners that construct wells. Increasing population in an area also tends to incentivize both new and expanded industrial and commercial water use.

Table 24 shows the projected change in population by percent between 2020 and 2040 for each locality located on the Eastern Shore. Both Accomack County and Northampton County are projected to decrease in population between 2020 and 2040, which is consistent with recent population trends on the Shore as well as in other primarily rural and agricultural communities. However, the Eastern Shore does enjoy a strong tourism economy which can result in short-term population growth, particularly during summer months.

Projected Water Use: The following section discusses projected water use through 2040 on the Eastern Shore based on projections provided in local and regional water supply plans. Table 25, included in the existing demand section above, is the basis for information discussed in this section.

Total demand within the basin is projected to increase by approximately 7.48% from 12.44 MGD to 13.37 MGD in 2040. The moderate increase in demand is driven primarily by projected groundwater demand increases for CWS facilities. Groundwater demand as a whole is projected to increase by 0.92 MGD, or 9.6%, by 2040. Surface water demand is not projected to change from 2020 to 2040.

Demand from CWS users on the Eastern Shore is projected to increase by approximately 87.3% by 2040. As noted above, groundwater supplies CWS demands, with the largest increases projected for Captain's Cove Utility Company, the Town of Exmore, and the Town of Chincoteague. Although the overall trend in population on the Eastern Shore is decreasing, service areas continue to see growth as new connections are added from new full or part-time residents.

Demand from Large SSUs on the Eastern Shore is projected to increase by approximately 8.7% by 2040. Projected increases are all from groundwater and are driven primarily by increased projected demands for Perdue's poultry processing plant.

Demand from Small SSUs on the Eastern Shore is projected to decrease by more than 10.1% by 2040. As noted previously, Small SSU demand is entirely met with groundwater and represents domestic/residential use. This decrease in demand aligns with the projected decrease in population in both Accomack and Northampton counties.

Demand from AG on the Eastern Shore is not projected to change significantly by 2040. As widespread agricultural users have been identified in recent years, agricultural demands within the basin are likely underrepresented. As the DEQ continues to issue permits and identify agricultural users in the basin increased understanding of agricultural water demands will continue throughout the planning period.

A.2.5 Cumulative Impact Analysis

The Eastern Shore does not include significant non-tidal surface water segments and therefore surface water cumulative impact analysis was not completed in this basin. The Trends and Goals sections below discusses results from the Cumulative Impact Analysis (CIA) Groundwater Modeling completed in the Eastern Shore Groundwater Management Area. The methods and results for the groundwater modeling scenarios are provided in Chapter 4, Section 4.3.5, Virginia Eastern Shore Model Results, which may warrant review prior to reading the following sections.

A.2.6 Spatial Overview of Groundwater Demands

A substantial portion of the demands in this basin are supplied by groundwater. Figure 95 identifies the location and size of projected groundwater demands in the basin for 2040 based on information provided by localities in water supply plans.

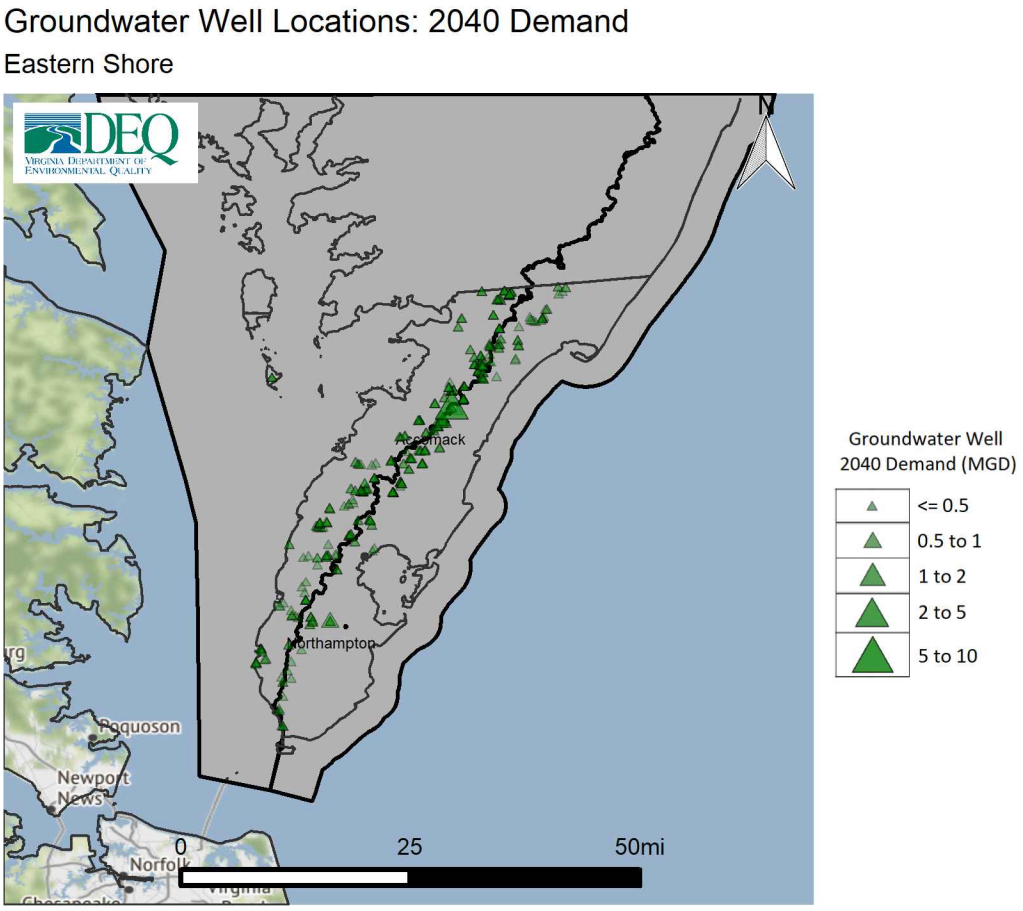

Figure 95: Projected 2040 Groundwater Demands on the Eastern Shore

A.2.7 Trends and Goals

The Code of Virginia mandates that the State Water Control Board should take into consideration the principle that "adequate and safe supplies shall be preserved and protected for human consumption, while conserving maximum supplies for other beneficial uses".[73] This principle is the key driver of the challenges in water resource management, which is that all beneficial uses must be adequately considered when evaluating impacts to water resources. The State Water Control Board is tasked with ensuring that water supply quantity needs are met at all times while also protecting Virginia's natural resources, and furthermore, ensuring equitable allocation during a time of shortage.[74] The primary purpose of this section is to identify where the most significant challenges to long-term sustainability of water supply and other beneficial uses are indicated based on the CIA and information collated from local water supply plans within this basin. Goals for future planning and areas for additional data collection or analysis are also suggested where appropriate.

- **Eastern Shore Groundwater Demand Scenarios:** The Eastern Shore is characterized by limited freshwater surface water availability and as noted in the above sections groundwater from the Yorktown-Eastover Aquifer system is the primary source across uses. Hydrogeology on the Eastern Shore is often characterized through the analogy of a freshwater lens, representing the freshwater aquifers like the Yorktown-Eastover and the water table, that sits atop groundwater that is substantially higher in chlorides, due to the proximity to the Chesapeake Bay to the west and the Atlantic Ocean to the east. CIA groundwater modeling of the 2020 and 2040 demand scenarios was completed using the VAHydro Virginia Eastern Shore Groundwater Model for the State Plan to evaluate not only changes in water levels in the aquifer but also chloride concentration. The results of these simulations are covered in detail in a number of figures provided in Chapter 4, Section 4.3.5 and conclusions on the model results are also provided in Section 4.3.6. This appendix is a brief summary. Two groundwater modeling scenarios were completed based on the 2020 and 2040 demands from the water supply plans. Each scenario included new estimates for domestic use that incorporated demand information from the plans. In neither scenario were critical cells simulated. Comparing the 2020 and 2040 demand scenario also did not indicate significant differences in water levels or chloride concentrations between the two scenarios at the end of the simulations. Given that demand was not projected to increase significantly between 2020 and 2040, this result is expected.

- Recent growth in the poultry industry was not included in recent water supply plan projections. Given agriculture's significant role on the Eastern Shore, it is critical that updated demand information for poultry farms and other agricultural operations be collected so that future planning efforts may reflect these changes. It is likely that particularly where the addition of new farms has overlapped existing large demands, impacts would be greater than seen in the two scenarios based on water supply plan demands.

- Given the status of the Yorktown-Eastover aquifer system as a sole source aquifer, investigating and investing in alternatives is critical. Increasing the proportion of use from the water table, or Columbia Aquifer, is one viable alternative. The Columbia Aquifer recharges more readily than does the Yorktown-Eastover, and in many areas can be both very productive and acceptable in quality, particularly for non-potable uses. DEQ is currently developing a regulation for a General Permit that would provide an additional incentive to withdraw from the Columbia Aquifer. Some municipalities are also investigating reverse osmosis or desalinization plants to treat surface water to drinking water quality. These are expensive processes but could offer another alternative source. Surface water from dug ponds and other types of surface water impoundments can be an effective alternative to groundwater for agricultural water use.

[73] § 62.1-44.36 of the Code of Virginia
[74] 9VAC25-390-20.1

A.3 James Appomattox Minor Basin

A.3.1 Watershed Overview

The James Appomattox Minor Basin is located in central Virginia. The Appomattox River is a major tributary to the James River flowing from Appomattox County towards the cities of Petersburg and Hopewell. The river forms boundaries between several counties including Buckingham, Prince Edward, Cumberland, Amelia, Powhatan, Chesterfield and others. Lake Chesdin is a major man-made impoundment within the Appomattox River located just west of Petersburg. Land use is primarily rural in the western portion of the watershed with heavy urban development increasing as you move east towards primary population centers in the basin.

The total spatial area of the basin occupies 1598.98 sq. miles and includes all or portions of the localities listed in Table 27. The major population centers within the basin include Chesterfield County, Prince George County, and the City of Petersburg.

A.3.2 Existing Water Sources

Major surface water sources within the basin include Briery Creek, Bush Creek, and Buffalo Creek. Lake Chesdin is the primary impoundment in the basin and is formed along the main channel of the Appomattox west of Petersburg. Groundwater within the basin is primarily withdrawn from wells constructed in bedrock or fractured rock aquifers.

Withdrawals within the basin are primarily used for public water supply. Other uses in the watershed include agriculture, irrigation, commercial, and industrial/manufacturing.

The location of wells and surface water intakes identified by DEQ within the basin are shown in figure 96. This map also shows locations of any In-stream Flow Incremental Method (IFIM) studies completed in the basin. The highest density and volume of withdrawals are located within the eastern portion of the watershed in support of major population centers such as Chesterfield County. Withdrawals within the more rural portions of the watershed are focused in close proximity to population centers such as the Town of Farmville. Surface water intakes are primarily located along the Appomattox River, with a major public water supply intake located in Lake Chesdin. Groundwater wells are not a primary source of water supply in the basin when compared to surface water. Groundwater wells are primarily located west of Chesterfield County - although domestic wells are not reflected on this map and may be spread more equally throughout.

Table 27: Population Trend by Locality in James Appomattox Basin

Localities	20 Year % Change
Amelia	9.34
Appomattox	9.61
Buckingham	4.66
Charlotte	-7.85
Chesterfield	22.51
Cumberland	5.05
Dinwiddie	11.12
Lunenburg	-11.86
Nottoway	-4.23
Powhatan	21.94
Prince Edward	12.54
Prince George	8.14
Colonial Heights	0.28
Hopewell	-1.83
Petersburg	-10.55

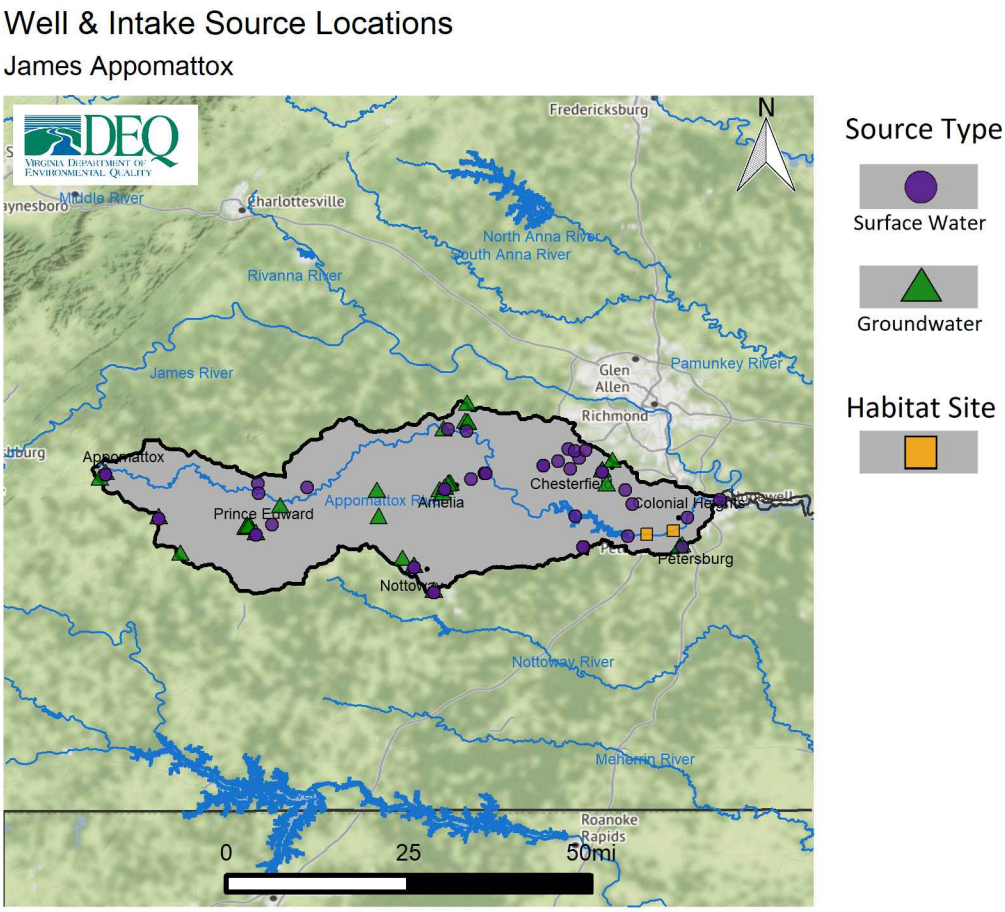

Figure 96: Spatial distribution of groundwater wells and intakes in the James Appomattox Minor Basin

A.3.3 Existing Water Use

The following section discusses existing (current) water use within the basin, which is based on existing demand information submitted to DEQ in the water supply plans. Table 28 provides a summary of all demands within the basin by system type and source type. It also provides a count of surface water or groundwater sources associated with each system type.

Table 28: Summary of James Appomattox Minor Basin Water Demand by Source Type and System Type

System Type	Source Count	2020 Demand (MGD)	2030 Demand (MGD)	2040 Demand (MGD)	20 Year Percent Change
Surface Water					
Agriculture	7	0.58	0.72	0.85	45.35
CWS	5	65.32	77.60	89.89	37.61
Large SSU	16	2.95	3.91	4.86	64.87
Small SSU	N/A	0.00	0.00	0.00	0.00
Total SW	**28**	**68.85**	**82.23**	**95.60**	**38.85**
Groundwater					
Agriculture	2	0.01	0.02	0.02	19.52
CWS	9	0.17	0.53	0.88	409.78
Large SSU	15	0.18	0.22	0.26	48.37
Small SSU	N/A	6.40	7.65	8.89	38.93
Total GW	**26**	**6.76**	**8.42**	**10.05**	**48.67**
Total (SW + GW)					
Agriculture	9	0.60	0.73	0.87	44.73
CWS	14	65.49	78.13	90.77	38.60
Large SSU	31	3.13	4.13	5.13	63.93
Small SSU	N/A	6.40	7.65	8.89	38.93
Minor Basin Total	**54**	**75.62**	**90.64**	**105.66**	**39.72**

* Small SSU demands are county-wide estimates of private well usage below 300,000 gallons a month. The number of private wells is not known.

The total existing demand from all surface and groundwater sources is approximately 75.62 MGD, with groundwater supplying approximately 6.76 MGD or 9% of total water demands. Groundwater demands in the basin are almost entirely driven by demands from Small Self-Supplied Users (Small SSUs) reliant on private wells for water supply. Surface water demands within the basin totals approximately 68.85 MGD, or 91% of current demands. Surface water demands are primarily driven from Community Water System (CWS) facilities to support large public water supplies in the basin. CWS demands represent approximately 95% of total surface water demands in the basin.

The five largest facility demands for each source type are provided in table 29. The largest groundwater demands include withdrawals to support Powhatan County's Courthouse Service Area, and the Dogwood Trace Golf Course. In comparison to surface water demands, these groundwater demands are relatively small. Surface water withdrawals from Lake Chesdin, Virginia American Water's Hopewell intake, and Chesterfield County's Swift Creek Reservoir are the greatest surface water demands in the basin. The Appomattox River Water Authority's withdrawal from Lake Chesdin represents approximately 33% of total surface water current demand in the watershed.

Table 29: Top 5 Users in 2040 by Source Type in the James Appomattox Minor Basin

Facility Name	System Type	Locality	2020 Demand (MGD)	2030 Demand (MGD)	2040 Demand (MGD)	20 Year Percent Change	% of Total Surface Water
Surface Water							
Chesdin Reservoir WTP	CWS	Chesterfield	33.76	42.38	51.01	51.1	53.36
Hopewell District	CWS	Hopewell	22.08	23.38	24.67	11.73	25.81
Swift Creek WTP	CWS	Chesterfield	8.13	10.31	12.48	53.51	13.05
Jack Stone Quarry	Large SSU	Dinwiddie	1.65	2.34	3.04	84.24	3.18
Farmville Service Area	CWS	Prince Edward	1.1	1.29	1.48	34.55	1.55
Total SW			66.72	79.7	92.68	38.91	96.95
Groundwater							**% of Total Groundwater**
Powhatan Courthouse Service Area	CWS	Powhatan	0.05	0.37	0.68	1260	6.77
Amelia Courthouse	CWS	Amelia	0.1	0.13	0.17	70	1.69
Hampden Sydney College	Large SSU	Prince Edward	0.1	0.12	0.15	50	1.49
Dogwood Trace Golf Course (Formerly Lee Park Golf Course)	Large SSU	Petersburg	0.03	0.03	0.04	33.33	0.4
Crewe Plant	Large SSU	Nottoway	0.02	0.03	0.03	50	0.3
Total GW			0.3	0.68	1.07	256.67	10.65

Table 28 also provides the proportion of each use category that is supplied by either surface water or groundwater. Use categories include Community Water System (CWS), Large Self-Supplied User (Large SSU), Small Self-Supplied (Small SSU), and Agricultural Self-Supplied User (AG). These categories are defined below.

The CWS category includes any public and private waterworks that serve at least 15 service connections used by year-round residents or regularly serve at least 25 year-round residents, and are regulated under the Virginia Department of Health's Waterworks Regulation (12VAC5-590). In the James Appomattox Basin, approximately 0.17 MGD of groundwater demand and 65.32 MGD of surface water demand is from CWS facilities. Significant groundwater users within this category include several small service areas within Powhatan and Amelia Counties. Surface water is the primary water source for CWS demands with major water users including the Appomattox Water Authority, Virginia American Water's Hopewell Intake, and Chesterfield County.

Large SSUs include any non-CWS or AG users who withdraw more than 300,000 gallons per month from a well or surface water intake. In the James Appomattox Basin, approximately 0.18 MGD of groundwater demand and 2.95 MGD of surface water demand is from Large SSUs. Significant groundwater users within this category include Hampden Sydney College, Dogwood Trace Golf Course, and the Tyson Foods Crewe Plant. Significant surface water users in the basin include several mining operations and golf courses.

Small SSUs include any users who withdraw less than 300,000 gallons per month from wells. Small SSUs generally consist of residential or domestic use for those who live outside service areas and provide their own water. Small SSU demand is generally met with groundwater. In the James Appomattox Basin,

approximately 6.4 MGD of groundwater demand is from Small SSUs. Localities within the basin with the greatest contribution from Small SSUs include Chesterfield, Prince Edward, and Appomattox counties. Small SSUs in the basin represent nearly all of the current and projected groundwater demands, as populations increase throughout the watershed additional private wells will likely be developed.

The AG category includes crop farms, livestock operations, aquaculture and other agricultural facilities. In the James Appomattox Basin, approximately 0.01 MGD of groundwater demand and 0.58 MGD of surface water demand is from AG. Significant groundwater users within this category include the Oakulgee Dairy. Significant surface water users in the basin include the Chesterfield Berry Farm, Green Hills Dairy, and estimated cumulative demands from users in Nottoway and Appomattox counties. Limited agricultural water withdrawal reporting is present in the basin at this time.

A.3.4 Projected Population and Water Use

Projected Population: Trends in water use are generally driven by trends in population change or economic development. Increasing population within an area generally means increased connections for community water systems or additional groundwater demand from homeowners that construct wells. Increasing population in an area also tends to incentivize both new and expanded industrial and commercial water use.

Table 27 shows the projected change in population by percent between 2020 and 2040 for each locality located partly or wholly within the basin. Significant growth in population is projected in the watershed and is focused primarily within Chesterfield, Powhatan, and Prince Edward counties. As the Richmond metro area continues to attract economic development, individuals are moving to it and surrounding localities. Chesterfield is the largest locality in the watershed and is projecting the greatest increase (more than 22%) in population over the planning period. While localities surrounding Richmond continue to grow, some areas in the basin are projecting decreasing populations over the planning period. Lunenburg County, the City of Petersburg, and Charlotte County are projecting decreases of approximately 10% over the planning period. Limited economic opportunity and more rural locations in the watershed contribute to the projected decreases in population by 2040.

Projected Water Use: The following section discusses projected water use through 2040 within the James Appomattox basin, based on projections provided in local and regional water supply plans. Table 28, included in the existing demand section above, is the basis for information discussed in this section.

Total demand within the basin is projected to increase from 75.62 MGD in 2020 to 105.66 MGD in 2040. Growth is focused within surface water demands from CWS and estimated groundwater demands from Small SSUs. The greatest driver of water demand in the basin is significant projected increases in population over the planning period, as residential homeowners develop wells and public water suppliers increase demands on surface water sources for supply. Surface water demands for CWS facilities are projected to increase by more than 37%, and Small SSU groundwater use is projected to increase nearly 39% by 2040.

The largest contributors to trends in total projected water demands include withdrawal increases projected by the Appomattox River Water Authority's Lake Chesdin withdrawal, Chesterfield County's Swift Creek Reservoir, and Virginia American Water's Appomattox River intake near Hopewell. All are CWS facilities that provide public water supply throughout the majority of the watershed.

Demand from CWS users within the basin is projected to increase by 38.6% by 2040. Within this category, surface water use is projected to increase by 37.6%, while groundwater use is projected to increase by 409.7%. Surface water demands are the primary water source for CWS with significant increases in water demand from the largest public water suppliers including Appomattox River Water Authority, Chesterfield County, and Virginia American Water. Groundwater is also projecting significant increases in demands with more than 400% increase by 2040, however limited groundwater demands are present currently so this is large percentage increase represents a fairly small projected increase by volume.

Demand from Large SSUs within the basin is projected to increase by 63.9% by 2040. Within this category, surface water use is projected to increase by 64.8%, while groundwater use is projected to increase by 19.5%. Surface and groundwater demands are driven primarily by increases in demands from mining operations and golf courses in the watershed. The largest contributors in the basin include the Jack Stone Quarry, Midlothian Quarry, and the Dogwood Trace Golf Course.

Demand from Small SSUs within the basin is projected to increase by 38.9% by 2040. As noted previously, Small SSU demand is entirely met with groundwater and represents domestic/residential use. With the Chesterfield, Amelia, and Nottoway counties projecting the greatest increases in residential groundwater demands throughout the planning period. Significant population growth in the basin is the primary driver of increased demands in the category.

Demand from Agriculture Users within the basin is projected to increase by 44.7% by 2040. Within this category, surface water use is projected to increase by 45.3%, while groundwater use is projected to increase by 19.5%. Cumulative withdrawals from small agricultural users in Nottoway County represent the primary driver in agricultural demands in the basin. Additional increases in demands from the Chesterfield Berry Farm and Okmulgee Dairy include the greatest increases in water demand in the category.

A.3.5 Cumulative Impact Analysis

The following section provides a brief summary of the Cumulative Impact Analysis (CIA) modeling results in the James Appomattox Minor Basin. Discussion of these results will primarily be found in the Trends and Goals section of this appendix. However a brief overview of the VAHydro model and the scenarios and metrics is provided below.

The VAHydro surface water model simulates streamflow using inputs such as precipitation, climate, land use, and topography, combined with data on all known withdrawals and discharges, and operational rules of major hydrologic features such as reservoirs. Each minor basin is broken into smaller hydrologic subsections, or river segments. The model simulates the water balance on a daily basis for each individual river segment, with each downstream segment being affected by the cumulative impact of streamflow changes occurring in upstream segments. The following figures help analyze this cumulative impact within the James Appomattox Minor Basin (model results summarized by river segment). Note that this section is not intended to document in detail the methods and assumptions for the VAHydro model or for the scenarios and metrics discussed. More documentation of the model and assumptions can be found in Chapter 4.

The VAHydro surface water model was used to simulate streamflow under a variety of scenarios. Demand scenarios examine how streamflow is impacted under 2030 or 2040 demands as compared to current (2020) demands. Demands were calculated based on current and future demand information submitted through local and regional water supply plans. Climate change scenarios examine how streamflow is impacted when 2040 demands are simulated in conjunction with a range of precipitation and temperature conditions that may occur in the future due to changing climate (Dry, Median, Wet scenarios). Finally, the exempt user scenario examines impacts from users excluded, or exempt, from VWP permit requirements per Va. Code § 62.1-44.15:22 B. Exempt users were simulated at the maximum possible demand identified through a review of demand justification values commonly asserted by exempt users, including but not limited to VDH pump capacity, maximum pre-1989 withdrawal, and maximum intake capacity. In order to effectively manage surface water resources and address the uncertainty related to these demands, DEQ determined the most conservative, or maximum possible, demand should be evaluated in this scenario. However, DEQ does not agree that the maximum values used in this scenario represent an allocation for, or the expectation of, a future withdrawal of that volume; nor does DEQ concede that any particular exempt user is necessarily entitled to withdraw any particular maximum value used in this scenario. The methods and assumptions for each of these modeling scenarios are discussed in more detail in Chapter 4.

For each scenario described above, different metrics can be used to evaluate the simulated streamflow. A metric is a method for measuring or evaluating a given set of data; different metrics can be evaluated to answer different questions. Within this section the following metrics will be discussed: the lowest 30 day

flow (L30), the lowest 90 day flow (L90), 7Q10, and overall change in flow. The L30 describes the lowest consecutive 30 day average daily streamflow over the simulation period. This metric is a representation of a short-term, or acute drought, and is a good metric for evaluating impacts to direct withdrawals without storage. Similarly, the lowest 90 day flow represents the lowest consecutive 90 day average daily streamflow over the simulation period. This would represent a prolonged drought and is often used to evaluate impacts to reservoirs. The 7Q10 is the lowest 7-day average flow that occurs (on average) once every 10 years. 7Q10 is generally used in the evaluations of in-stream beneficial uses such as waste assimilative capacity. Overall change in flow describes the net loss of water from the riverine system as a result of off-stream use not otherwise returned through point source discharges, or losses due to evapotranspiration. This metric is useful for evaluating impacts to aquatic life and is discussed in more detail in Chapter 4.

Demand Scenarios: 2020 demand or current demand, 2030 demand, and 2040 demand scenarios were simulated. The following series of figures compares the 2030 and 2040 demand scenarios to the current demand scenario. The change in flow depicted on each map is the change expected when comparing two scenarios - in this case future demands compared to current demands. Each page includes two figures comparing either the 2030 or 2040 demand scenario to current demand using the L30, L90, and 7Q10 metrics. This allows for comparisons of simulated impacts between the 2030 and 2040 demand scenarios. The scenarios and metrics are identified in the paragraph below and in the figure captions.

Figures 97 and 98 compare the lowest 30 day flow simulated with the current demand scenario with the lowest 30 day flow simulated in the 2030 and 2040 demand scenarios respectively. Figures 99 and 100 compare the lowest 90 day low flow simulated with the current demand scenario with the lowest 90 day flow simulated in the 2030 and 2040 demand scenarios respectively. Figures 101 and 102 compare the 7Q10 simulated with the current demand scenario with the 7Q10 simulated in the 2030 and 2040 demand scenarios respectively.

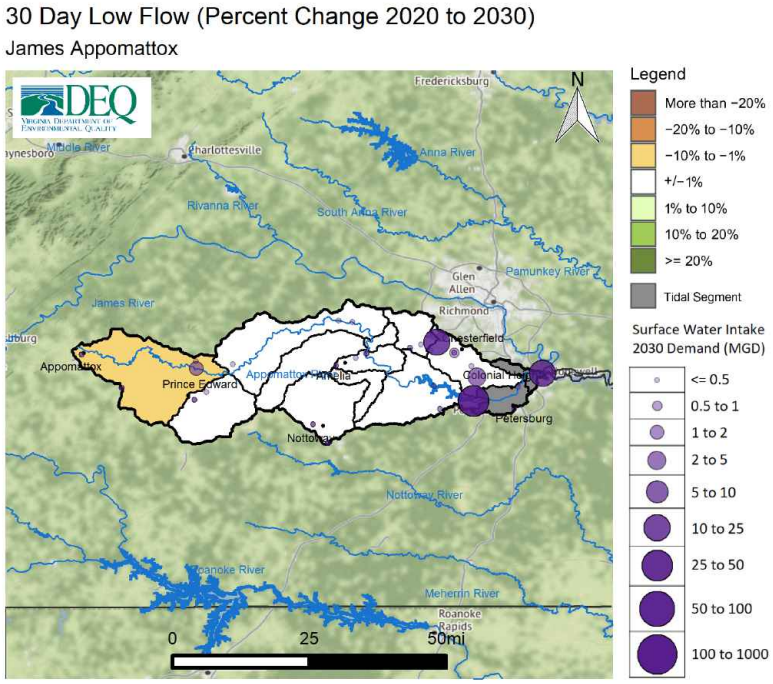

Figure 97: Change in 30 day low flow between 2020 and 2030 demand scenarios within the James Appomattox Minor Basin

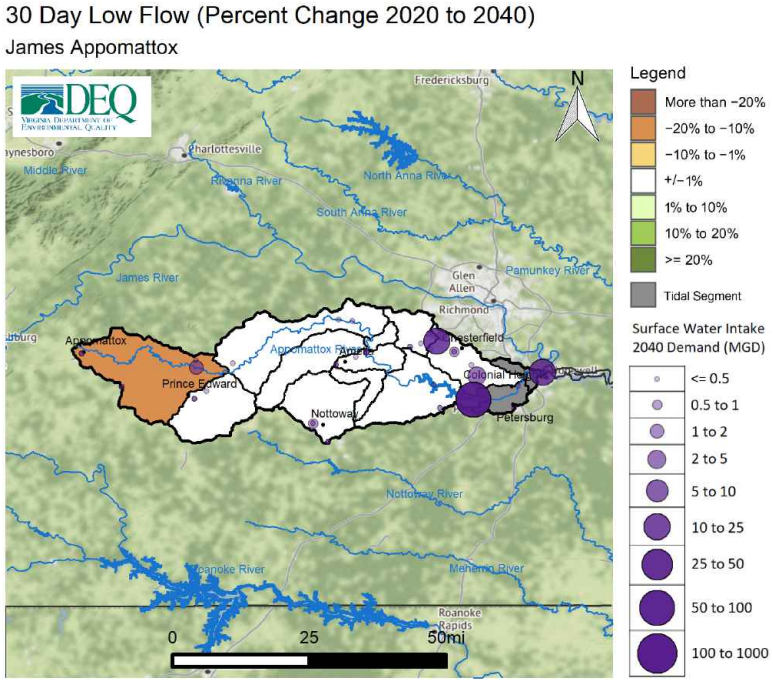

Figure 98: Change in 30 day low flow between 2020 and 2040 demand scenarios within the James Appomattox Minor Basin

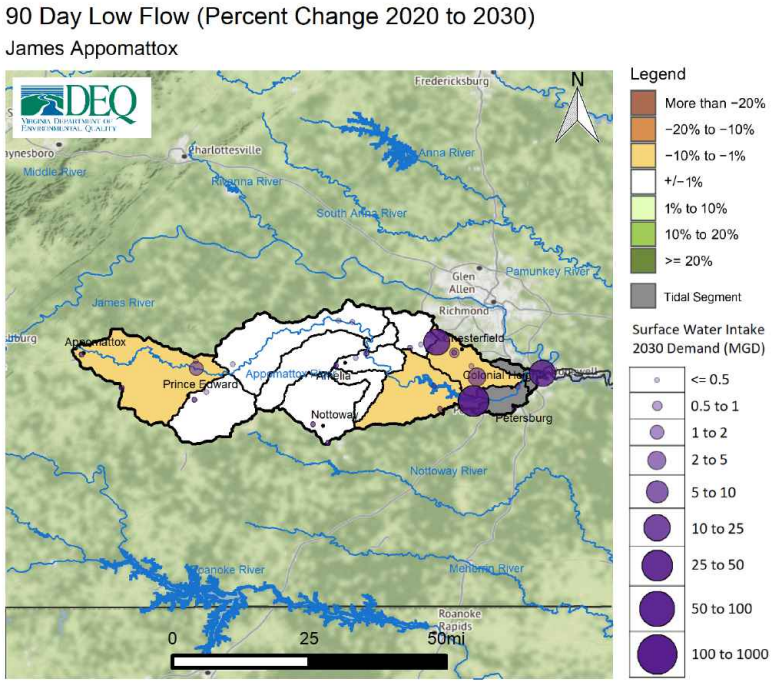

Figure 99: Change in 90 day low flow between 2020 and 2030 demand scenarios within the James Appomattox Minor Basin

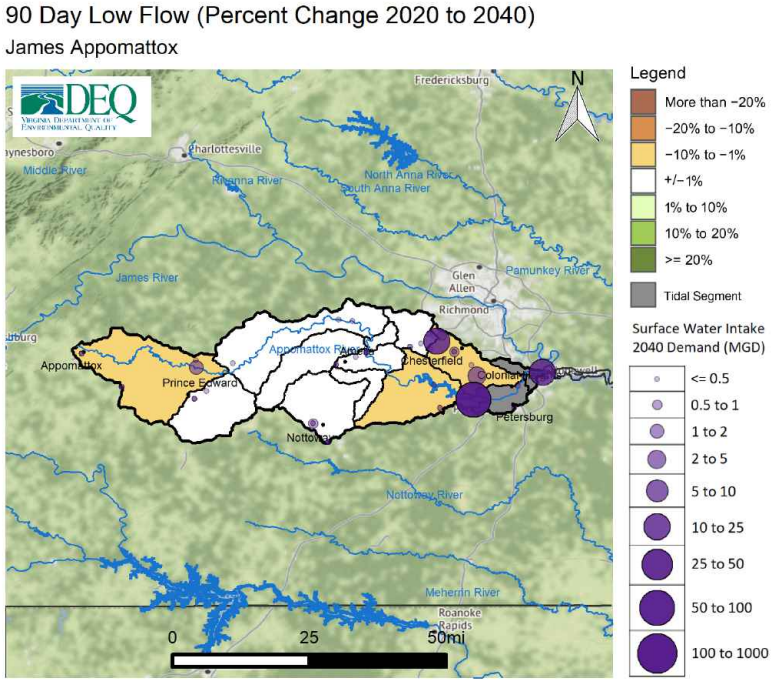

Figure 100: Change in 90 day low flow between 2020 and 2040 demand scenarios within the James Appomattox Minor Basin

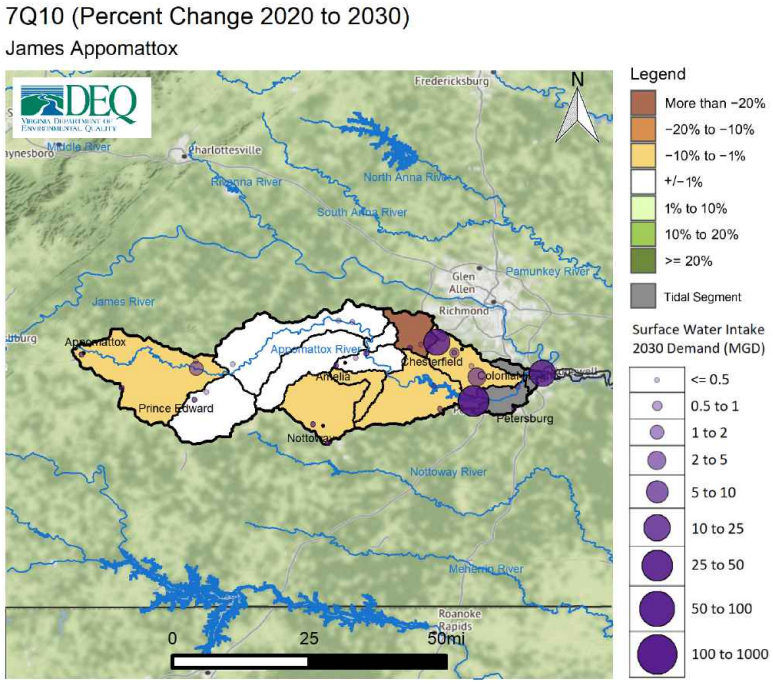

Figure 101: Change in 7Q10 between 2020 and 2030 demand scenarios within the James Appomattox Minor Basin

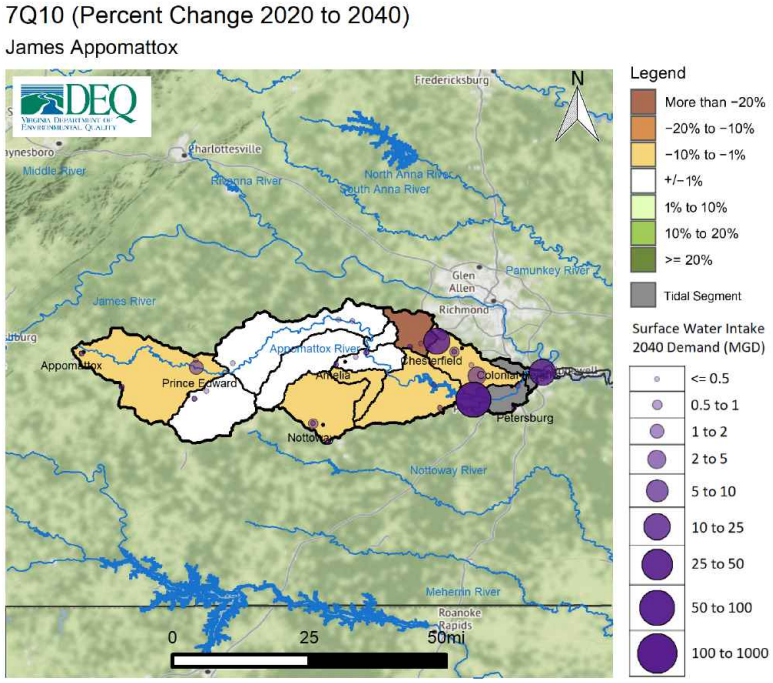

Figure 102: Change in 7Q10 between 2020 and 2040 demand scenarios within the James Appomattox Minor Basin

The figures above show a comparison between two scenarios. An additional way to evaluate impacts to streamflow is to examine the total reduction in streamflow resulting from all withdrawals within a river segment, as well as losses due to evapotranspiration, while taking into consideration any discharges back to the source. To use a common industry term, the overall change in flow metric evaluates "consumptive use", or the amount of water removed from the river that is not returned through discharges. This can help describe potential impacts to downstream withdrawals, while also providing a basis for evaluating impacts to aquatic life. In general, total reductions in streamflow can result in a reduction in aquatic biodiversity.[75] The relationship between streamflow and aquatic biodiversity is discussed in more detail in Chapter 4. Figure 103 shows the overall change in streamflow for the 2030 Demand Scenario, while figure 104 shows the overall change in streamflow for the 2040 Demand Scenario.

[75] Rapp, J.L., R. Burgholzer, J. Kleiner, D. Scott, and E. Passero. 2020. "Application of a New Species-Richness Based Flow Ecology Framework for Assessing Flow Reduction Effects on Aquatic Communities." Journal of the American Water Resources Association 1–14.https://doi.org/10.1111/1752-1688.12877.

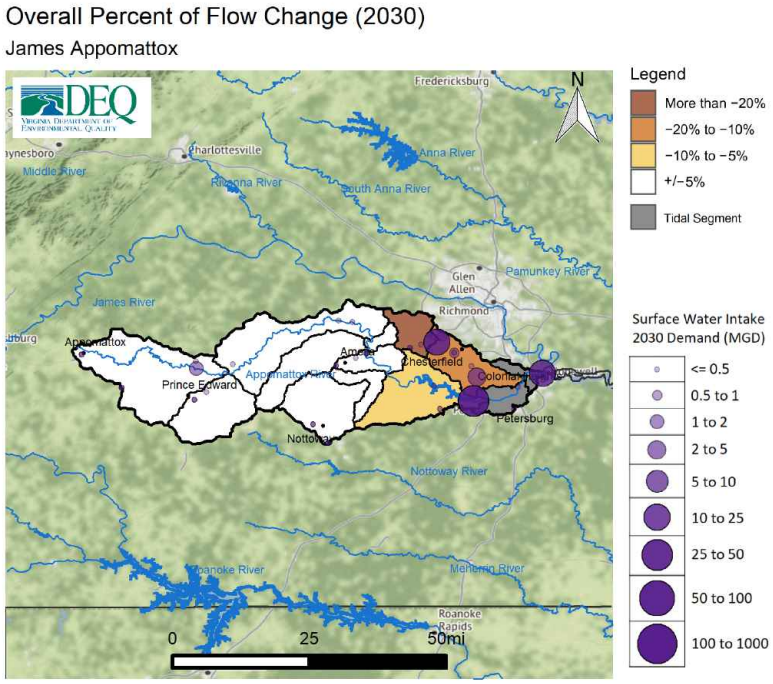

Figure 103: Overall change in flow in percent for 2030 demand scenario within the James Appomattox Minor Basin

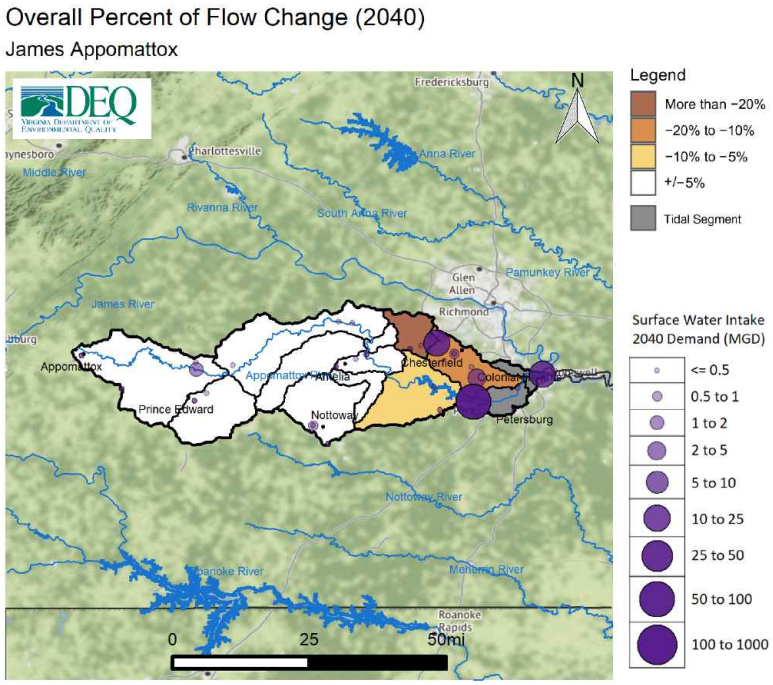

Figure 104: Overall change in flow in percent for 2040 demand scenario within the James Appomattox Minor Basin

Climate Scenarios: Three scenarios that simulate impacts to streamflow in response to changes in temperature and climate were completed for areas in the state where climate data was available, which includes the portions of the Commonwealth located in the Chesapeake Bay watershed. Details on the methods and assumptions employed for these scenarios can be found in Appendix B. The three scenarios can be described as dry, median, and wet scenarios. Virginia is expected to experience a range of precipitation and temperature changes that may vary spatially and from year to year. The potential for both more severe and prolonged droughts as well as for higher intensity and more frequent rain events must be considered. These three scenarios are not intended as predictions of future climate conditions, but as representations of several possibilities that climate change models indicate could occur. Should they occur, these results provide an evaluation of how streamflows may be impacted. Their purpose is to build upon existing climate modeling to provide a foundation for state and local government, as well as other stakeholders, to better evaluate what practical water resource challenges may be associated with the range of climate conditions Virginia could experience.

Figure 105 depicts the percent change in the L30 for the dry climate scenario in conjunction with 2040 demands, as compared to the current climate and demand scenario. Reductions in streamflow in this scenario may be caused by reduced precipitation, increased demand, or as is generally the case, a combination of both. Figures 106 and 107 depict the L30 for the median and wet climate scenarios (in conjunction with 2040 demands) as compared to the current climate and demand scenario.

Figure 108 depicts the percent change in the L90 for the dry climate scenario in conjunction with 2040 demands, as compared to the current climate and demand scenario. Figures 109 and 110 depict the L30 for the median and wet climate scenarios (in conjunction with 2040 demands) as compared to the current climate and demand scenario.

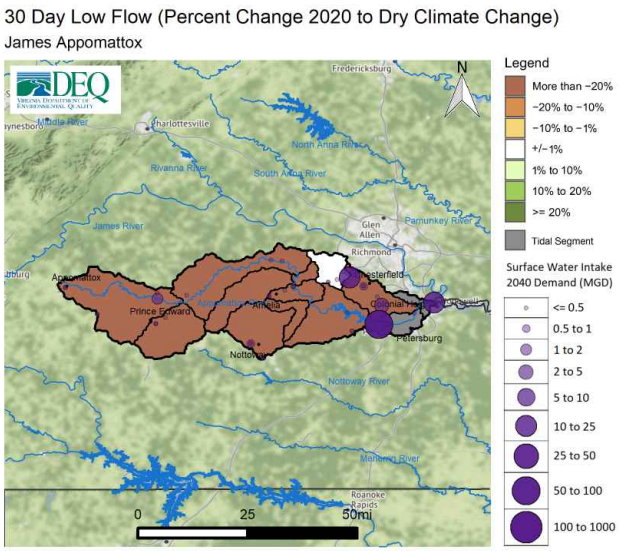

Figure 105: Change in 30 day low flow between current climate/demand scenario and the dry climate/2040 demand scenario within the James Appomattox Minor Basin

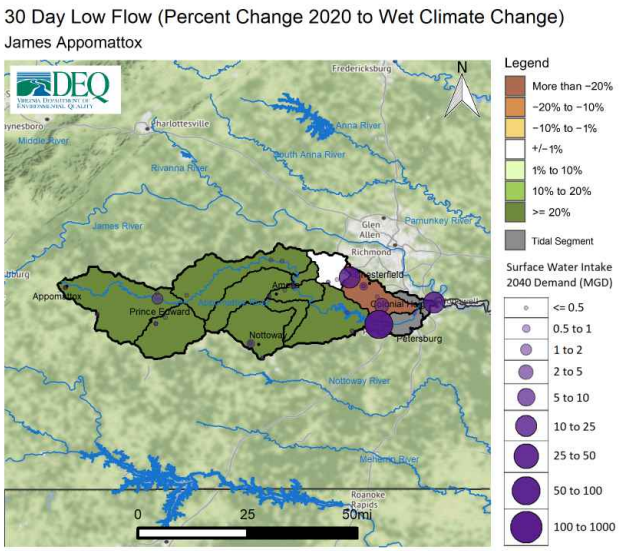

Figure 107: Change in 30 day low flow between current climate/demand scenario and the wet climate/2040 demand scenario within the James Appomattox Minor Basin

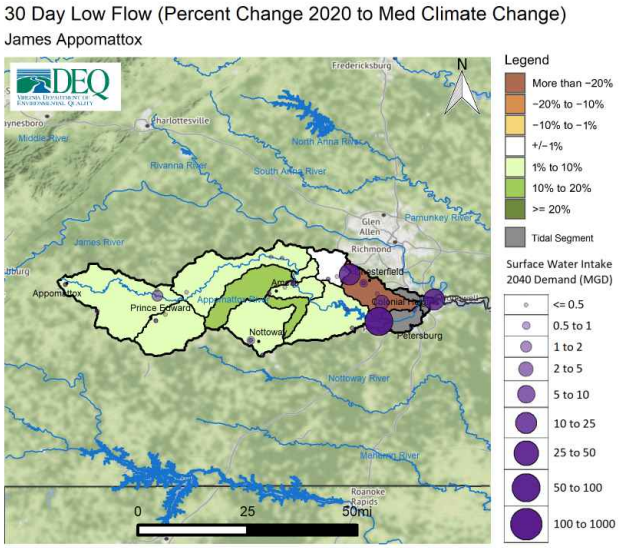

Figure 106: Change in 30 day low flow between current climate/demand scenario and the median climate/2040 demand scenario within the James Appomattox Minor Basin

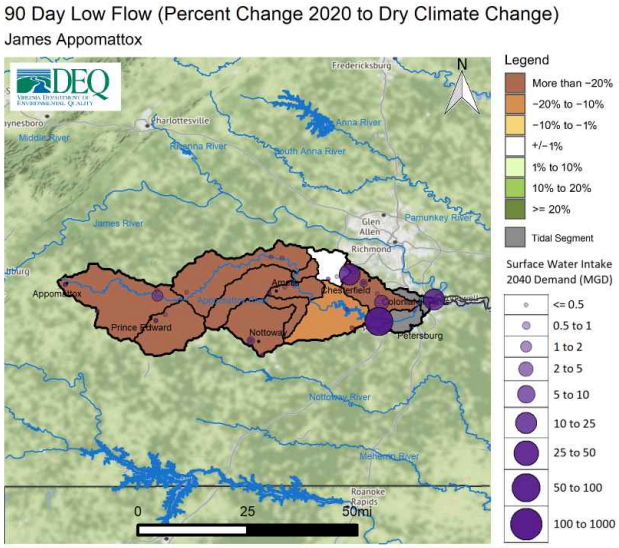

Figure 108: Change in 90 day low flow between current climate/demand scenario and the dry climate/2040 demand scenario within the James Appomattox Minor Basin

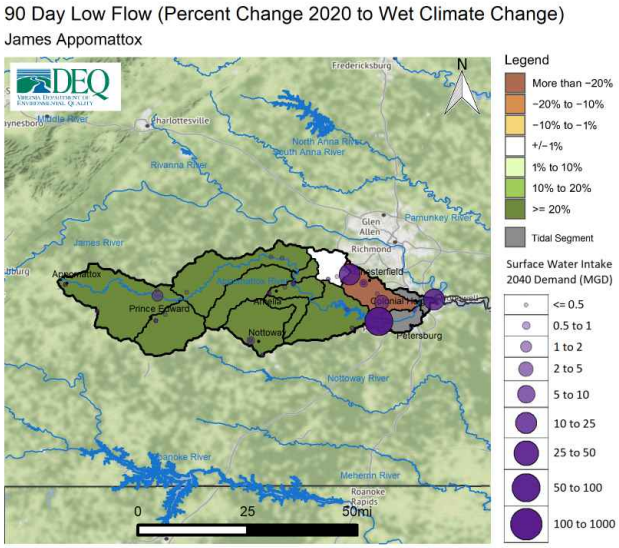

Figure 110: Change in 90 day low flow between current climate/demand scenario and wet climate/2040 demand scenario within the James Appomattox Minor Basin

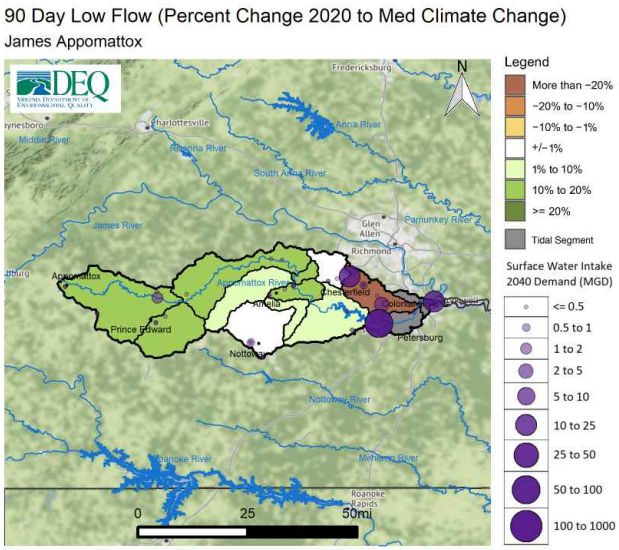

Figure 109: Change in 90 day low flow between current climate/demand scenario and median climate/2040 demand scenario within the James Appomattox Minor Basin

Exempt User Scenario: The exempt user scenario simulates the maximum possible exempt demand for users excluded from Virginia Water Protection permitting requirements per Va. Code § 62.1-44.15:22 B, in combination with the permitted withdrawal limits for those users that are permitted. A more detailed discussion of the data and assumptions used in this scenario can be found in Appendix B. Note that this scenario uses current climate conditions. Figure 111 depicts the percent change in 30 day low flow between the exempt user scenario and current (2020) demand. Figure 112 depicts the percent change in 90 day low flow between the exempt user scenario and current (2020) demand. Figure 113 depicts the percent change in the 7Q10 between the exempt user scenario and current (2020) demand. Finally, Figure 114 depicts the overall change in flow in percent (consumptive use) for the exempt user scenario.

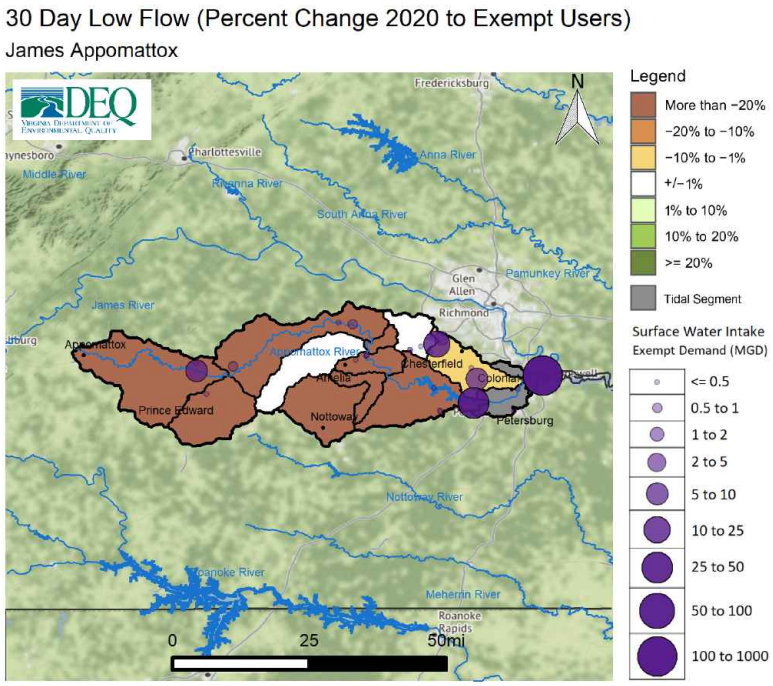

Figure 111: Change in 30 day low flow between current demand scenario and exempt user scenario within the James Appomattox Minor Basin

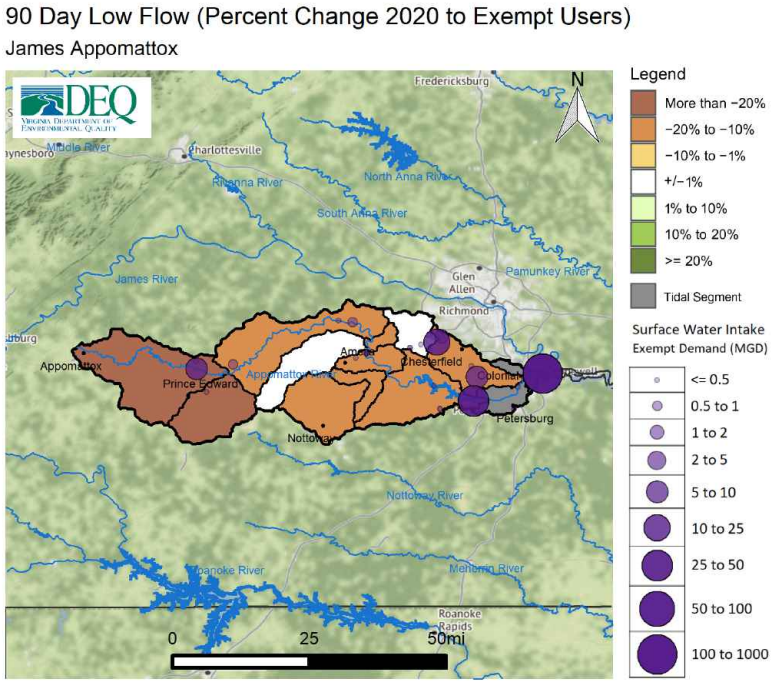

Figure 112: Change in 90 day low flow between current demand scenario and exempt user scenario within the James Appomattox Minor Basin

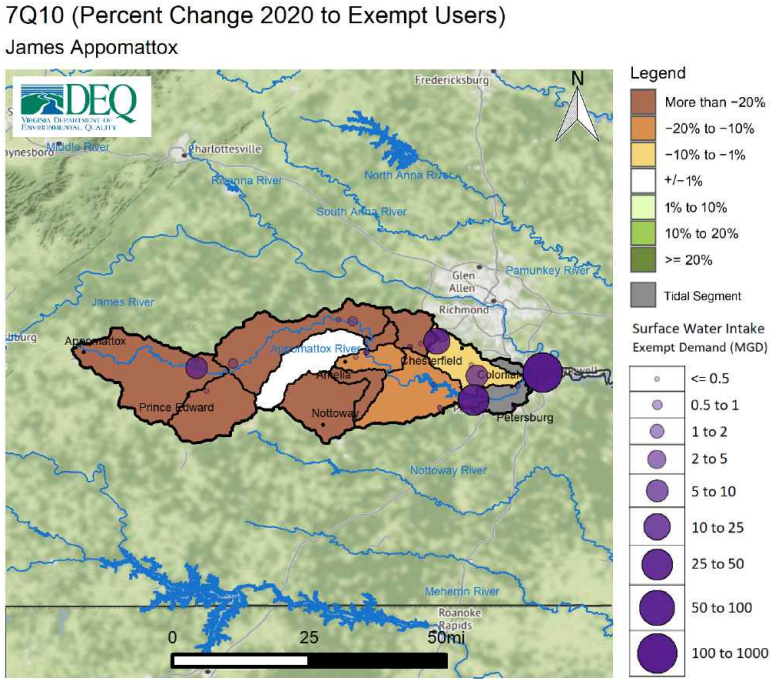

Figure 113: Change in 7Q10 between current demand scenario and exempt user scenario within the James Appomattox Minor Basin

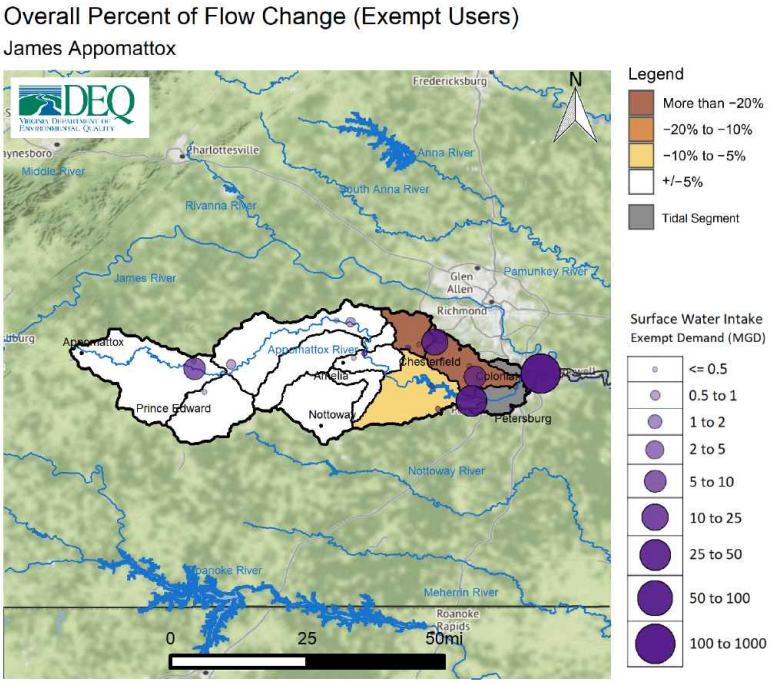

Figure 114: Overall change in flow in percent for exempt user scenario within the James Appomattox Minor Basin

Potential Unmet Demand: Potential unmet demand was evaluated for all facilities within the basin for each scenario. Potential unmet demand is the portion of surface water demand for a specific facility that is limited by available streamflow as simulated in a given model scenario, including any known operational limits such as flow-by requirements. This unmet demand, if realized, could be managed through water conservation, through alternative sources, operational changes, or from available storage. Absent of these or other options, this portion of demand could remain unmet. As with all scenarios, demand requirements were determined using demand projections provided in the water supply plans. In the case of the exempt user scenario, the highest possible withdrawal amount was used for users exempt from VWP permitting requirements.

This metric is useful for evaluating where the results seen in the above figures may result in challenges in meeting future demands under a variety of conditions including increasing demands in the basin, changing climate, or withdrawals from users exempt from permitting requirements. Table 30 provides for each facility the highest average daily potential unmet demand over a 30 day period over the course of the simulation for the following scenarios: 2020 demand, 2030 demand, 2040 demand, dry climate, and exempt user. Only facilities showing potential unmet demand in at least one scenario appear on this table. The dry climate scenario is selected among the climate scenarios as the dry scenario represents the potential for increased drought intensity and frequency, and therefore poses the greatest challenge for water supply.

Table 30: Change in Highest 30 Day Potential Unmet Demand (MGD) in James Appomattox Minor Basin

Facility	**2020 Demand**	**2030 Demand**	**2040 Demand**	**Dry Climate**	**Exempt User**
Swift Creek WTP	0.00	0.00	0.00	0.00	12.38
Jack Stone Quarry	1.62	2.32	3.02	2.64	5.15
Farmville Service Area	0.00	0.00	0.03	0.00	4.09
Sandy River Reservoir Intake	0.00	0.00	0.00	0.00	2.95
Dale Plant	0.00	0.00	0.00	0.00	1.29
Midlothian Quarry	0.39	0.51	0.61	0.55	1.13
Reamford Farms	0.00	0.00	0.00	0.00	0.80
Magnolia Green Golf Club	0.00	0.00	0.00	0.00	0.02
Chester Golf Club	0.00	0.00	0.00	0.00	0.01

* Climate scenarios were not completed in areas located outside of the Chesapeake Bay watershed

Note: Potential unmet demand is the portion of surface water demand for a specific facility that is limited by available streamflow as simulated in a given model scenario, including any known operational limits such as flow-by requirements. This unmet demand, if realized, could be managed through water conservation, alternative sources, operational changes, or from available storage.

A.3.6 Spatial Overview of Groundwater Demands

The cumulative impact analysis figures above provide an overview of surface water demands in the basin but did not include groundwater demands. A substantial portion of the demands in this basin are supplied by groundwater. Figure 115 identifies the location and size of projected groundwater demands in the basin for 2040 based on information provided by localities in water supply plans.

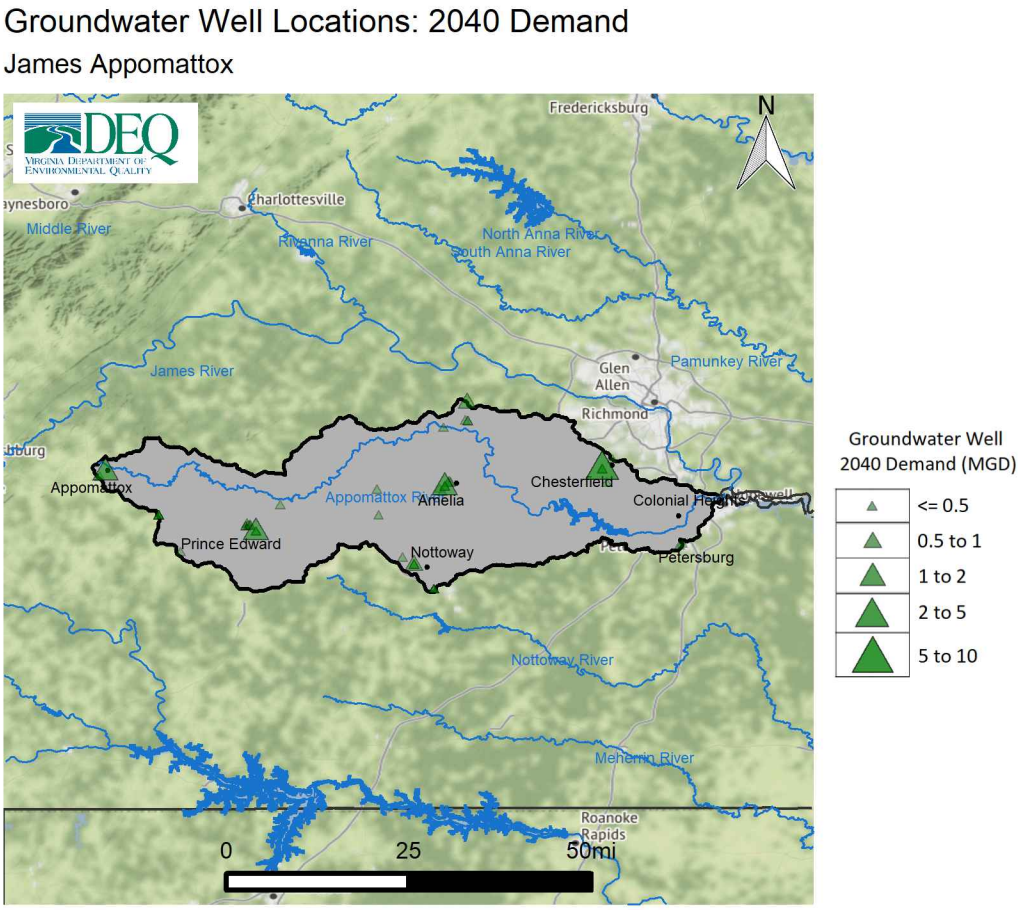

Figure 115: Projected 2040 Groundwater Demands in the James Appomattox Minor Basin

A.3.7 Trends and Goals

The Code of Virginia mandates that the State Water Control Board should take into consideration the principle that "adequate and safe supplies shall be preserved and protected for human consumption, while conserving maximum supplies for other beneficial uses".[76] This principle is the key driver of the challenges in water resource management, which is that all beneficial uses must be adequately considered when evaluating impacts to surface water resources. The State Water Control Board is tasked with ensuring that water supply quantity needs are met at all times while also protecting Virginia's natural resources, and furthermore, ensuring equitable allocation during a time of shortage.[77] While evaluating and planning for the long-term sustainability of water supply for Virginia is the primary goal for the State Plan, evaluating and limiting impacts to in-stream beneficial uses such as aquatic habitat life is also part of DEQ's responsibility.

The primary purpose of this section is to identify where the most significant challenges to long-term sustainability of water supply and other beneficial uses are indicated based on the CIA and information collated from local water supply plans within this basin. Goals for future planning and areas for additional data collection or analysis are also suggested where appropriate.

The CIAs were completed using the best available data and methods known to DEQ. This discussion focuses on the evaluation of trends - in other words the prevailing tendency or inclination. This means evaluating whether streamflow is simulated to increase or decrease in a given scenario, and by how much. A relative trend indicating reductions of greater than or equal to 10% in streamflow, whether driven by demand increases, changing climate conditions, or exempt user demands was considered a threshold for potential impacts to beneficial uses. The following summarize the key trends or goals for this basin:

- **Demand Scenarios:** Surface water demand in the James Appomattox Minor Basin is projected to increase by 39% between 2020 and 2040, primarily supporting large increases in CWS demand throughout the basin. Impacts to streamflows from the projected increases in surface water demands are simulated within the watershed, with a greater than 10% flow reduction in short-term drought (L30) and overall percent of flow change. Simulated reductions in short term drought are driven by increased withdrawals from the Appomattox River to support increased demands within the Town of Farmville Service Area. The Town of Farmville is the primary water supplier within the river segment, and currently does not operate under a VWP permit and does not have required flow-by limits. Increases in demand and operational rules also result in a more than 20% reduction in overall flow below Swift Creek Reservoir. A reduction of less than 10% in overall flow occurs below Lake Chesdin as a result of 2040 demands. Lake Chesdin is the primary water source for the Appomattox River Water Authority, and supplies drinking water to five localities including Chesterfield, Petersburg, Dinwiddie, Colonial Heights, and Prince George. Lake Chesdin operates primarily as a public water supply reservoir under VWP 01-1719 and includes power generation when storage is over 158 ft above sea level. Potential unmet demand as a result of increased demands was not simulated to occur for any public water supplier in the 2030 or 2040 demand scenario.
- **Climate Scenarios:** Current climate modeling suggests Virginia will generally receive more precipitation on average in the future. However, data also suggests the possibility of more severe droughts despite overall trends in increased precipitation. The dry climate scenario results in reductions in short (L30) and long term (L90) drought in the majority of the basin of more than 20% when compared to the current demand and climate scenario. Simulations show short-term and long-term droughts with potential reductions in streamflows greater than 20% lower than those experienced during previous significant droughts, which would result in broad impacts to public water supply as well as aquatic life and other beneficial uses during these periods. Potential unmet demand is not simulated to occur for any public water supplies in the dry climate scenario, which is largely because the major demands in the area are met with storage that helps mitigate drought impacts.

[76] § 62.1-44.36 of the Code of Virginia
[77] 9VAC25-390-20.1

- **Exempt User Scenario:** The exempt user scenario models cumulative maximum possible exempt demands from all users exempt from VWP permitting requirements. Reductions in streamflow of more than 20% occur during simulated short term drought (L30), long term drought (L90), 7Q10, and overall reduction in flow metrics when compared to current demands. The greatest reductions to short term L30 flows occur within West Creek, Bushy River, and the Appomattox River above Farmville. L30 reductions are driven by withdrawals from irrigation users in West Creek and the Town of Farmville's Appomattox River intake. Simulated streamflow reductions in the Bushy River for the exempt user scenario are driven by inclusion of the proposed demands associated with the Sandy River Reservoir project in Prince Edward County. Prince Edward County was issued VWP 05-1464 authorizing construction of a reservoir and intake. This withdrawal was included in the 2040 demand and exempt user scenario, however since the reservoir has not yet been constructed it was excluded from the 2020 demand scenario. The largest streamflow reductions from simulated maximum possible exempt demands occur within Swift Creek Reservoir, Swift Creek, and Lake Chesdin. The largest impacts and maximum possible exempt demands are from exempt public water supply intakes within Swift Creek Reservoir. The Town of Farmville's Appomattox River intake is the primary driver of reductions in the head water portions of the watershed with more than a 20% reduction in simulated short and long term drought. Additionally, withdrawals from Swift Creek Reservoir are simulated to reduce overall downstream flows by more than 20% when compared to the current demand scenario. These results indicate that the cumulative maximum possible exempt demands in the basin exceed the water budget in many river segments. Preserving water supply and other beneficial uses will require managing these demands with respect to their cumulative impacts and in the context of the available resources in the basin.

A.4 Upper James Minor Basin

A.4.1 Watershed Overview

Beginning along the Virginia/West Virginia state line, the James River is formed by the confluence of the Jackson and Cowpasture rivers in the Allegheny Mountains. The James River flows 242 miles to the fall-line at Richmond, and another 106 miles before it enters the Chesapeake Bay. Spanning across four physiographic provinces, the topography and climate of the James River Basin varies throughout. The Upper James portion originates in the elongated parallel ridges and valleys that define the Valley and Ridge Province, and flows eastward into the Blue Ridge Province. With distinctive highland topography and dramatic elevation changes, the Blue Ridge Province differs from the Valley and Ridge. It is characterized by rugged terrain with steep slopes and narrow ridges in the north that gradually subside to moderate slopes in the south. The Lower James River Basin begins as the river moves through the Piedmont Province, flowing through scattered hills and small mountains that gradually develop into gently rolling slopes and lower elevations moving east towards the fall-line. The fall-line is a distinct three-mile stretch of river that separates the Piedmont from the Coastal Plain. Running through the City of Richmond the river descends 84 ft of elevation and exits the hard resistant rocks of the Piedmont into the softer sediments of the Coastal Plain before entering the Chesapeake Bay.

The total spatial area of the Upper James Minor Basin occupies 7,904 sq. miles and includes all or portions of the localities listed in Table 31. The major population centers within the basin include the cities of Lexington and Buena Vista. The basin is generally rural with mixes of forests and farmland.

A.4.2 Existing Water Sources

Major surface water sources within the basin include the James River, Jackson River, Maury River, Catawba Creek, and several large springs. Groundwater within the basin is primarily withdrawn from bedrock aquifers. There are more groundwater sources than surface water sources, but as is typical elsewhere in the state, surface water makes up the majority of demand. Usage of spring water for community water systems is more common within the Upper James than elsewhere in the state. Major surface water impoundments include Lake Moomaw (Gathright) and the Bath County Pumped Storage Facility. Withdrawals within the basin are used for public water supply as well as for agriculture, irrigation, commercial, and industrial/manufacturing.

The location of wells and surface water intakes identified to DEQ within the basin are shown in Figure 116. This map also shows locations of any Instream Flow Incremental Method (IFIM) studies completed in the basin. Surface water sources are spread throughout the basin while groundwater sources are concentrated in the southern and western portions of the basin.

Table 31: Population Trend by Locality in Upper James Basin

Localities	20 Year % Change
Alleghany	-18.69
Amherst	-3.87
Augusta	9.92
Bath	-19.00
Bedford County	12.05
Botetourt	5.22
Craig	-3.72
Giles	-2.03
Highland	-16.69
Montgomery	13.10
Nelson	-0.94
Roanoke County	5.24
Rockbridge	4.45
Buena Vista	-3.74
Covington	-14.91
Lexington	3.37

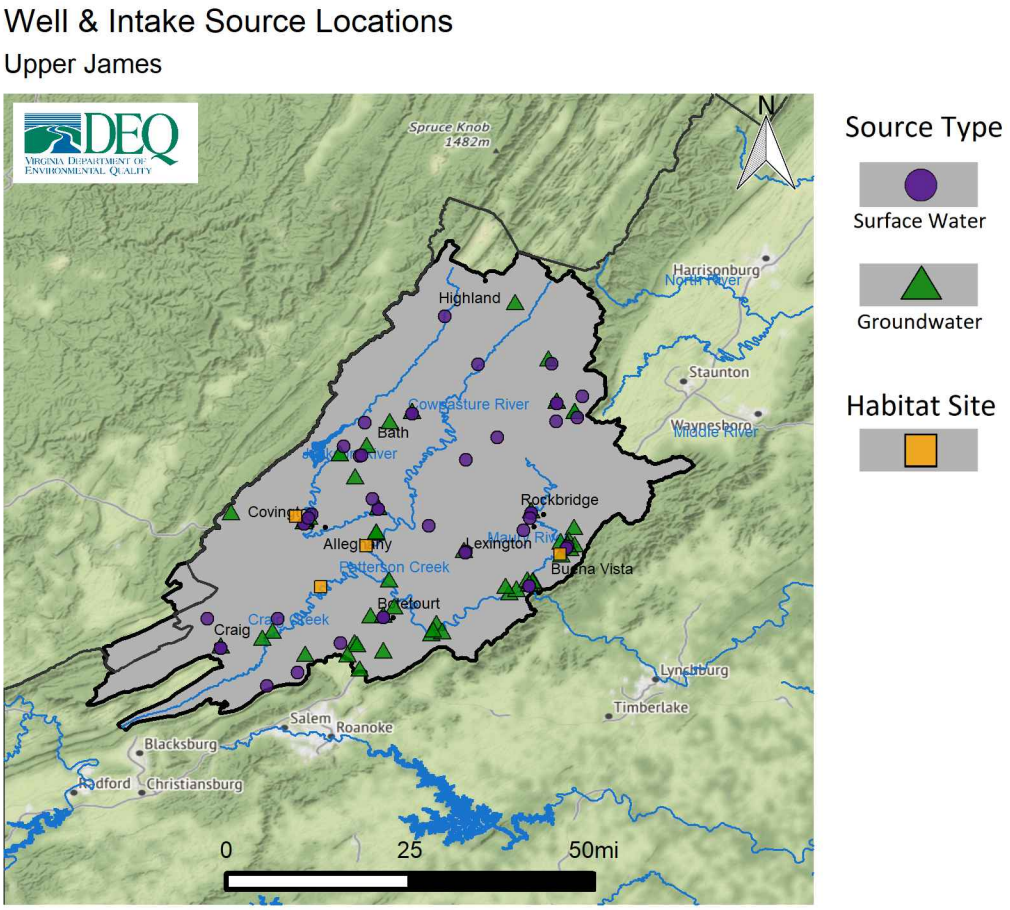

Figure 116: Spatial distribution of groundwater wells and intakes in the Upper James Minor Basin

A.4.3 Existing Water Use

The following section discusses existing (current) water use within the basin, which is based on existing demand information submitted to DEQ in the water supply plans. Table 32 provides a summary of all demands within the basin by system type and source type including power generation. It also provides a count of surface water or groundwater sources associated with each system type.

Table 32: Summary of Upper James Minor Basin Water Demand by Source Type and System Type (including Power Generation)

System Type	Source Count	2020 Demand (MGD)	2030 Demand (MGD)	2040 Demand (MGD)	20 Year Percent Change
Surface Water					
Agriculture	7	18.38	18.86	19.34	5.25
CWS	10	9.03	9.69	10.35	14.65
Large SSU	10	39.57	39.58	39.60	0.05
Small SSU	N/A	0.00	0.00	0.00	0.00
Total SW	**27**	**66.98**	**68.13**	**69.29**	**3.45**
Groundwater					
Agriculture	1	0.14	0.18	0.22	54.17
CWS	48	2.30	2.44	2.58	12.51
Large SSU	7	1.08	1.08	1.09	1.04
Small SSU	N/A	6.11	6.45	6.80	11.17
Total GW	**56**	**9.63**	**10.15**	**10.69**	**11.01**
Total (SW + GW)					
Agriculture	8	18.52	19.04	19.56	5.63
CWS	58	11.33	12.13	12.94	14.22
Large SSU	17	40.65	40.67	40.68	0.08
Small SSU	N/A	6.11	6.45	6.80	11.17
Minor Basin Total	**83**	**76.61**	**78.29**	**79.98**	**4.40**

* Small SSU demands are county-wide estimates of private well usage below 300,000 gallons a month. The number of private wells is not known.

The total existing demand from all surface and groundwater sources is approximately 76.61 MGD, with groundwater supplying approximately 9.63 MGD or 12.57% of total water demands. Surface water demand within the basin totals approximately 66.98 MGD, or 76.61% of current demands. Surface water comprises the majority of demand in the Upper James Minor Basin, which is consistent with water use in Virginia statewide.

The five largest withdrawals for each source type including power generation are provided in table 33. The largest groundwater withdrawals include the City of Buena Vista's municipal system and Mohawk Industries' Glasgow Plant. The largest surface water withdrawals include Westrock's Covington Plant, which comprises 56% of all surface water demand in the basin, and Coursey Spring Fisheries.

Table 33: Top 5 Users in 2040 by Source Type in the Upper James Minor Basin (including Power Generation)

Facility Name	System Type	Locality	2020 Demand (MGD)	2030 Demand (MGD)	2040 Demand (MGD)	20 Year Percent Change	% of Total Surface Water
Surface Water							
Covington Plant Westrock	Large SSU	Alleghany	39.35	39.35	39.35	0.00	56.79
Coursey Spring Fisheries	AG	Bath	11.91	11.91	11.91	0.00	17.19
Laurel Hill Trout Farm-South Monterey	AG	Highland	3.72	3.72	3.72	0.00	5.37
Tinker Cr-Catawba Cr Diversion	CWS	Botetourt	2.44	2.97	3.49	43.03	5.04
Paint Bank Fish Cultural Sta.	AG	Craig	2.33	2.7	3.08	32.19	4.45
Total SW			59.75	60.65	61.55	3.01	88.83
Groundwater							**% of Total Groundwater**
Buena Vista	CWS	Buena Vista	1.13	1.13	1.13	0.00	10.57
Glasgow Plant Of Mohawk Industries	Large SSU	Rockbridge	0.71	0.71	0.71	0.00	6.64
Buchanan (Town) Service Area	CWS	Botetourt	0.26	0.29	0.32	23.08	2.99
Covington Plant Westrock	Large SSU	Alleghany	0.26	0.26	0.26	0.00	2.43
Craigsville Service Area	CWS	Augusta	0.18	0.19	0.21	16.67	1.96
Total GW			2.54	2.58	2.63	3.54	24.6

Table 32 also provides the proportion of each use category that is supplied by either surface water or groundwater. Use categories include Community Water System (CWS), Large Self-Supplied User (Large SSU), Small Self-Supplied User (Small SSU), and Agricultural Self-Supplied User (AG). These categories are defined below. Surface water demand is primarily comprised of Large SSU and AG demands. Groundwater demand is primarily comprised of Small SSU and CWS demands.

The CWS category includes any public and private waterworks that serve at least 15 service connections used by year-round residents or regularly serve at least 25 year-round residents, and are regulated under the Virginia Department of Health's Waterworks Regulation (12VAC5-590). In the Upper James Minor Basin, approximately 2.30 MGD of groundwater demand and 9.03 MGD of surface water demand is from CWS. Significant groundwater users within this category include the City of Buena Vista, the Town of Buchanan, and the Town of Craigsville. Significant surface water users from this category include the Western Virginia Water Authority Tinker Creek-Catawba Creek Diversion, the Jackson River Water Treatment Plant, the Maury River Water Treatment Plant, and the Clifton Forge Water Treatment Plant.

Large SSUs include any users who withdraw more than 300,000 gallons per month from a well or surface water intake. In the Upper James Minor Basin, approximately 1.08 MGD of groundwater demand and 39.57 MGD of surface water demand is from Large SSUs. Significant groundwater users within this category include Mohawk Industries' Glasgow Plant and Westrock's Covington Plant. Surface water demand in this category is largely from Westrock's Covington Plant which is the largest withdrawal in the basin of any type.

Small SSUs include any non-CWS or AG users who withdraw less than 300,000 gallons per month from wells. Small SSUs generally consist of residential or domestic use for those who live outside service areas and provide their own water. Small SSU demand is generally met with groundwater in the Upper James Minor Basin; approximately 6.11 MGD of groundwater demand is from Small SSUs. Localities within the basin with the greatest contribution from Small SSUs include the Town of Craigsville, Botetourt County, the Town of Glasgow, Craig County, and Alleghany County.

The AG category includes crop farms, livestock operations, aquaculture and other agricultural facilities. In the Upper James Minor Basin, approximately 0.14 MGD of groundwater demand and 18.38 MGD of surface water demand is from AG. Most AG demand is met by surface water in this basin. Significant surface water users from this category include the Coursey Spring Fisheries, the Laurel Hill Trout Farm Blue Spring, and Paint Bank Fish Cultural Station.

A.4.4 Projected Population and Water Use

Projected Population: Trends in water use are generally driven by trends in population change or economic development. Increasing population within an area generally means increased connections for community water systems or additional groundwater demand from homeowners that construct wells. Increasing population in an area also tends to incentivize both new and expanded industrial and commercial water use. Alternatively, the addition of new economic opportunities such as a large employer may include additional water withdrawals for operational needs. Reviewing short and long term population projections can inform water supply planning efforts.

Table 31 shows the projected change in population by percent between 2020 and 2040 for each locality partly or wholly within the basin. More than half of the localities are projected to experience population declines with the greatest declines projected in Bath County (19%) and Alleghany County (18.69%). Several localities are projecting population increases including Montgomery County (13.10%), Bedford County (12.05%), and Augusta County (9.92%). As observed across most of the state, rural communities are observing declining populations over the planning period. Localities with available economic opportunity or major universities are exceptions to this. For example, growth within Montgomery County is largely influence by expansion of Virginia Tech.

Projected Water Use: The following section discusses projected water use through 2040 within the Upper James Minor Basin, based on projections provided in local and regional water supply plans. Table 32, included in the existing demand section above, is the basis for information discussed in this section.

Total demand within the basin is projected to increase from 76.61 MGD to 79.98 MGD in 2040, or approximately 4.40%. As a whole the Upper James Minor Basin is expected to see marginal to moderate increases in demand, primarily driven by increasing CWS and Small SSU demands. Surface water demand is projected to increase by 2.31 MGD, or 3.45%, by 2040. Groundwater demand is projected to increase by 2.31 MGD, or 11%, by 2040. The largest contributors to increasing demands in the basin include projected growth for Western Virginia Water Authority, the Paint Bank Branch Fish Cultural Station, the Maury River Water Treatment Plant as well as for county wide projections for growth in Small SSU and AG demands.

Demand from CWS users within the basin is projected to increase by 14.22% by 2040. Within this category, surface water use is projected to increase by 14.65%, while groundwater use is projected to increase by 12.51%. Increase CWS demand is driven by increasing population and expansion of service areas, and overlaps generally with areas where population is expected to grow.

Demand from Large SSUs within the basin is projected to remain generally constant through 2040. Groundwater use by Large SSUs is projected to increase by approximately 1%, surface water is projected to remain constant over the planning period. This is because Large SSU demand in this basin is dominated by Westrock's Covington Plant which is not projected to increase or decrease in demands through 2040.

Demand from Small SSUs within the basin is projected to increase by 11.17% by 2040. Small SSU demand largely represents domestic residential use supplied by individual wells. Groundwater use is projected to increase a total of 0.69 MGD between 2020 and 2040 within the basin. Craig County, Botetourt County, and the Town of Craigsville project the largest increases in Small SSU demands.

Demand from Agriculture Users within the basin is projected to increase in demand by 5% by 2040. Surface water is the major source for agriculture use in the basin and is projected to increase by 5.25%.

A.4.5 Cumulative Impact Analysis

The following section provides a brief summary of the Cumulative Impact Analysis (CIA) modeling results in the Upper James Minor Basin. Discussion of these results will primarily be found in the Trends and Goals section of this appendix. However a brief overview of the VAHydro model and the scenarios and metrics is provided below.

The VAHydro surface water model simulates streamflow using inputs such as precipitation, climate, land use, and topography, combined with data on all known withdrawals and discharges, and operational rules of major hydrologic features such as reservoirs. Each minor basin is broken into smaller hydrologic subsections, or river segments. The model simulates the water balance on a daily basis for each individual river segment, with each downstream segment being affected by the "cumulative impact" of streamflow changes occurring in upstream segments. The following figures help analyze this cumulative impact within the Upper James Minor Basin (model results summarized by river segment). Note that this section is not intended to document in detail the methods and assumptions for the VAHydro model or for the scenarios and metrics discussed. More documentation of the model and assumptions can be found in Chapter 4.

The VAHydro surface water model was used to simulate streamflow under a variety of scenarios. Demand scenarios examine how streamflow is impacted under 2030 or 2040 demands as compared to current (2020) demands. Demands were calculated based on current and future demand information submitted through local and regional water supply plans. Climate change scenarios examine how streamflow is impacted when 2040 demands are simulated in conjunction with a range of precipitation and temperature conditions that may occur in the future due to changing climate (Dry, Median, Wet scenarios). Finally, the exempt user scenario examines impacts from users excluded, or exempt, from VWP permit requirements per Va. Code § 62.1-44.15:22 B. Exempt users were simulated at the maximum possible demand identified through a review of demand justification values commonly asserted by exempt users, including but not limited to VDH pump capacity, maximum pre-1989 withdrawal, and maximum intake capacity. In order to effectively manage surface water resources and address the uncertainty related to these demands, DEQ determined the most conservative, or maximum possible, demand should be evaluated in this scenario. However, DEQ does not agree that the maximum values used in this scenario represent an allocation for, or the expectation of, a future withdrawal of that volume; nor does DEQ concede that any particular exempt user is necessarily entitled to withdraw any particular maximum value used in this scenario. The methods and assumptions for each of these modeling scenarios are discussed in more detail in Chapter 4.

For each scenario described above, different metrics can be used to evaluate the simulated streamflow. A metric is a method for measuring or evaluating a given set of data; different metrics can be evaluated to answer different questions. Within this section the following metrics will be discussed: the lowest 30 day flow (L30), the lowest 90 day flow (L90), 7Q10, and overall change in flow. The L30 describes the lowest consecutive 30 day average daily streamflow over the simulation period. This metric is a representation of a short-term, or acute drought, and is a good metric for evaluating impacts to direct withdrawals without storage. Similarly, the lowest 90 day flow represents the lowest consecutive 90 day average daily streamflow over the simulation period. This would represent a prolonged drought and is often used to evaluate impacts to reservoirs. The 7Q10 is the lowest 7-day average flow that occurs (on average) once every 10 years. 7Q10 is generally used in the evaluations of in-stream beneficial uses such as waste assimilative capacity. Overall change in flow describes the net loss of water from the riverine system as a result of off-stream use not otherwise returned through point source discharges, or losses due to evapotranspiration. This metric is useful for evaluating impacts to aquatic life and is discussed in more detail in Chapter 4.

Demand Scenarios: 2020 demand or "current demand", 2030 demand, and 2040 demand scenarios were simulated. The following series of figures compares the 2030 and 2040 demand scenarios to the current demand scenario. The change in flow depicted on each map is the change expected when comparing two scenarios - in this case future demands compared to current demands. Each page includes two figures comparing either the 2030 or 2040 demand scenario to current demand using the L30, L90, and 7Q10 metrics. This allows for comparisons of simulated impacts between the 2030 and 2040 demand scenarios. The scenarios and metrics are identified in the paragraph below and in the figure captions.

Figures 117 and 118 compare the lowest 30 day flow simulated with the current demand scenario with the lowest 30 day flow simulated in the 2030 and 2040 demand scenarios respectively. Figures 119 and 120 compare the lowest 90 day low flow simulated with the current demand scenario with the lowest 90 day flow simulated in the 2030 and 2040 demand scenarios respectively. Figures 121 and 122 compare the 7Q10 simulated with the current demand scenario with the 7Q10 simulated in the 2030 and 2040 demand scenarios respectively.

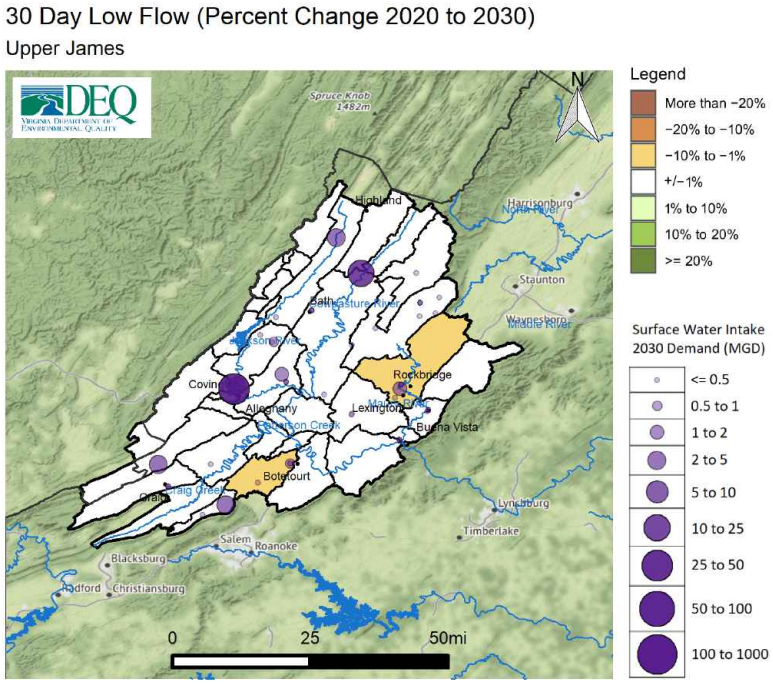

Figure 117: Change in 30 day low flow between 2020 and 2030 demand scenarios within the Upper James Basin

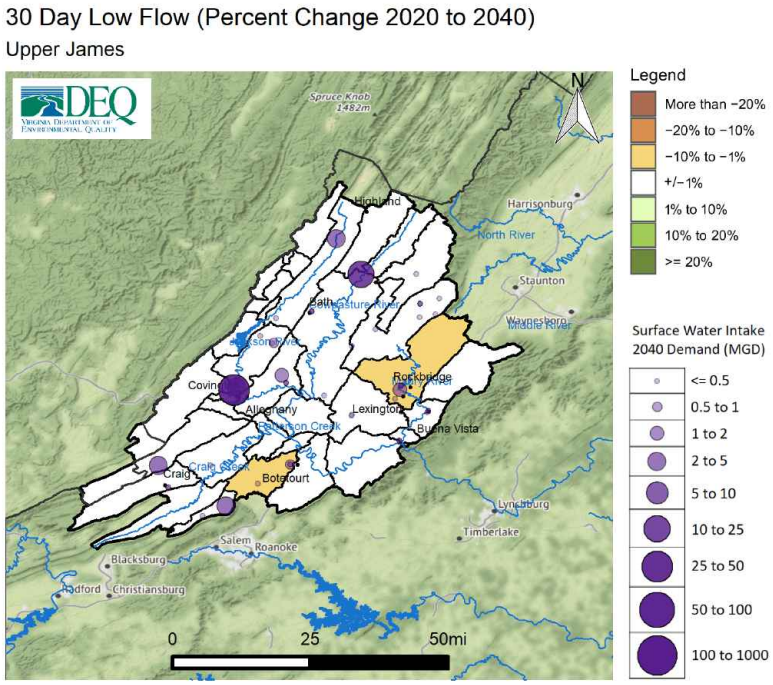

Figure 118: Change in 30 day low flow between 2020 and 2040 demand scenarios within the Upper James Basin

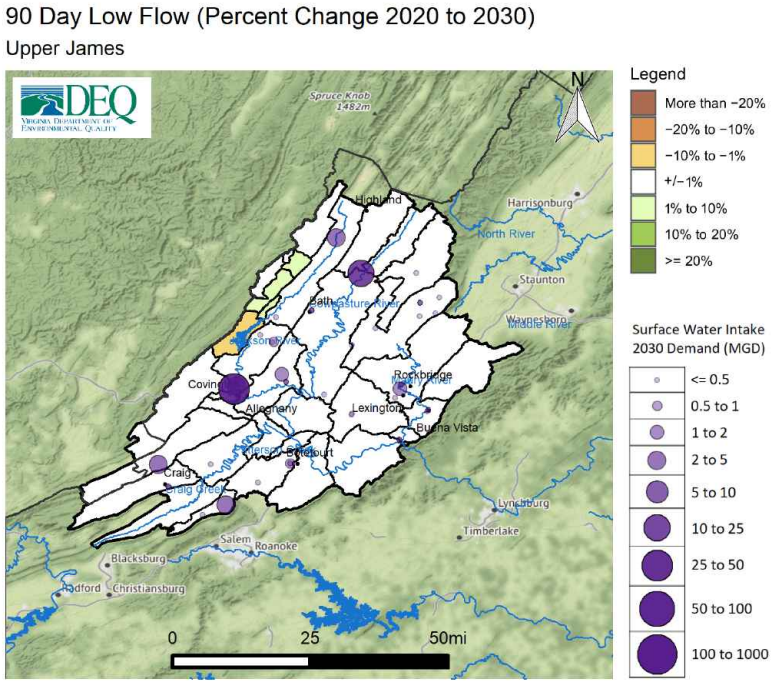

Figure 119: Change in 90 day low flow between 2020 and 2030 demand scenarios within the Upper James Basin

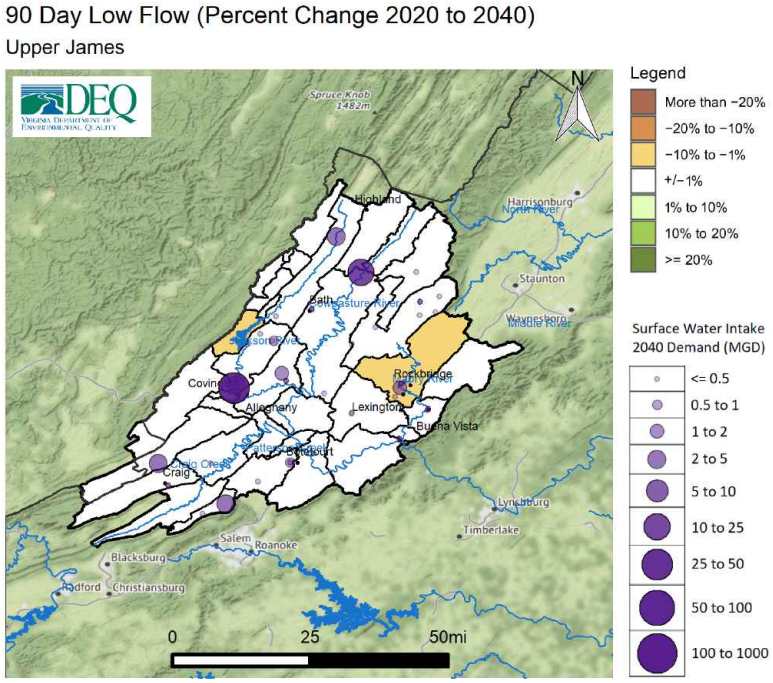

Figure 120: Change in 90 day low flow between 2020 and 2040 demand scenarios within the Upper James Basin

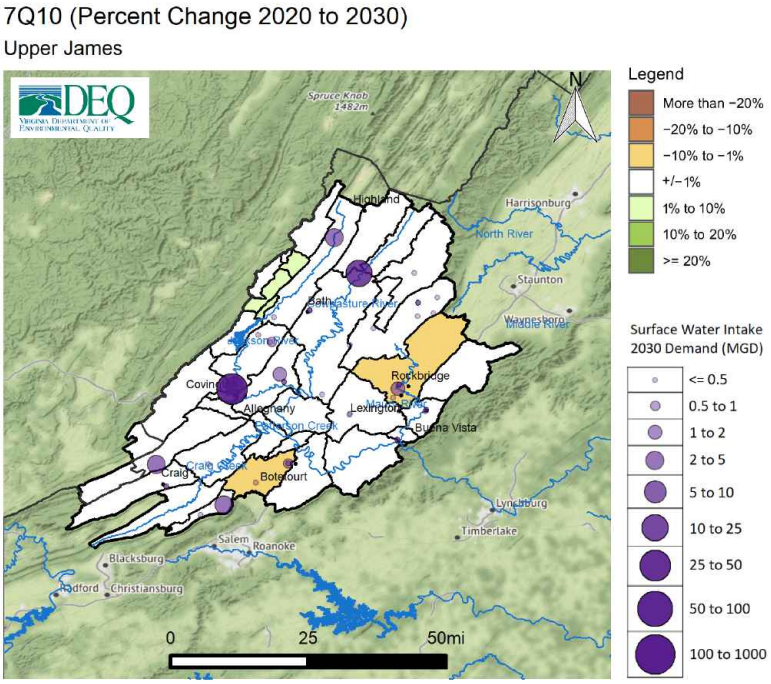

Figure 121: Change in 7Q10 between 2020 and 2030 demand scenarios within the Upper James Basin

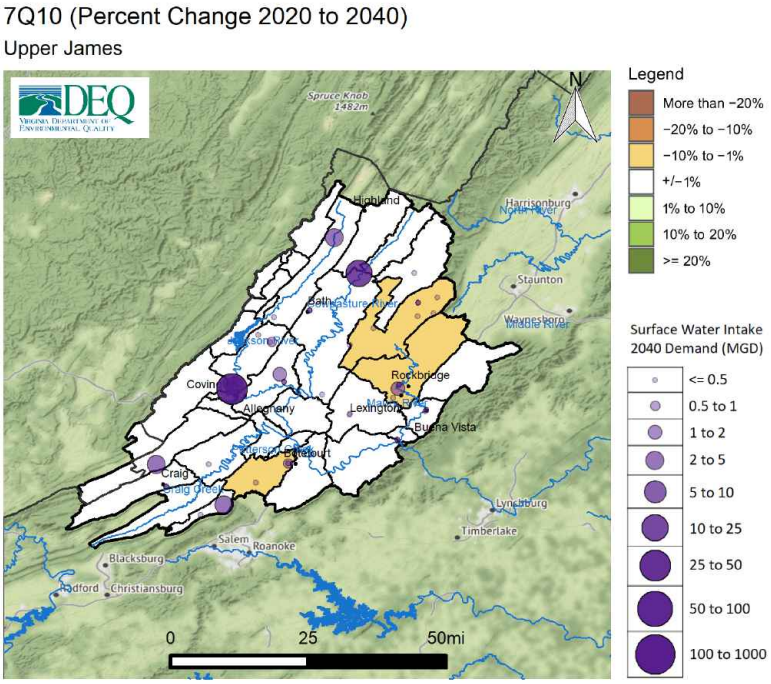

Figure 122: Change in 7Q10 between 2020 and 2040 demand scenarios within the Upper James Basin

The figures above show a comparison between two scenarios. An additional way to evaluate impacts to streamflow is to examine the total reduction in streamflow resulting from all withdrawals within a river segment, as well as losses due to evapotranspiration, while taking into consideration any discharges back to the source. To use a common industry term, the overall change in flow metric evaluates "consumptive use", or the amount of water removed from the river that is not returned through discharges. This can help describe potential impacts to downstream withdrawals, while also providing a basis for evaluating impacts to aquatic life. In general, total reductions in streamflow can result in a proportional reduction in aquatic biodiversity[78]. The relationship between streamflow and aquatic biodiversity is discussed in more detail in Chapter 4. Figure 123 shows the overall change in streamflow for the 2030 Demand Scenario, while figure 124 shows the overall change in streamflow for the 2040 Demand Scenario.

[78]Rapp, J.L., R. Burgholzer, J. Kleiner, D. Scott, and E. Passero. 2020. "Application of a New Species-Richness Based Flow Ecology Framework for Assessing Flow Reduction Effects on Aquatic Communities." Journal of the American Water Resources Association 1–14.https://doi.org/10.1111/1752-1688.12877.

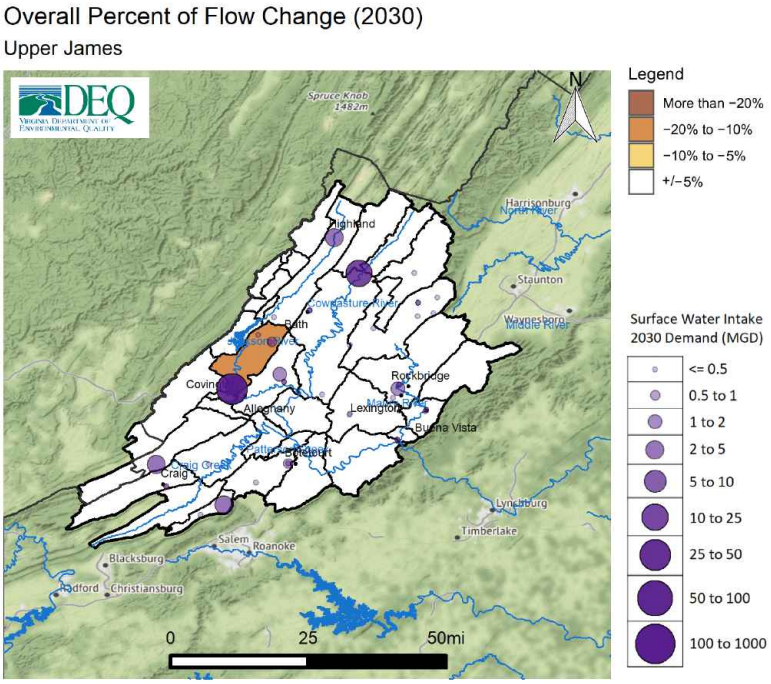

Figure 123: Overall change in flow in percent for 2030 demand scenario within the Upper James Basin

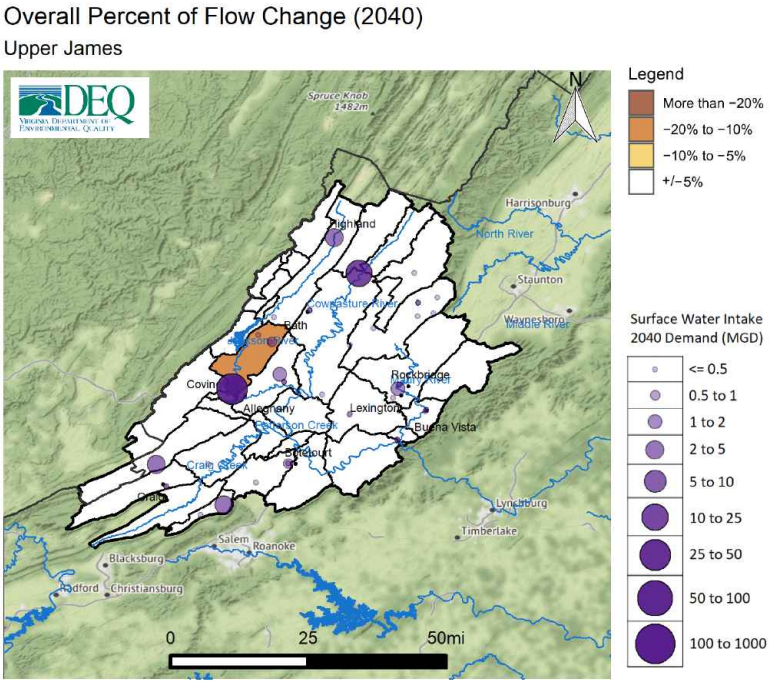

Figure 124: Overall change in flow in percent for 2040 demand scenario within the Upper James Basin

Climate Scenarios: Three scenarios that simulate impacts to streamflow in response to changes in temperature and climate were completed for areas in the state where climate data was available, which includes the portions of the Commonwealth located in the Chesapeake Bay watershed. Details on the methods and assumptions employed for these scenarios can be found in Appendix B. The three scenarios can be described as dry, median, and wet scenarios. Virginia is expected to experience a range of precipitation and temperature changes that may vary spatially and from year to year. The potential for both more severe and prolonged droughts as well as for higher intensity and more frequent rain events must be considered. These three scenarios are not intended as predictions of future climate conditions, but as representations of several possibilities that climate change models indicate could occur. Should they occur, these results provide an evaluation of how streamflows may be impacted. Their purpose is to build upon existing climate modeling to provide a foundation for state and local government, as well as other stakeholders, to better evaluate what practical water resource challenges may be associated with the range of climate conditions Virginia could experience.

Figure 125 depicts the percent change in the L30 for the dry climate scenario in conjunction with 2040 demands, as compared to the current climate and demand scenario. Reductions in streamflow in this scenario may be caused by reduced precipitation, increased demand, or as is generally the case, a combination of both. Figures 126 and 127 depict the L30 for the median and wet climate scenarios (in conjunction with 2040 demands) as compared to the current climate and demand scenario.

Figure 128 depicts the percent change in the L90 for the dry climate scenario in conjunction with 2040 demands, as compared to the current climate and demand scenario. Figures 129 and 130 depict the L30 for the median and wet climate scenarios (in conjunction with 2040 demands) as compared to the current climate and demand scenario.

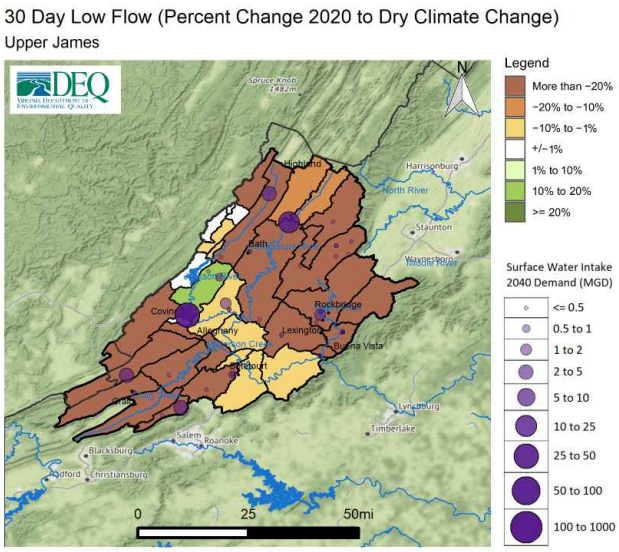

Figure 125: Change in 30 day low flow between current climate/demand scenario and the dry climate/2040 demand scenario within the Upper James Basin

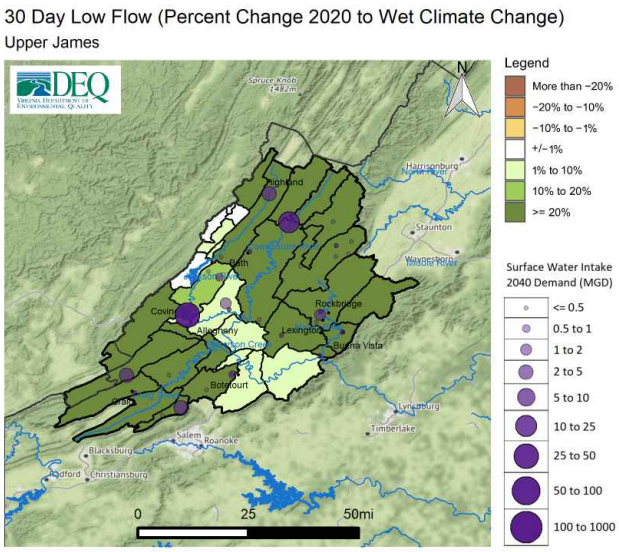

Figure 127: Change in 30 day low flow between current climate/demand scenario and the wet climate/2040 demand scenario within the Upper James Basin

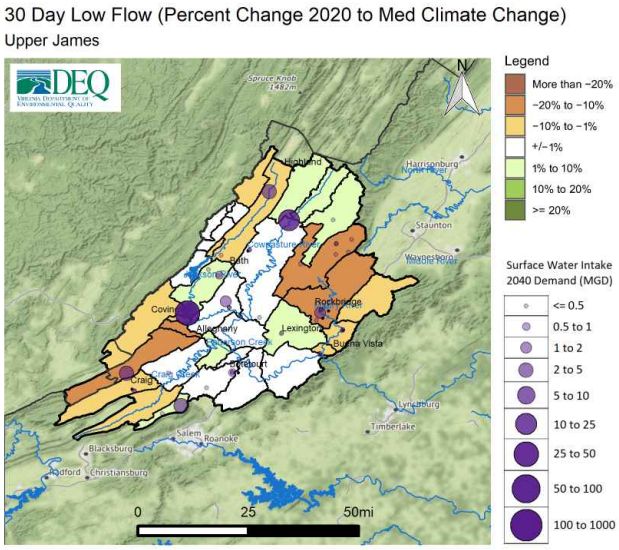

Figure 126: Change in 30 day low flow between current climate/demand scenario and the median climate/2040 demand scenario within the Upper James Basin

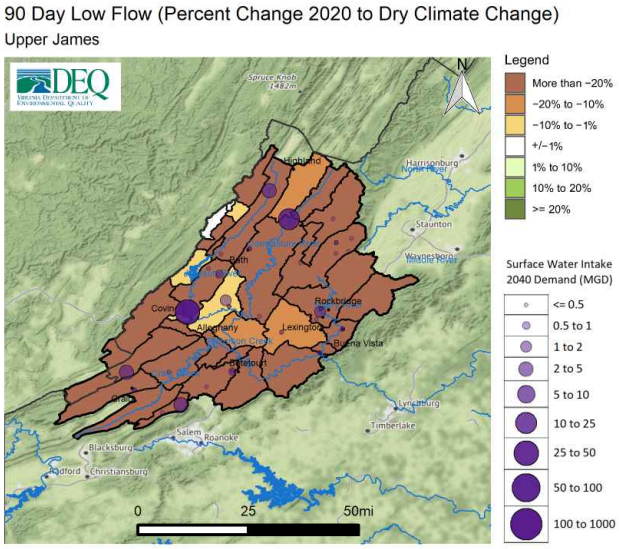

Figure 128: Change in 90 day low flow between current climate/demand scenario and the dry climate/2040 demand scenario within the Upper James Basin

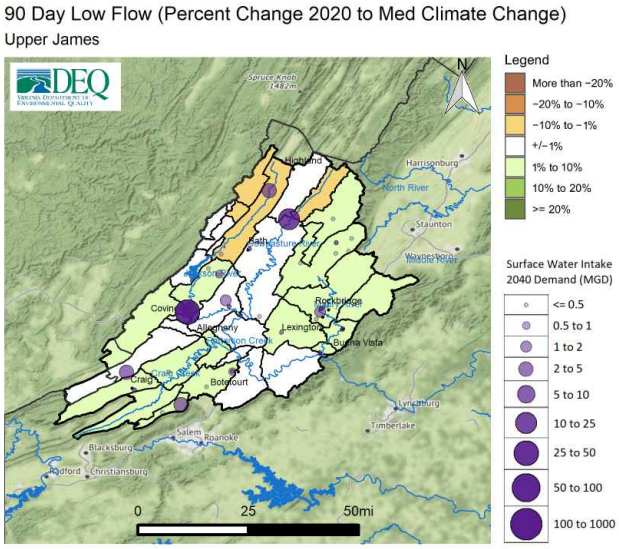

Figure 129: Change in 90 day low flow between current climate/demand scenario and median climate/2040 demand scenario within the Upper James Basin

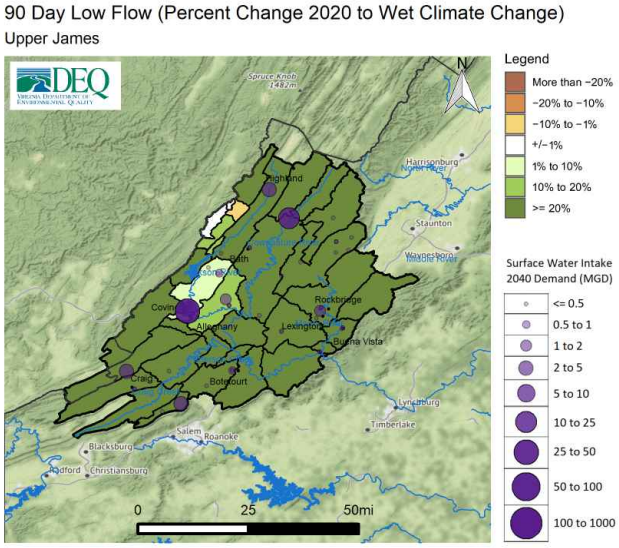

Figure 130: Change in 90 day low flow between current climate/demand scenario and wet climate/2040 demand scenario within the Upper James Basin

Exempt User Scenario: The exempt user scenario simulates the maximum possible exempt demand for users excluded from Virginia Water Protection permitting requirements per Va. Code § 62.1-44.15:22 B, in combination with the permitted withdrawal limits for those users that are permitted. A more detailed discussion of the data and assumptions used in this scenario can be found in Appendix B. Note that this scenario uses current climate conditions. Figure 131 depicts the percent change in 30 day low flow between the exempt user scenario and current (2020) demand. Figure 132 depicts the percent change in 90 day low flow between the exempt user scenario and current (2020) demand. Figure 133 depicts the percent change in the 7Q10 between the exempt user scenario and current (2020) demand. Finally, Figure 134 depicts the overall change in flow in percent (consumptive use) for the exempt user scenario.

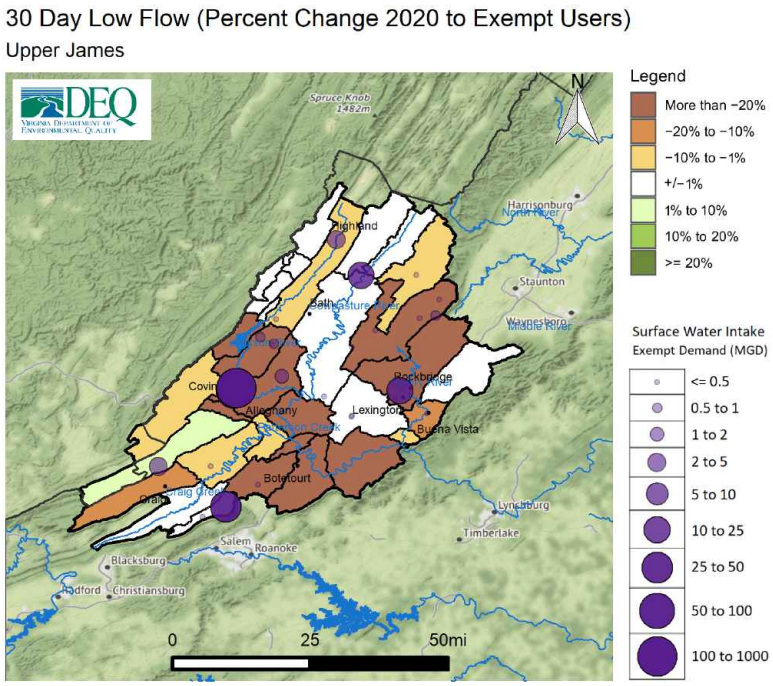

Figure 131: Change in 30 day low flow between current demand scenario and exempt user scenario within the Upper James Basin

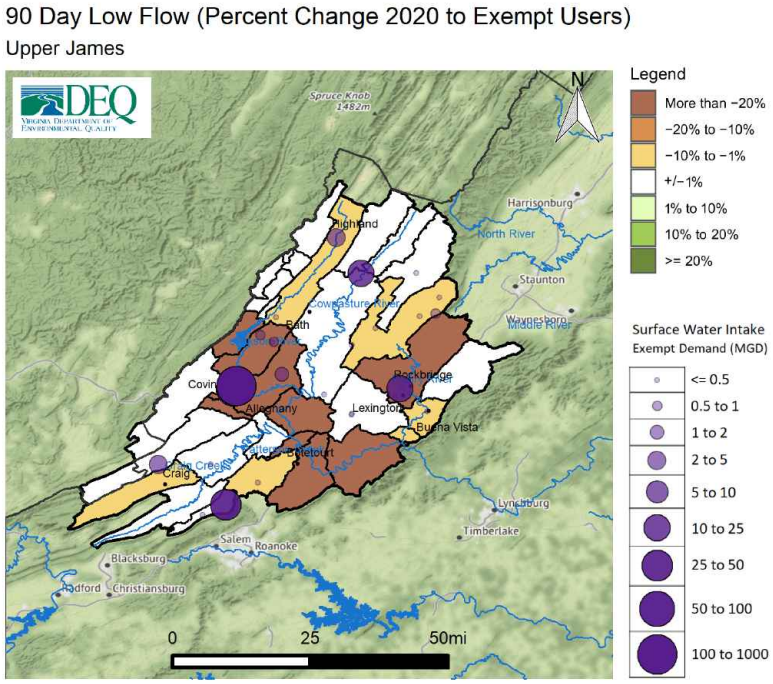

Figure 132: Change in 90 day low flow between current demand scenario and exempt user scenario within the Upper James Basin

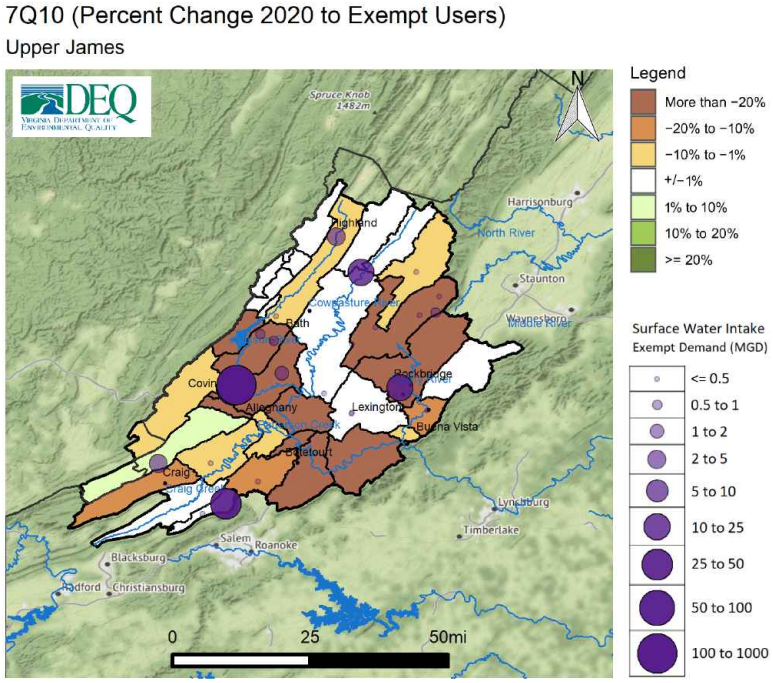

Figure 133: Change in 7Q10 between current demand scenario and exempt user scenario within the Upper James Basin

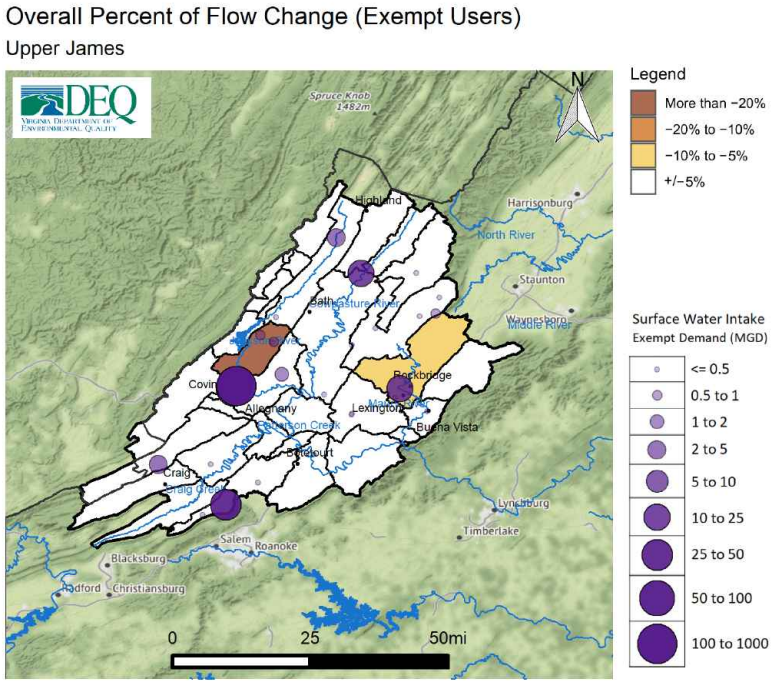

Figure 134: Overall change in flow in percent for exempt user scenario within the Upper James Basin

Potential Unmet Demand: Potential unmet demand was evaluated for all facilities within the basin for each scenario. Potential unmet demand is the portion of surface water demand for a specific facility that is limited by available streamflow as simulated in a given model scenario, including any known operational limits such as flow-by requirements. This unmet demand, if realized, could be managed through water conservation, through alternative sources, operational changes, or from available storage. Absent of these or other options, this portion of demand could remain unmet. As with all scenarios, demand requirements were determined using demand projections provided in the water supply plans. In the case of the exempt user scenario, the highest possible withdrawal amount was used for users exempt from VWP permitting requirements.

This metric is useful for evaluating where the results seen in the above figures may result in challenges in meeting future demands under a variety of conditions including increasing demands in the basin, changing climate, or withdrawals from users exempt from permitting requirements. Table 34 provides for each facility the highest average daily potential unmet demand over a 30 day period over the course of the simulation for the following scenarios: 2020 demand, 2030 demand, 2040 demand, dry climate, and exempt user. Only facilities showing potential unmet demand in at least one scenario appear on this table. The dry climate scenario is selected among the climate scenarios as the dry scenario represents the potential for increased drought intensity and frequency, and therefore poses the greatest challenge for water supply.

Table 34: Change in Highest 30 Day Potential Unmet Demand (MGD) in Upper James Minor Basin

Facility	**2020 Demand**	**2030 Demand**	**2040 Demand**	**Dry Climate**	**Exempt User**
Jackson River WTP 1	0.00	0.00	0.00	0.00	98.67
Covington Plant Westrock	6.03	6.01	5.99	2.38	56.67
Maury River WTP	0.00	0.00	0.00	0.00	14.88
Potts Creek Intake	0.00	0.00	0.00	0.00	5.40
Laurel Hill Trout Farm-South Monterey	3.3	3.3	3.3	2.9	4.22
Paint Bank Fish Cultural Sta.	1.5	1.5	1.5	2.22	3.47
Coursey Spring Fisheries	0.02	0.02	0.02	0.26	1.05
New Castle WTP	0.00	0.00	0.00	0.00	0.08
Craigsville Service Area	0.00	0.00	0.00	0.00	0.06
Bath County Regional Water System	0.01	0.01	0.01	0.01	0.02
Warm Springs Service Area	0.00	0.00	0.00	0.00	0.02
Homestead Golf Irrigation & Snow Production	0.00	0.00	0.00	0.00	0.02

* Climate scenarios were not completed in areas located outside of the Chesapeake Bay watershed

Note: Potential unmet demand is the portion of surface water demand for a specific facility that is limited by available streamflow as simulated in a given model scenario, including any known operational limits such as flow-by requirements. This unmet demand, if realized, could be managed through water conservation, alternative sources, operational changes, or from available storage.

A.4.6 Spatial Overview of Groundwater Demands

The cumulative impact analysis figures above provide an overview of surface water demands in the basin but did not include groundwater demands. Figure 135 identifies the location and size of projected groundwater demands in the basin for 2040 based on information provided by localities in water supply plans.

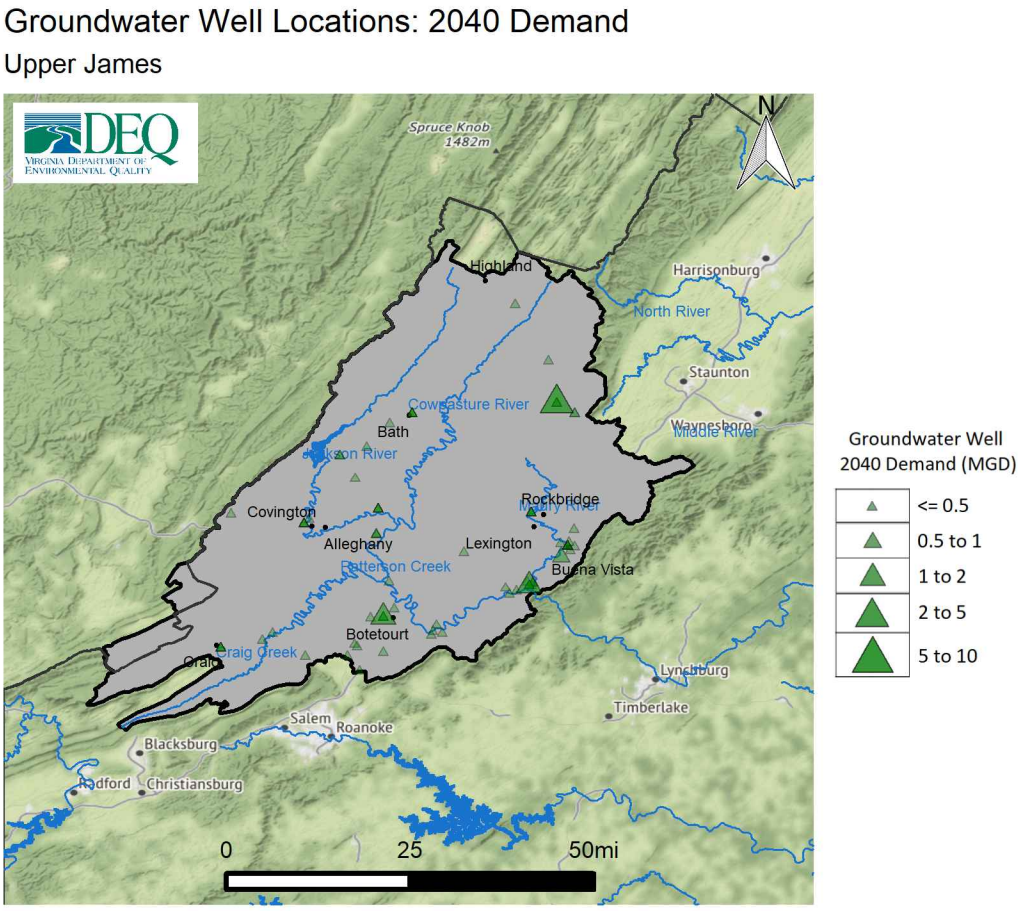

Figure 135: Projected 2040 Groundwater Demands in the Upper James Minor Basin

A.4.7 Trends and Goals

The Code of Virginia mandates that the State Water Control Board should take into consideration the principle that "adequate and safe supplies shall be preserved and protected for human consumption, while conserving maximum supplies for other beneficial uses".[79] This principle is the key driver of the challenges in water resource management, which is that all beneficial uses must be adequately considered when evaluating impacts to surface water resources. The State Water Control Board is tasked with ensuring that water supply quantity needs are met at all times while also protecting Virginia's natural resources, and furthermore, ensuring equitable allocation during a time of shortage.[80] While evaluating and planning for the long-term sustainability of water supply for Virginia is the primary goal for the State Plan, evaluating and limiting impacts to in-stream beneficial uses such as aquatic habitat life is also part of DEQ's responsibility.

The primary purpose of this section is to identify where the most significant challenges to long-term sustainability of water supply and other beneficial uses are indicated based on the CIA and information collated from local water supply plans within this basin. Goals for future planning and areas for additional data collection or analysis are also suggested where appropriate.

The CIAs were completed using the best available data and methods known to DEQ. This discussion focuses on the evaluation of trends - in other words the prevailing tendency or inclination. This means evaluating whether streamflow is simulated to increase or decrease in a given scenario, and by how much. A relative trend indicating reductions of greater than or equal to 10% in streamflow, whether driven by demand increases, changing climate conditions, or exempt user demands was considered a threshold for potential impacts to beneficial uses. The key trends or goals for this basin are as follows:

- **Demand Scenarios:** Demands in the Upper James Minor Basin are projected to increase approximately 4% through 2040, and therefore impacts driven by demand increases are not simulated to be significant. When comparing the 2020 and 2040 demand scenarios, no streamflow reductions of more than 10% were simulated within the basin for the long-term drought (L90), short-term drought (L30), or 7Q10 metrics. Overall percent of flow change (consumptive use) is simulated to exceed 10% in the Jackson River near the City of Covington in both the 2020 and 2040 demand scenarios. This is driven by consumptive use associated with Westrock's Covington Plant and the City of Covington's WTP. However, this overall flow reduction only impacts a 1/2 mile stretch of the river between the points of withdrawal and discharge downstream from the intake. It should also be noted that low flows in this reach are augmented above natural levels by releases from Gathright Dam which likely further mitigates impacts from these withdrawals. Potential unmet demand is simulated to occur at one CWS, with minimal unmet demand (0.01 MGD) projected to occur for the Bath County Regional Water System.
- **Climate Scenarios:** Current climate modeling suggests Virginia will generally receive more precipitation on average in the future. However, the data also suggests the possibility of more severe droughts despite this overall trend of increasing precipitation. The dry climate scenario simulates significant reductions in streamflow of more than 20% for more than half the basin for both the short-term (L30) and long-term drought (L90) metrics. The most significant reductions occur in headwaters, particularly in Craig Creek, Maury River, Johns Creek, Potts Creek, and South River. The dry climate scenario also results in potential unmet demand for Westrock's Paper Mill, although this could likely be mitigated through releases from Gathright Dam. Where in the future climate conditions resemble this dry scenario, the simulations indicate drought conditions more severe than the current drought of record will be experienced for most of the basin. Simulations show short-term and long-term droughts with streamflows 20-50% lower than those experience during the drought of record, which would result in broad impacts to public water supply as well as aquatic life and other beneficial uses during these periods. The potential for more severe droughts must be considered by localities and users when evaluating existing sources and alternatives, as well as for broader planning and resource management efforts by all stakeholders whether state or local.

[79] § 62.1-44.36 of the Code of Virginia
[80] 9VAC25-390-20.1

- **Exempt User Scenario:** The exempt user scenario, which models the cumulative maximum possible exempt demands from all users exempt from VWP permitting requirements, shows reductions in streamflow of more than 10% during short term droughts (L30) and long term droughts (L90), as well as in the 7Q10, for nearly half the basin when compared to current demands. The most significant reductions are simulated in the Jackson River in the City of Covington area before the confluence with the James River, primarily driven by maximum possible exempt demands from Westrock's Paper Mill and the City of Covington WTP. Reductions of more than 40% are also simulated in the Maury River in the area of the Maury Service Authority WTP. The exempt user scenario results in potential unmet demand for several CWS facilities including the City of Covington's WTP, Maury Service Authority's Maury River WTP, and the Town of New Castle's WTP. These results indicate that the cumulative maximum possible exempt demands in the basin exceed the water budget in many river segments. Preserving water supply and other beneficial uses may require managing these demands with respect to their cumulative impacts and in the context of the available resources in the basin.

A.5 Middle James River Basin

A.5.1 Watershed Overview

Beginning along the Virginia/West Virginia state line, the James River is formed by the confluence of the Jackson and Cowpasture Rivers in the Allegheny Mountains. The James River flows 242 miles to the fall-line at Richmond, and another 106 miles before it enters the Chesapeake Bay. Spanning across four physiographic provinces, the topography and climate of the James River Basin varies throughout. The Upper James portion originates in the elongated parallel ridges and valleys that define the Valley and Ridge Province, and flows eastward into the Blue Ridge Province. With distinctive highland topography and dramatic elevation changes, the Blue Ridge Province differs from the Valley and Ridge. It is characterized by rugged terrain with steep slopes and narrow ridges in the north that gradually subside to moderate slopes in the south. The Middle James River Basin begins as the river moves through the Piedmont Province, flowing through scattered hills and small mountains that gradually develop into gently rolling slopes and lower elevations moving east towards the fall-line. The fall-line is a distinct three-mile stretch of river that separates the Piedmont from the Coastal Plain. Running through the City of Richmond the river descends 84 ft of elevation and exits the hard resistant rocks of the Piedmont into the softer sediments of the Coastal Plain before entering the Chesapeake Bay.

The Middle James River Basin is generally characterized by a mix of forested and agricultural land use with decreasing slope and elevation as it drains eastward towards the fall-line. The total area of the Middle James Minor Basin is 9750.28 sq. miles. Table 35 includes all localities that are either wholly or partially included in the basin. The major population centers within the basin include the west end of the City of Richmond including Short Pump, the City of Charlottesville, and the City of Lynchburg.

Table 35: Population Trend by Locality in Middle James Basin

Localities	20 Year % Change
Albemarle	24.72
Amherst	-3.87
Appomattox	9.61
Augusta	9.92
Bedford County	12.05
Botetourt	5.22
Buckingham	4.66
Campbell	4.62
Chesterfield	22.51
Cumberland	5.05
Fluvanna	22.74
Goochland	25.07
Greene	21.16
Hanover	16.94
Henrico	17.18
Louisa	26.67
Nelson	-0.94
Orange	25.12
Powhatan	21.94
Rockbridge	4.45
Rockingham	14.04
Charlottesville	5.20
Lynchburg	17.11
Richmond City	9.70

A.5.2 Existing Water Sources

Major surface water sources within the basin include the James, South Fork Rivanna, North Fork Rivanna, and Buffalo rivers, as well as several reservoirs including South Rivanna, Ragged Mountain, Totier Creek, Cobbs Creek, Sugar Hollow, Pedlar, and Beaver Creek. Groundwater within the basin is primarily withdrawn from bedrock aquifers. Withdrawals within the basin are used for public water supply as well as for agriculture, irrigation, commercial, and industrial/manufacturing.

The location of wells and surface water intakes identified to DEQ within the basin are shown in figure 136. This figure does not include private or domestic wells. This map also shows locations of any Instream Flow Incremental Method (IFIM) studies completed in the basin.

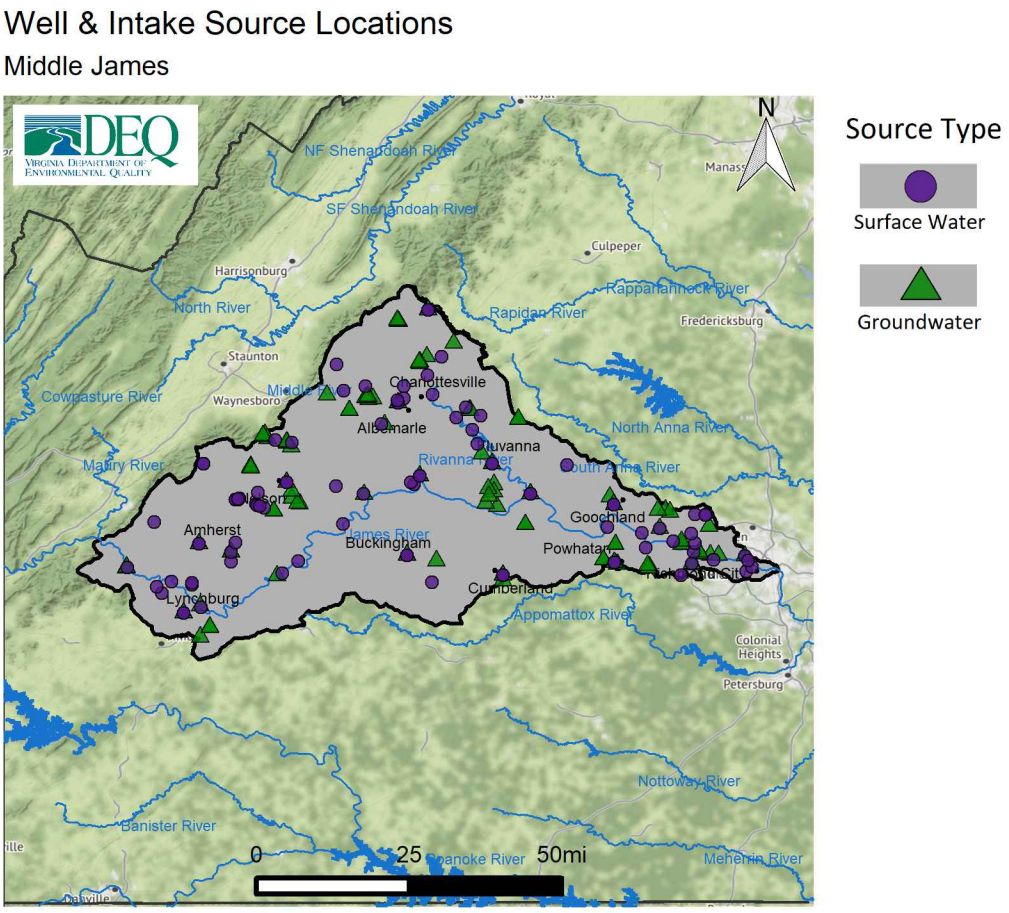

Figure 136: Spatial distribution of groundwater wells and intakes in the Middle James River Basin

A.5.3 Existing Water Use

The following section discusses existing (current) water use within the basin, which is based on existing demand information submitted to DEQ in the water supply plans. Table 36 provides a summary of all demands including power generation within the basin, by system and source type. It also provides a count of surface water or groundwater sources associated with each system type.

Table 36: Summary of Middle James Minor Basin Water Demand by Source Type and System Type (including Power Generation)

System Type	Source Count	2020 Demand (MGD)	2030 Demand (MGD)	2040 Demand (MGD)	20 Year Percent Change
Surface Water					
Agriculture	24	2.54	2.54	2.54	0.00
CWS	22	119.18	140.50	161.81	35.77
Large SSU	33	26.08	29.82	33.55	28.66
Small SSU	N/A	0.00	0.00	0.00	0.00
Total SW	**79**	**147.80**	**172.86**	**197.90**	**33.90**
Groundwater					
Agriculture	6	0.54	0.54	0.54	0.00
CWS	112	0.53	0.79	1.06	100.21
Large SSU	31	0.32	0.48	0.65	104.04
Small SSU	N/A	13.90	16.29	18.68	34.33
Total GW	**149**	**15.29**	**18.10**	**20.93**	**36.89**
Total (SW + GW)					
Agriculture	30	3.08	3.08	3.08	0.00
CWS	134	119.71	141.29	162.87	36.05
Large SSU	64	26.40	30.30	34.20	29.57
Small SSU	N/A	13.90	16.29	18.68	34.33
Minor Basin Total	**228**	**163.09**	**190.96**	**218.83**	**34.18**

* Small SSU demands are county-wide estimates of private well usage below 300,000 gallons a month. The number of private wells is not known.

The total existing demand from all surface and groundwater sources is approximately 163.09 MGD, with groundwater supplying approximately 15.29 MGD or 9% of total water demands. Surface water demand within the basin totals approximately 147.80 MGD, or 91% of current demands. Surface water constitutes the vast majority of demands within the basin, and as will be discussed below is the primary source by volume for all demand categories but Small SSUs. However, in terms of the number of sources, there are more groundwater sources (149) than surface water sources (79).

The five largest withdrawals for each source type are provided in table 37. The City of Richmond has the largest surface water demand of approximately 63.96 MGD, which accounts for 39% of all surface water demands in the basin. Henrico County has the second largest surface water demand 29.87 MGD, accounting for 24% of surface water demands in the basin. The top 5 surface water demands comprise over 80% of basin wide surface water demand. The largest groundwater demands include the Fork Union Service Area (0.19 MGD), the Independence Golf Club (0.12 MGD), and the Manakin Farms Service Area (0.07 MGD). The top 5 groundwater demands make up only 4.11% of basin wide demand, indicating that groundwater is characterized by numerous smaller sources rather than several large withdraws. This is not atypical of groundwater use statewide.

Table 37: Top 5 Users in 2040 by Source Type in the Middle James Minor Basin (including Power Generation)

Facility Name	System Type	Locality	2020 Demand (MGD)	2030 Demand (MGD)	2040 Demand (MGD)	20 Year Percent Change	% of Total Surface Water
Surface Water							
Richmond (City) WTP	CWS	Richmond City	63.96	71.02	78.08	22.08	39.45
Henrico County WTP & Service Area	CWS	Henrico	29.87	38.72	47.57	59.26	24.04
Pedlar Reservoir Intake	CWS	Amherst	9.93	12.16	14.38	44.81	7.27
Georgia-Pacific Big Island WTP	Large SSU	Bedford County	9.15	11.15	13.16	43.83	6.65
South Rivanna WTP	CWS	Albemarle	7.32	8.88	10.44	42.62	5.28
Total SW			120.23	141.93	163.63	36.1	82.68
Groundwater							**% of Total Groundwater**
Fork Union Service Area	CWS	Fluvanna	0.19	0.24	0.28	47.37	1.34
Manakin Farms Service Area	CWS	Goochland	0.07	0.14	0.2	185.71	0.96
Powhatan Courthouse Service Area	CWS	Powhatan	0.01	0.1	0.18	1700	0.86
Independence Golf Club	Large SSU	Chesterfield	0.12	0.12	0.12	0.00	0.57
Cumberland County Water System	CWS	Cumberland	0.02	0.05	0.08	300	0.38
Total GW			0.41	0.65	0.86	109.76	4.11

Table 36 also provides the proportion of each use category that is supplied by either surface water or groundwater. Use categories include Community Water System (CWS), Large Self-Supplied User (Large SSU), Small Self-Supplied User (Small SSU), and Agricultural Self-Supplied User (AG). These categories are defined below. Surface water demand is primarily comprised of CWS and Large SSU demands. Groundwater demand is primarily comprised of Small SSU demand.

The CWS category includes any public and private waterworks that serve at least 15 service connections used by year-round residents or regularly serve at least 25 year-round residents, and are regulated under the Virginia Department of Health's Waterworks Regulation (12VAC5-590). In the Middle James Basin, approximately 0.53 MGD of groundwater demand and 119.18 MGD of surface water demand is from CWS. Significant groundwater users within this category include the Fork Union Service Area, Manakin Farms Service Area, and the Powhatan Courthouse Service Area. Significant surface water users from this category include: the City of Richmond, Henrico County, and the City of Lynchburg's Pedlar Reservoir.

Large SSUs include any non-CWS or AG users who withdraw more than 300,000 gallons per month from a well or surface water intake. In the Middle James Basin, approximately 0.32 MGD of groundwater demand and 26.08 MGD of surface water demand is from Large SSUs. Significant surface water users from this category include the Georgia-Pacific Big Island Plant and East Coast Transport. Groundwater use associated with this category is limited and generally small in volume within this basin.

Small SSUs include any users who withdraw less than 300,000 gallons per month from wells. Small SSUs generally consist of residential or domestic use for those who lives outside service areas and provide their own

water. Small SSU demand is generally met with groundwater. In the Middle James Basin, approximately 13.90 MGD of groundwater demand is from Small SSUs. Localities within the basin with the greatest contribution from Small SSUs include Albemarle, Goochland, and Powhatan.

The AG category includes crop farms, livestock operations, aquaculture and other agricultural facilities. In the Middle James Basin, approximately 0.54 MGD of groundwater demand and 2.54 MGD of surface water demand is from AG. The highest AG demands were estimated in Fluvanna, Cumberland, and Goochland counties.

A.5.4 Projected Population and Water Use

Projected Population: Trends in water use are generally driven by trends in population change or economic development. Increasing population within an area generally means increased connections for community water systems or additional groundwater demand from homeowners that construct wells. Increasing population in an area also tends to incentivize both new and expanded industrial and commercial water use.

Table 35 shows the projected change in population by percent between 2020 and 2040 for each locality located partly or wholly within this minor basin. Most of the Middle James basin is projected to see significant population growth. Only Nelson County and Amherst County project a decrease in population. Albemarle, Goochland, Louisa, Chesterfield, Powhatan, Orange, Fluvanna, and Greene counties all project more than 20% increase in population between 2020 and 2040. This growth drives increased demand from Small SSUs (residential wells) and CWS.

Projected Water Use: The following section discusses projected water use through 2040 within the Middle James Minor Basin, based on projections provided in local and regional water supply plans. Table 36, included in the existing demand section above, is the basis for information discussed in this section.

Total demand within the basin is projected to increase from 163.09 MGD in 2020 to 218.83 MGD in 2040, or 34.1% overall. Surface water demand is projected to increase by 50.1 MGD, or 33.90%, by 2040. Groundwater demand is projected to increase by 5.64 MGD, or 36.89%, by 2040. Surface water is projected to comprise 90% of total demand in the basin by 2040 and also constitutes the majority of the projected demand increase. The largest contributors to this increase in total projected demand comes from demand increases for the City of Richmond's WTP, Henrico County's WTP, and Lynchburg's Pedlar Reservoir.

Demand from CWS users within the basin is projected to increase by 36% by 2040. Within this category, surface water use is projected to increase by 35.77%, while groundwater use is projected to increase by 100%. However, by volume the projected groundwater demand increase for CWS users is only 0.53 MGD.

Demand from Large SSUs within the basin is projected to increase by 29.57% in total demand by 2040. Within this category, surface water use is projected to increase by 28.66%, while groundwater use is projected to increase by 104.04%. However, by volume the projected groundwater demand increase for Large SSUs is only 0.33 MGD while surface water is 7.47 MGD. Major contributors to increased demand for Large SSUs include the Georgia-Pacific Big Island WTP, the Riverville Mill WTP, and locality estimates for Large SSU increases in the City of Lynchburg and Powhatan County.

Demand from Small SSUs within the basin is projected to increase by 34.33% by 2040. As noted previously, Small SSU demand is entirely met with groundwater. Increased Small SSU demand is largely driven by increasing demands in Goochland, Fluvanna, Albemarle, and Powhatan counties, among others. These demands align closely with increasing population projections in the basin.

Demand from Agriculture Users within the basin is not projected to change significantly by 2040 for either surface water or groundwater. As populations expand, loss of agricultural lands occur. As a result water demands for agricultural use is projected to remain constant over the planning period.

A.5.5 Cumulative Impact Analysis

The following section provides a brief summary of the Cumulative Impact Analysis (CIA) modeling results in the Middle James River Basin. Discussion of these results will primarily be found in the "Trends and Goals" section of this appendix. However a brief overview of the VAHydro model and the scenarios and metrics is provided below.

The VAHydro surface water model simulates streamflow using inputs such as precipitation, climate, land use, and topography, combined with data on all known withdrawals and discharges, and operational rules of major hydrologic features such as reservoirs. Each minor basin is broken into smaller hydrologic subsections, or river segments. The model simulates the water balance on a daily basis for each individual river segment, with each downstream segment being affected by the "cumulative impact" of streamflow changes occurring in upstream segments. The following figures help analyze this cumulative impact within the Middle James Minor Basin. Note that this section is not intended to document in detail the methods and assumptions for the VAHydro model or for the scenarios and metrics discussed. Detailed documentation of the model and assumptions can be found in Chapter 4.

The VAHydro surface water model was used to simulate streamflow under a variety of scenarios. Demand scenarios examine how streamflow is impacted under 2030 or 2040 demands as compared to current (2020) demands. Demands were calculated based on current and future demand information submitted through local and regional water supply plans. Climate change scenarios examine how streamflow is impacted when 2040 demands are simulated in conjunction with a range of precipitation and temperature conditions that may occur in the future due to changing climate (Dry, Median, Wet scenarios). Finally, the exempt user scenario examines impacts from users excluded, or exempt, from VWP permit requirements per Va. Code § 62.1-44.15:22 B. Exempt users were simulated at the maximum possible demand identified through a review of demand justification values commonly asserted by exempt users, including but not limited to VDH pump capacity, maximum pre-1989 withdrawal, and maximum intake capacity. In order to effectively manage surface water resources and address the uncertainty related to these demands, DEQ determined the most conservative, or maximum possible, demand should be evaluated in this scenario. However, DEQ does not agree that the maximum values used in this scenario represent an allocation for, or the expectation of, a future withdrawal of that volume; nor does DEQ concede that any particular exempt user is necessarily entitled to withdraw any particular maximum value used in this scenario. The methods and assumptions for each of these modeling scenarios are discussed in more detail in Chapter 4.

For each scenario described above, different metrics can be used to evaluate the simulated streamflow. A metric is a method for measuring or evaluating a given set of data; different metrics can be evaluated to answer different questions. Within this section the following metrics will be discussed: the lowest 30 day flow (L30), the lowest 90 day flow (L90), 7Q10, and overall change in flow. The L30 describes the lowest consecutive 30 day average daily streamflow over the simulation period. This metric is a representation of a short-term, or acute drought, and is a good metric for evaluating impacts to direct withdrawals without storage. Similarly, the lowest 90 day flow represents the lowest consecutive 90 day average daily streamflow over the simulation period. This would represent a prolonged drought and is often used to evaluate impacts to reservoirs. The 7Q10 is the lowest 7-day average flow that occurs (on average) once every 10 years. 7Q10 is generally used in the evaluations of in-stream beneficial uses such as waste assimilative capacity. Overall change in flow describes the net loss of water from the riverine system as a result of off-stream use not otherwise returned through point source discharges, or losses due to evapotranspiration. This metric is useful for evaluating impacts to aquatic life and is discussed in more detail in Chapter 4.

Demand Scenarios: 2020 demand or "current demand", 2030 demand, and 2040 demand scenarios were simulated. The following series of figures compares the 2030 and 2040 demand scenarios to the current demand scenario. The change in flow depicted on each map is the change expected when comparing two scenarios - in this case future demands compared to current demands. Each page includes two figures comparing either the 2030 or 2040 demand scenario to current demand using the L30, L90, and 7Q10 metrics. This allows for comparisons of simulated impacts between the 2030 and 2040 demand scenarios. The scenarios and metrics are identified in the paragraph below and in the figure captions.

Figures 137 and 138 compare the lowest 30 day flow simulated with the current demand scenario with the lowest 30 day flow simulated in the 2030 and 2040 demand scenarios respectively. Figures 139 and 140 compare the lowest 90 day low flow simulated with the current demand scenario with the lowest 90 day flow simulated in the 2030 and 2040 demand scenarios respectively. Figures 141 and 142 compare the 7Q10 simulated with the current demand scenario with the 7Q10 simulated in the 2030 and 2040 demand scenarios respectively.

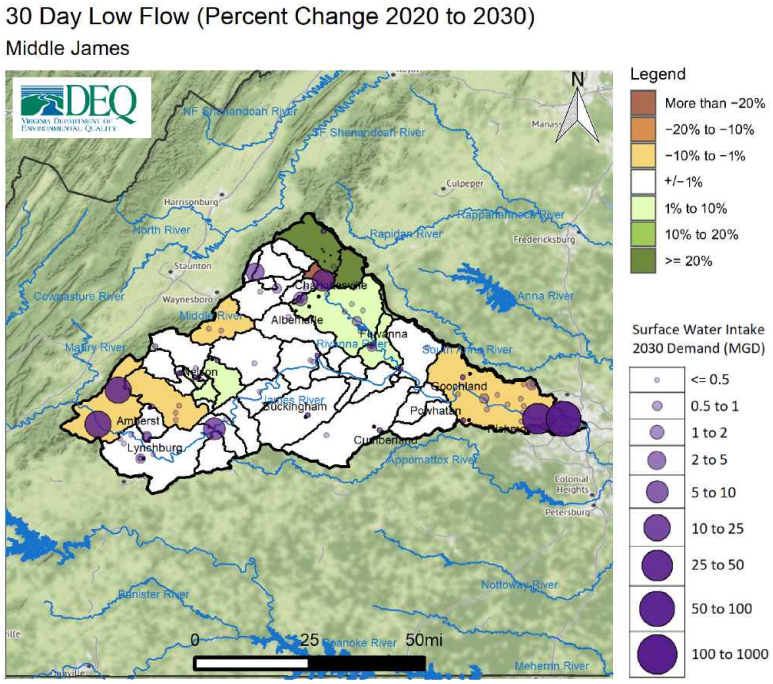

Figure 137: Change in 30 day low flow between 2020 and 2030 demand scenarios within the Middle James River Basin

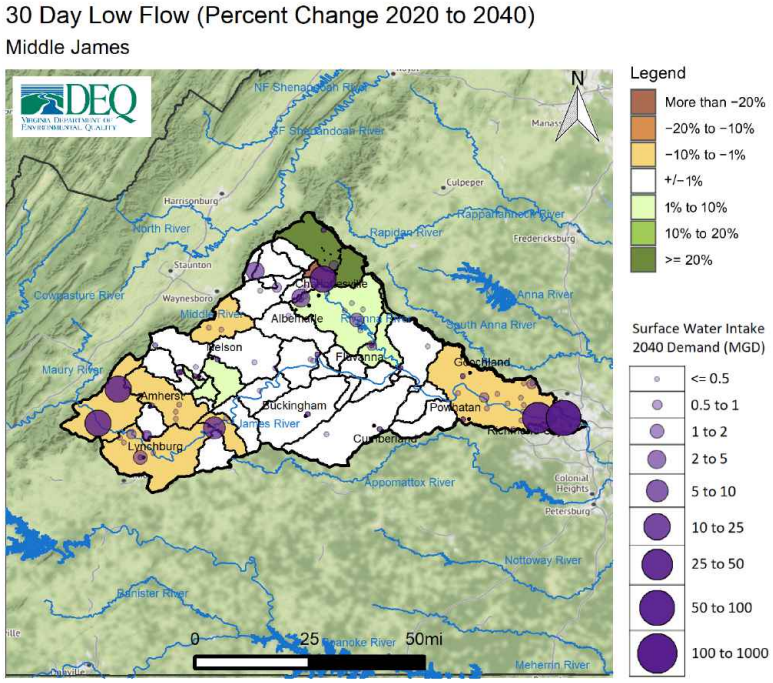

Figure 138: Change in 30 day low flow between 2020 and 2040 demand scenarios within the Middle James River Basin

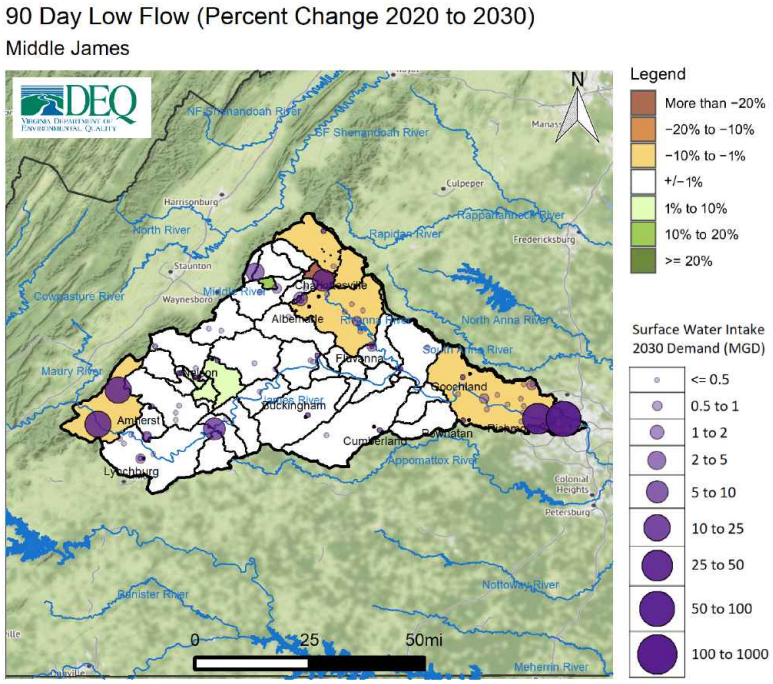

Figure 139: Change in 90 day low flow between 2020 and 2030 demand scenarios within the Middle James River Basin

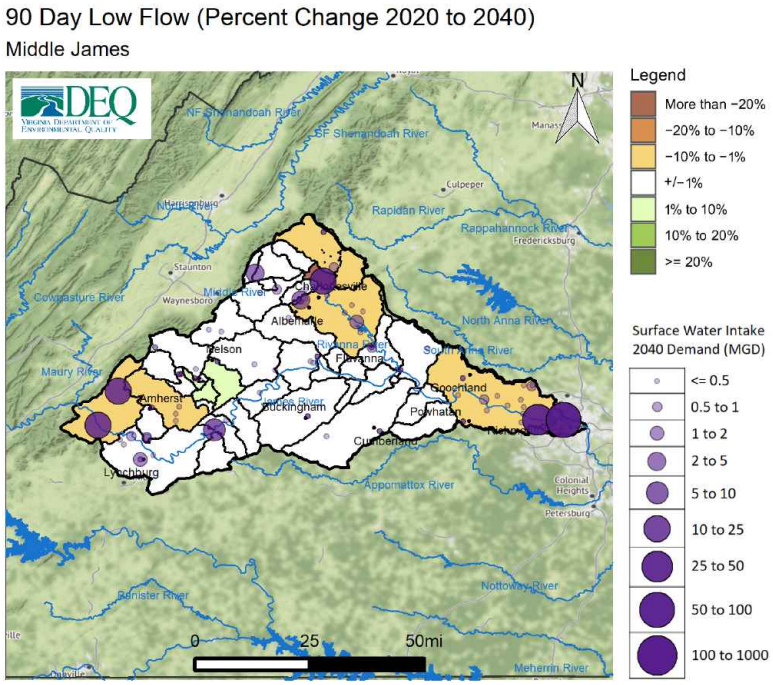

Figure 140: Change in 90 day low flow between 2020 and 2040 demand scenarios within the Middle James River Basin

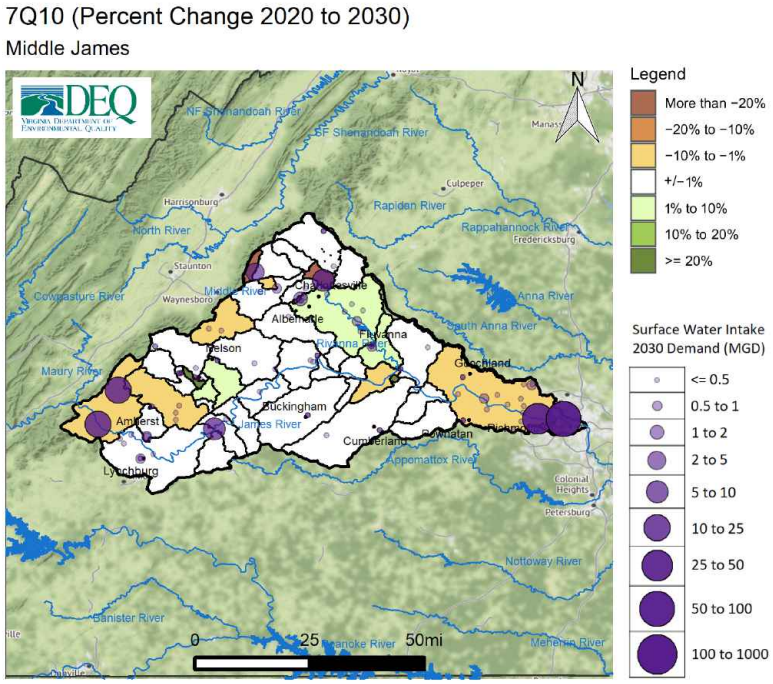

Figure 141: Change in 7Q10 between 2020 and 2030 demand scenarios within the Middle James River Basin

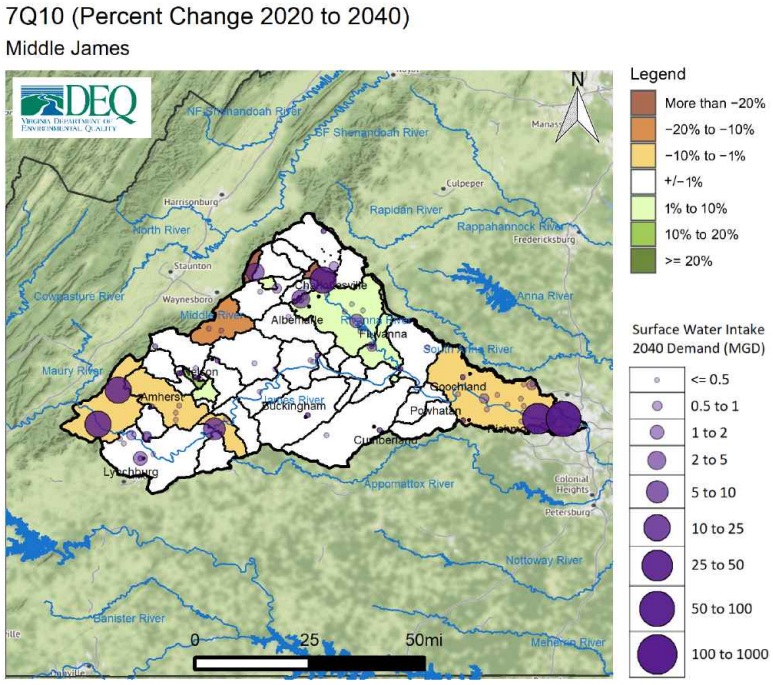

Figure 142: Change in 7Q10 between 2020 and 2040 demand scenarios within the Middle James River Basin

The figures above show a comparison between two scenarios. An additional way to evaluate impacts to streamflow is to examine the total reduction in streamflow resulting from all withdrawals within a river segment, as well as losses due to evapotranspiration, while taking into consideration any discharges back to the source. To use a common industry term, the overall change in flow metric evaluates "consumptive use", or the amount of water removed from the river that is not returned through discharges. This can help describe potential impacts to downstream withdrawals, while also providing a basis for evaluating impacts to aquatic life. In general, total reductions in streamflow can result in a reduction in aquatic biodiversity [81]. The relationship between streamflow and aquatic biodiversity is discussed in Chapter 4. Figure 143 shows the overall change in streamflow for the 2030 Demand Scenario, while figure 144 shows the overall change in streamflow for the 2040 Demand Scenario.

[81] Rapp, J.L., R. Burgholzer, J. Kleiner, D. Scott, and E. Passero. 2020. "Application of a New Species-Richness Based Flow Ecology Framework for Assessing Flow Reduction Effects on Aquatic Communities." Journal of the American Water Resources Association 1–14.https://doi.org/10.1111/1752-1688.12877.

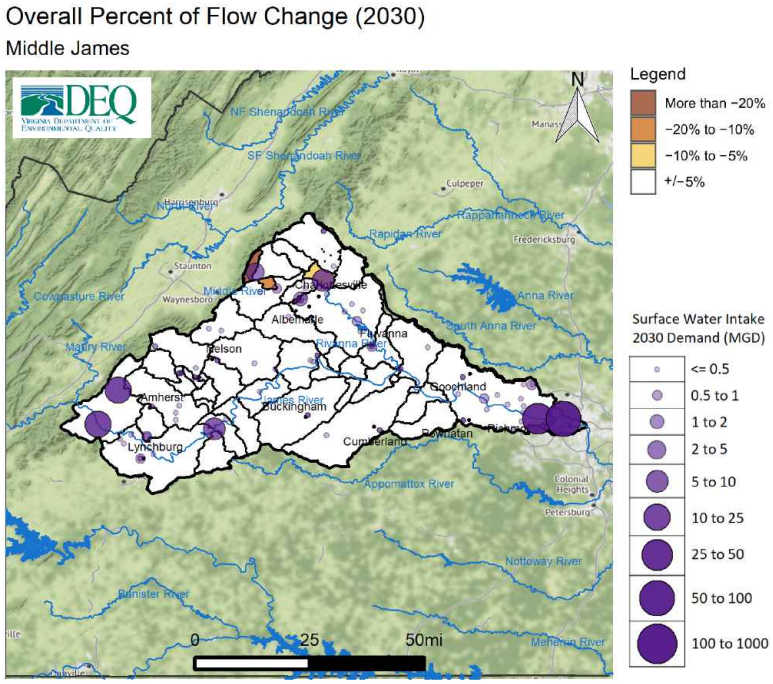

Figure 143: Overall change in flow in percent for 2030 demand scenario within the Middle James River Basin

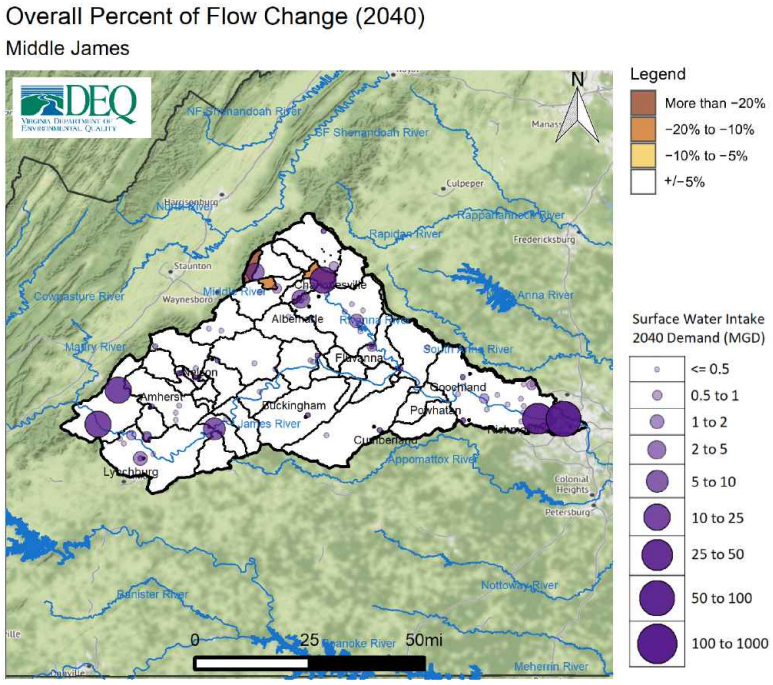

Figure 144: Overall change in flow in percent for 2040 demand scenario within the Middle James River Basin

Climate Scenarios: Three scenarios that simulate impacts to streamflow in response to changes in temperature and climate were completed for areas in the state where climate data was available, which includes the portions of the Commonwealth located in the Chesapeake Bay watershed. Details on the methods and assumptions employed for these scenarios can be found in Appendix B. The three scenarios can be described as dry, median, and wet scenarios. Virginia is expected to experience a range of precipitation and temperature changes that may vary spatially and from year to year. The potential for both more severe and prolonged droughts as well as for higher intensity and more frequent rain events must be considered. These three scenarios are not intended as predictions of future climate conditions, but as representations of several possibilities that climate change models indicate could occur. Should they occur, these results provide an evaluation of how streamflows may be impacted. Their purpose is to build upon existing climate modeling to provide a foundation for state and local government, as well as other stakeholders, to better evaluate what practical water resource challenges may be associated with the range of climate conditions Virginia could experience.

Figure 145 depicts the percent change in the L30 for the dry climate scenario in conjunction with 2040 demands, as compared to the current climate and demand scenario. Reductions in streamflow in this scenario may be caused by reduced precipitation, increased demand, or as is generally the case, a combination of both. Figures 146 and 147 depict the L30 for the median and wet climate scenarios (in conjunction with 2040 demands) as compared to the current climate and demand scenario.

Figure 148 depicts the percent change in the L90 for the dry climate scenario in conjunction with 2040 demands, as compared to the current climate and demand scenario. Figures 149 and 150 depict the L30 for the median and wet climate scenarios (in conjunction with 2040 demands) as compared to the current climate and demand scenario.

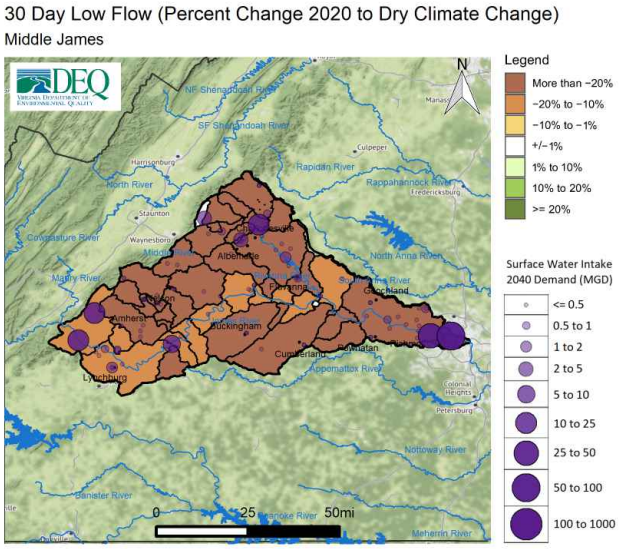

Figure 145: Change in 30 day low flow between current climate/demand scenario and the dry climate/2040 demand scenario within the Middle James River Basin

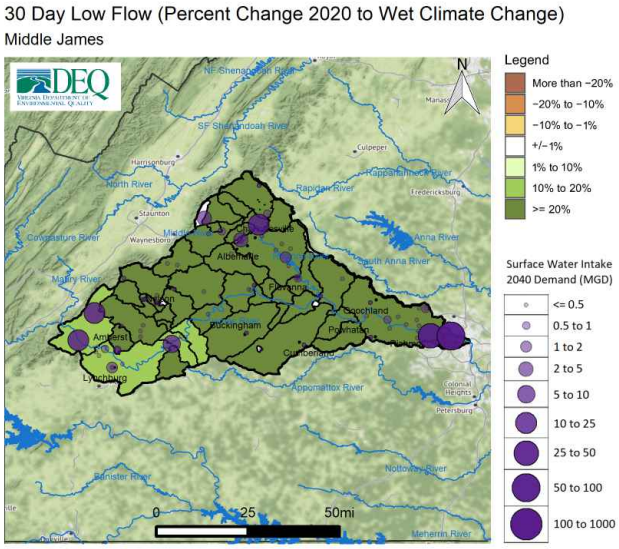

Figure 147: Change in 30 day low flow between current climate/demand scenario and the wet climate/2040 demand scenario within the Middle James River Basin

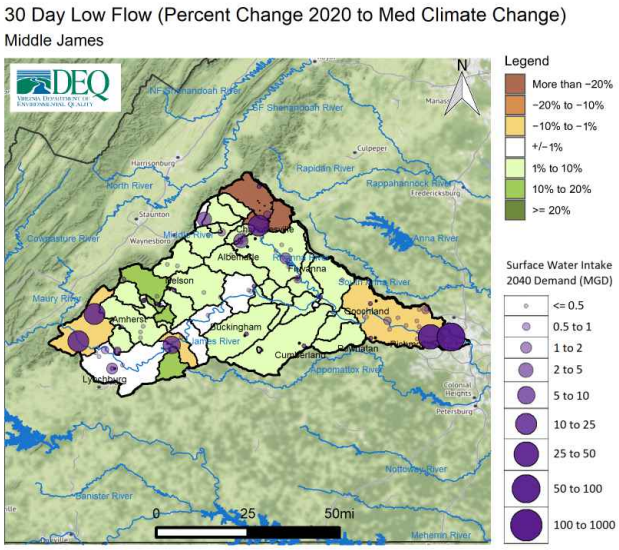

Figure 146: Change in 30 day low flow between current climate/demand scenario and the median climate/2040 demand scenario within the Middle James River Basin

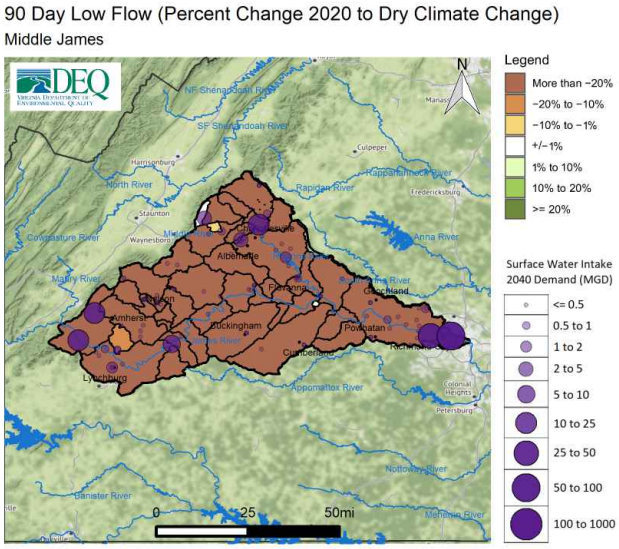

Figure 148: Change in 90 day low flow between current climate/demand scenario and the dry climate/2040 demand scenario within the Middle James River Basin

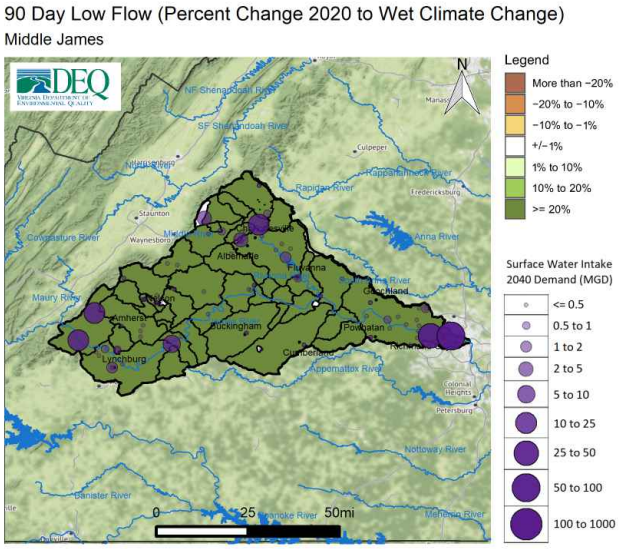

Figure 150: Change in 90 day low flow between current climate/demand scenario and wet climate/2040 demand scenario within the Middle James River Basin

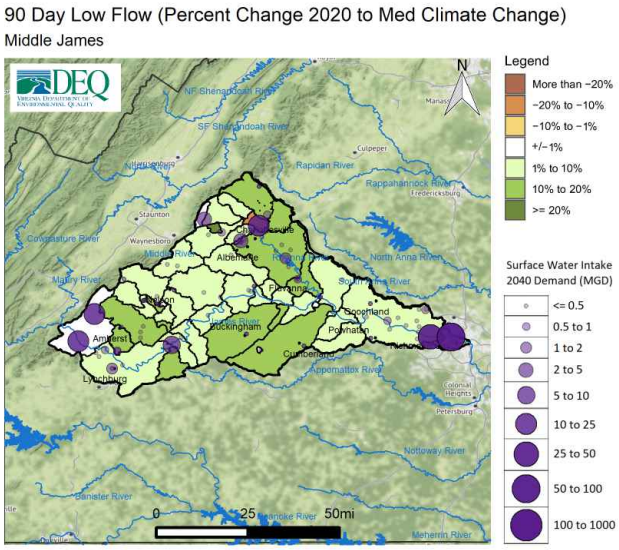

Figure 149: Change in 90 day low flow between current climate/demand scenario and median climate/2040 demand scenario within the Middle James River Basin

Exempt User Scenario: The exempt user scenario simulates the maximum possible exempt demand for users excluded from Virginia Water Protection permitting requirements per Va. Code § 62.1-44.15:22 B, in combination with the permitted withdrawal limits for those users that are permitted. A more detailed discussion of the data and assumptions used in this scenario can be found in Appendix B. Note that this scenario uses current climate conditions. Figure 151 depicts the percent change in 30 day low flow between the exempt user scenario and current (2020) demand. Figure 152 depicts the percent change in 90 day low flow between the exempt user scenario and current (2020) demand. Figure 153 depicts the percent change in the 7Q10 between the exempt user scenario and current (2020) demand. Finally, figure 154 depicts the overall change in flow in percent (consumptive use) for the exempt user scenario.

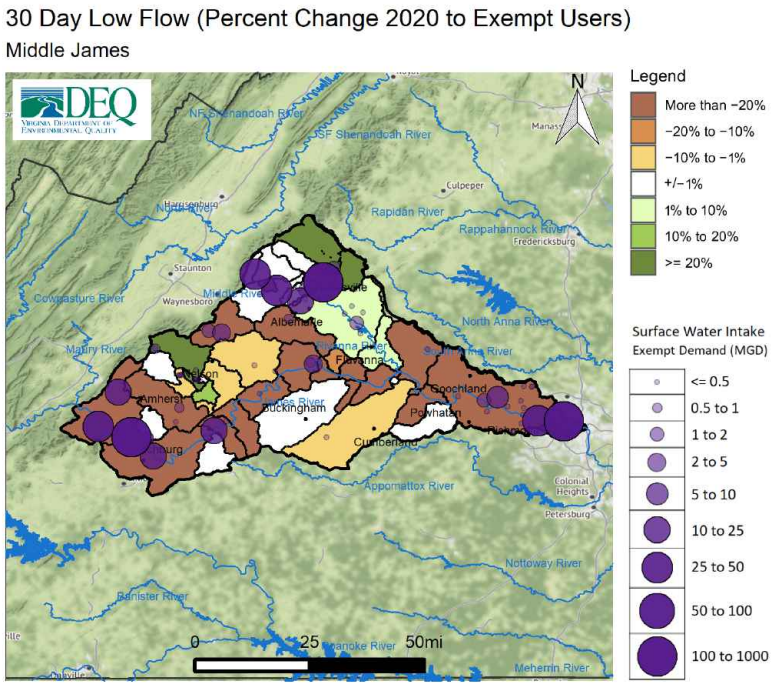

Figure 151: Change in 30 day low flow between current demand scenario and exempt user scenario within the Middle James River Basin

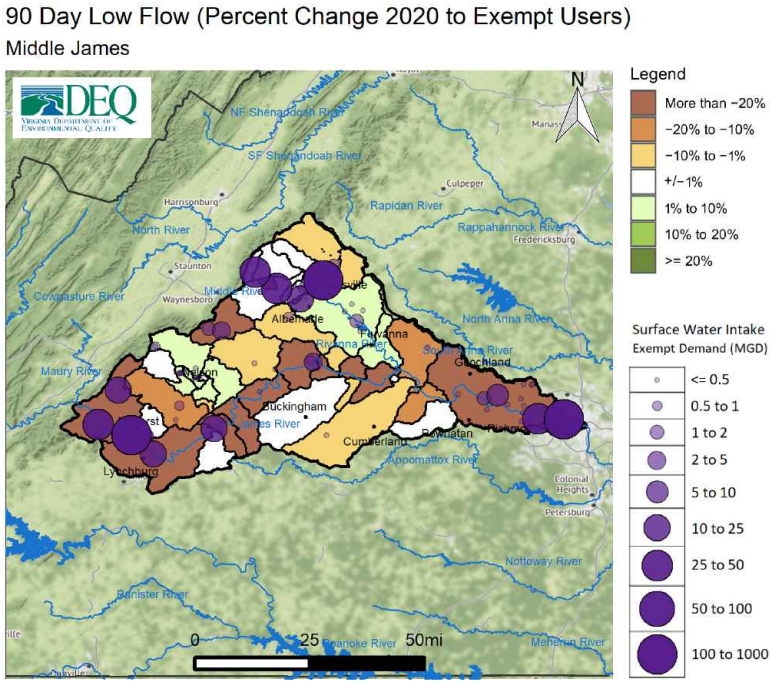

Figure 152: Change in 90 day low flow between current demand scenario and exempt user scenario within the Middle James River Basin

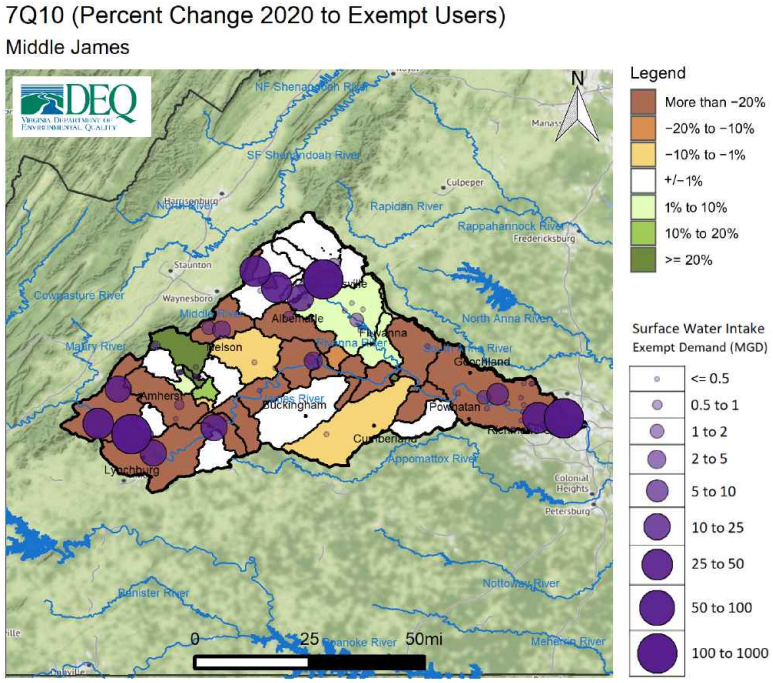

Figure 153: Change in 7Q10 between current demand scenario and exempt user scenario within the Middle James River Basin

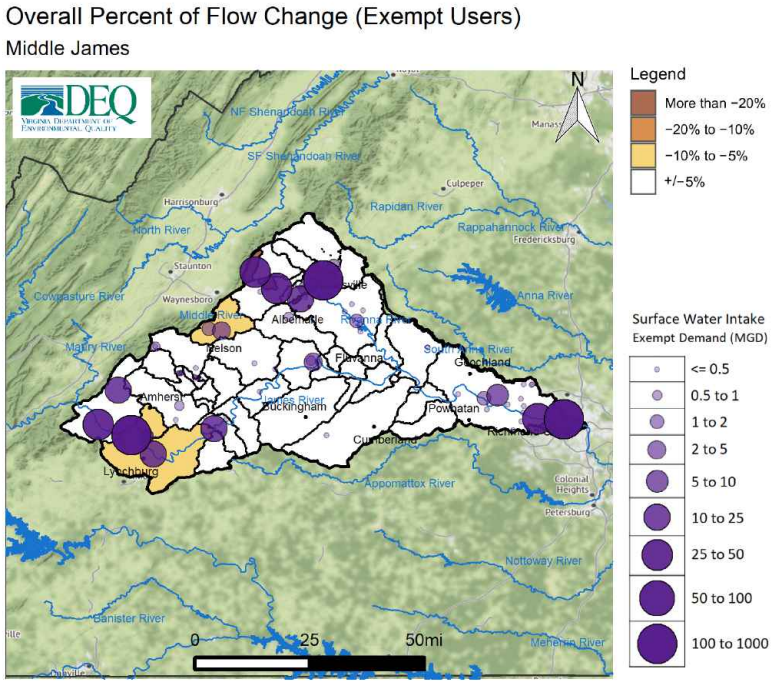

Figure 154: Overall change in flow in percent for exempt user scenario within the Middle James River Basin

Potential Unmet Demand: Potential unmet demand was evaluated for all facilities within the basin for each scenario. Potential unmet demand is the portion of surface water demand for a specific facility that is limited by available streamflow as simulated in a given model scenario, including any known operational limits such as flow-by requirements. This unmet demand, if realized, could be managed through water conservation, through alternative sources, operational changes, or from available storage. Absent of these or other options, this portion of demand could remain unmet. As with all scenarios, demand requirements were determined using demand projections provided in the water supply plans. In the case of the exempt user scenario, the highest possible withdrawal amount was used for users exempt from VWP permitting requirements.

This metric is useful for evaluating where the results seen in the above figures may result in challenges in meeting future demands under a variety of conditions including increasing demands in the basin, changing climate, or withdrawals from users exempt from permitting requirements. Table 38 provides for each facility the highest average daily potential unmet demand over a 30 day period over the course of the simulation for the following scenarios: 2020 demand, 2030 demand, 2040 demand, dry climate, and exempt user. Only facilities showing potential unmet demand in at least one scenario appear on this table. The dry climate scenario is selected among the climate scenarios as the dry scenario represents the potential for increased drought intensity and frequency, and therefore poses the greatest challenge for water supply. Additional information on the potential unmet demand metric can be found in Chapter 4.

Table 38: Change in Highest 30 Day Potential Unmet Demand (MGD) in Middle James Minor Basin

Facility	2020 Demand	2030 Demand	2040 Demand	Dry Climate	Exempt User
Richmond (City) WTP	8.8	9.77	10.74	12.26	760.91
Abert WTP	0.00	0.00	0.00	0.00	149.39
Crozet WTP	0.03	0.04	0.04	0.04	34.91
Bremo Bluff Power Plant	0.00	0.00	0.00	0.00	16.73
Lake Monacan-Stoney Creek (Wintergreen)	0.00	0.01	0.01	0.01	3.61
Meadowcreek Golf Course	0.03	0.03	0.03	0.03	0.86
Georgia-Pacific Big Island WTP	0.00	0.00	0.00	0.00	0.84
Willis Mountain Mining Complex	0.02	0.02	0.02	0.02	0.36
Glenmore Country Club	0.08	0.08	0.08	0.08	0.26
Montebello Fish Station	0.00	0.00	0.00	0.00	0.23
Willow Oaks Country Club	0.00	0.00	0.00	0.00	0.2
Amherst (Town) WTP	0.00	0.00	0.00	0.00	0.16
Lake Monticello Golf Course	0.06	0.06	0.06	0.06	0.08
Saunders Brothers, Inc.	0.25	0.25	0.25	0.2	0.05
Thomas Wheaton	0.11	0.11	0.11	0.14	0.03
Richmond Plant James River	0.00	0.00	0.00	0.00	0.03
Richmond Mill	0.00	0.00	0.00	0.00	0.02
Red Hill Quarry	0.00	0.00	0.00	0.00	0.01
Saunders Brothers, Inc.	0.02	0.02	0.02	0.03	0.00
South Rivanna WTP	0.00	0.00	0.00	8.27	0.00

* Climate scenarios were not completed in areas located outside of the Chesapeake Bay watershed

Note: Potential unmet demand is the portion of surface water demand for a specific facility that is limited by available streamflow as simulated in a given model scenario, including any known operational limits such as flow-by requirements. This unmet demand, if realized, could be managed through water conservation, alternative sources, operational changes, or from available storage.

A.5.6 Spatial Overview of Groundwater Demands

The cumulative impact analysis figures above provide an overview of surface water demands in the basin but did not include groundwater demands. Figure 155 identifies the location and size of projected groundwater demands in the basin for 2040 based on information provided by localities in water supply plans.

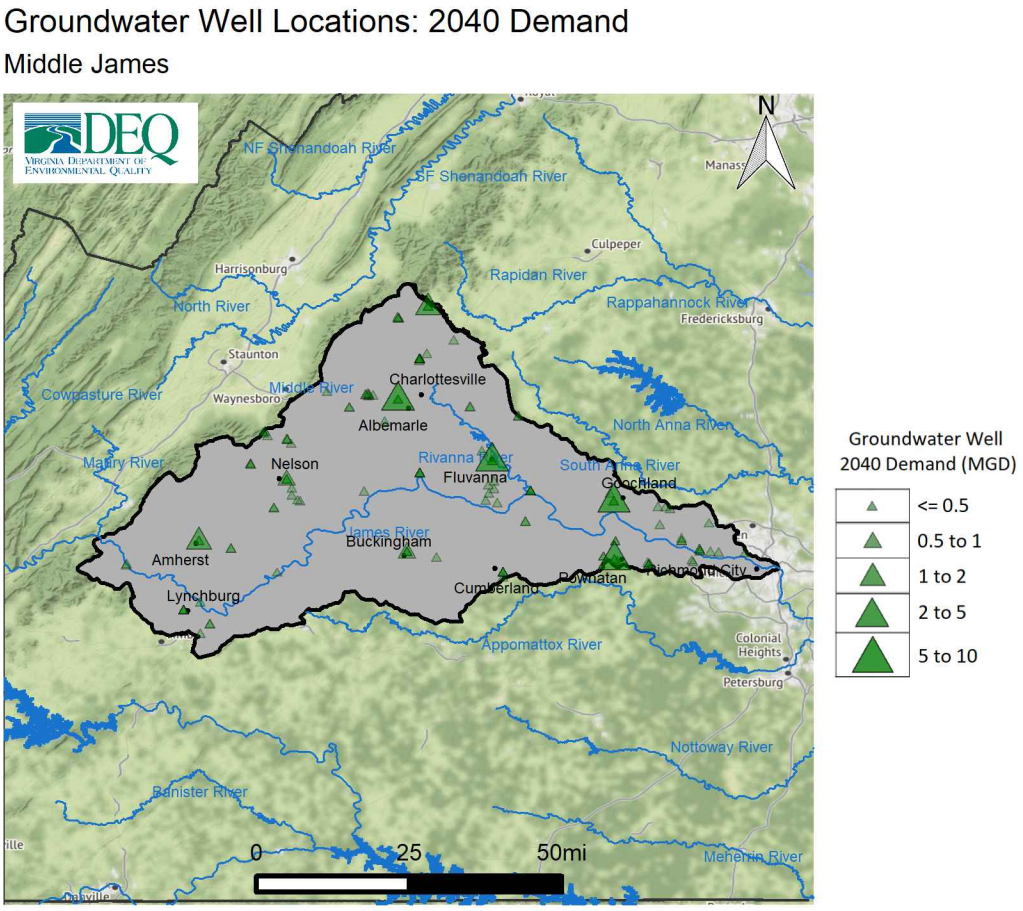

Figure 155: Projected 2040 Groundwater Demands in the Middle James Minor Basin

A.5.7 Trends and Goals

The Code of Virginia mandates that the State Water Control Board should take into consideration the principle that "adequate and safe supplies shall be preserved and protected for human consumption, while conserving maximum supplies for other beneficial uses".[82] This principle is the key driver of the challenges in water resource management, which is that all beneficial uses must be adequately considered when evaluating impacts to surface water resources. The State Water Control Board is tasked with ensuring that water supply quantity needs are met at all times while also protecting Virginia's natural resources, and furthermore, ensuring equitable allocation during a time of shortage.[83] While evaluating and planning for the long-term sustainability of water supply for Virginia is the primary goal for the State Plan, evaluating and limiting impacts to in-stream beneficial uses such as aquatic habitat life is also part of DEQ's responsibility.

The primary purpose of this section is to identify where the most significant challenges to long-term sustainability of water supply and other beneficial uses are indicated based on the CIA and information collated from local water supply plans within this basin. Goals for future planning and areas for additional data collection or analysis are also suggested where appropriate.

The CIAs were completed using the best available data and methods known to DEQ. This discussion focuses on the evaluation of trends - in other words the prevailing tendency or inclination. This means evaluating whether streamflow is simulated to increase or decrease in a given scenario, and by how much. A relative trend indicating reductions of greater than or equal to 10% in streamflow, whether driven by demand increases, changing climate conditions, or exempt user demands was considered a threshold for potential impacts to beneficial uses. The key trends or goals for this basin are as follows:

- **Demand Scenarios:** Surface water demands are projected to increase in the Middle James Minor Basin by approximately 34%, a total of 50 MGD increase primarily driven by large CWS demands from localities such as the City of Richmond and Henrico County. The majority of this demand is projected towards the fall-line and is intended to be mitigated in part by releases from the Cobb's Creek Pump Storage Reservoir. A more than 50% reduction in the short-term drought (L30) metric was simulated when comparing the 2040 and 2020 demand scenarios in the South Rivanna Reservoir segment due to reduced releases from the reservoir as increasing demands impact storage in the reservoir. Elsewhere in the basin, the 2040 demand scenario shows minimal simulated streamflow reductions compared to the 2020 scenario (less than 5%) for short term drought (L30) and long term drought (L90). A more than 30% reduction in 7Q10 is simulated when comparing the 2020 and 2040 demand scenarios below the Sugar Hollow and South Fork Rivanna River reservoirs driven by reduced releases from the reservoir when system storage falls as a result of increasing demands. The 2040 demand scenario also simulates potential unmet demand for the City of Richmond, Crozet WTP, and several Large SSUs. The potential unmet demand simulated for the City of Richmond is driven by drought restrictions, which are active in the model during short-term droughts (L30), the period where the maximum 30 day potential unmet demand most commonly occurs in these simulations. In the 2040 demand scenario, a reduction in overall flow (consumptive use) of more than 20% is simulated below Sugar Hollow and Ragged Mountain reservoirs. A more than 10% reduction in overall flow is simulated below South Fork Rivanna and Beaver Creek reservoirs. Impacts to aquatic life and species biodiversity become increasingly likely when overall streamflow is reduced more than 20%. These reductions are mitigated once discharges are returned to the receiving stream, but in the bypass regions impacts are possible. The Rivanna Water and Sewer Authority (RWSA) urban system, which includes South Fork, Ragged Mountain, and Sugar Hollow reservoirs, currently operates under a VWP permit which is structured to minimize these potential impacts. However, there is likely room for optimization in system management as ongoing data collection improves with better understanding of the reservoir inflows, releases, and streamflows in the system. As demands increase to the projected system capacity, ongoing evaluation of how to best manage the system to minimize impacts to aquatic life will be necessary. Beaver Creek Reservoir, which serves the Crozet area, is currently exempt from VWP regulation and has no

[82] § 62.1-44.36 of the Code of Virginia
[83] 9VAC25-390-20.1

mandatory release; however, RWSA is currently evaluating upgrades to the dam and is expected to apply for a VWP permit application. A VWP withdrawal permit, if issued, would include release requirements that would regulate downstream flows below the reservoir.

- **Climate Scenarios:** The dry climate scenario shows significant reductions in simulated streamflow in both the short-term (L30) and long-term (L90) drought scenarios when compared to current climate. Thirty out of forty-five river segments show reductions greater than 20% in simulated streamflow during a short term drought (L30), with thirty-nine out of forty-five simulating more than 20% during a long-term drought (L90). Potential unmet demand in the dry climate scenario is simulated for several CWS facilities including the City of Richmond WTP, Crozet WTP (Beaver Creek Reservoir), and South Rivanna WTP. Where future climate conditions resemble this dry scenario, the simulations indicate drought conditions more severe than historic droughts will be experienced for most of the basin. Simulations show short-term and long-term droughts with 20-50% reductions in streamflow compared to previous droughts in the majority of the basin. The potential for more severe droughts must be considered by localities and users when evaluating existing sources and alternatives, as well as for broader planning and resource management efforts by all stakeholders.

- While Cobb's Creek Reservoir can help mitigate increasing demands seen in the demand scenarios, it does not significantly impact the severe streamflow reductions simulated during the long-term drought (L90) metric in the dry climate scenario. Henrico County operates Cobb's Creek Reservoir under a VWP permit which requires that when streamflows fall below the thirtieth percentile, water will be released at a rate equal to the downstream demands from the project partners. When streamflows fall below the fifth percentile, releases are intended to raise flows back to the fifth percentile, up to a maximum of 100 MGD, or until reservoir storage falls below 25%. During the dry climate scenario, simulated streamflows remain below the fifth percentile for the entirety of the long-term drought period (L90). Cobb's Creek releases in the simulation do function to increase flows marginally back to the fifth percentile while maintaining adequate Cobb's Creek storage. However, as seen in the dry climate scenario figures, the simulated drought is greater in extent and severity than historic droughts and as a result the length of time spent at or below the fifth percentile is greater.

- **Exempt User Scenario:** The exempt user scenario, which models the cumulative maximum possible exempt demands from all users exempt from VWP permitting requirements, shows widespread reductions in streamflow with 19 of 45 river segments showing reductions of more than 20% in short term drought (L30) and 13 of 45 for long-term drought (L90) compared to the 2020 demand scenario. Significant reductions are simulated in the James River in the Lynchburg area. These are driven by the maximum possible exempt demands from Georgia-Pacific Big Island WTP, Lynchburg's Pedlar Reservoir, and Abert WTP. Reductions are also simulated down towards the fall-line due to the maximum possible exempt demands from the City of Richmond and Henrico County. Significant streamflow reductions (>50%) are also simulated below Beaver Creek Reservoir and in the North Fork of the Rockfish River, primarily due to the maximum possible exempt demand from Wintergreen Resort. In the exempt user scenario, potential unmet demand is simulated to occur for numerous facilities including the largest CWS in the basin. These include the City of Richmond's WTP, City of Lynchburg's Abert WTP, Crozet WTP, and Amherst WTP. Additionally, a more than 10% decrease in overall flow (consumptive use) in the exempt user scenario is simulated in the James River near Lynchburg. As with the 2040 demand scenario, reduction in overall flow are also simulated below Ragged Mountain, Beaver Creek, Sugar Hollow, and South Rivanna reservoirs. Where overall flow is reduced by more than 20%, impacts to aquatic life are increasingly likely. In summary, the cumulative maximum possible exempt demands in the basin exceed the water budget in many river segments. Preserving water supply and other beneficial uses may require managing these demands with respect to their cumulative impacts and in the context of the available resources in the basin.

- The Middle James Basin is projected to experience an increase in groundwater demands for Small SSUs (domestic use) of more than 30%, or 4.78 MGD, between 2020 and 2040. Evaluation and investigation of local aquifer systems in areas where growth is concentrated may be necessary to ensure adequate supply. As already recognized by Albemarle County, in the Piedmont region groundwater aquifer productivity can vary significantly over short distances and geotechnical evaluations may be necessary

to confirm demands can be met where growth is expected, particularly for subdivisions with separate wells completed for each home.

A.6 Lower James Minor Basin

A.6.1 Watershed Overview

Beginning along the Virginia/West Virginia state line, the James River is formed by the confluence of the Jackson and Cowpasture Rivers in the Allegheny Mountains. The James flows 242 miles to the fall-line at Richmond, and another 106 miles before it enters the Chesapeake Bay. Spanning across four physiographic provinces, the topography and climate of the James River Basin varies throughout. The Upper James portion originates in the elongated parallel ridges and valleys that define the Valley and Ridge Province, and flows eastward into the Blue Ridge Province. With distinctive highland topography and dramatic elevation changes, the Blue Ridge Province differs from the Valley and Ridge. It is characterized by rugged terrain with steep slopes and narrow ridges in the north that gradually subside to moderate slopes in the south. The Lower James River Basin begins as the river moves through the Piedmont Province, flowing through scattered hills and small mountains that gradually develop into gently rolling slopes and lower elevations moving east towards the fall-line. The fall-line is a distinct three-mile stretch of river that separates the Piedmont from the Coastal Plain. Running through the City of Richmond the river descends 84 ft of elevation and exits the hard resistant rocks of the Piedmont into the softer sediments of the Coastal Plain before entering the Chesapeake Bay.

The Lower James Minor Basin includes the portion of the James between the fall-line through it's eventual discharge into the Chesapeake Bay. This area is characterized by decreasing elevation above sea level and flattening terrain generally. Land use is predominantly agricultural with increasing development near urban centers like the City of Richmond and the Hampton Roads region. Rivers and streams in this area are generally tidally influenced and salinity increases moving towards the Chesapeake Bay, resulting in increasing reliance on groundwater as a major water source.

The total spatial area of the basin occupies 2,163 sq. miles and includes all or portions of the localities listed in Table 39. The major population centers within the basin include the City of Richmond and the Hampton Roads region which includes localities such as Portsmouth, Norfolk, Williamsburg, Suffolk, and Virginia Beach.

A.6.2 Existing Water Sources

Major surface water sources within the basin include the James and Chickahominy rivers as well as reservoirs such as Western Branch, Lee Hall, Diascund, and Skiff's Creek. Groundwater within the basin is primarily withdrawn from Coastal Plain confined aquifers, particularly from the Potomac Aquifer, with increasing use of the Virginia Beach Aquifer closer to the coast.

Withdrawals within the basin are used for public water supply as well as for power generation, agriculture, irrigation, commercial, and industrial/manufacturing.

The location of wells and surface water intakes identified to DEQ within the basin are shown in Figure 156. This figure does not include private or domestic wells. As indicated by the map, this basin includes numerous sources both in groundwater and surface water. Groundwater is increasingly used as the primary source for CWS demand in the tidal sections, with the exception of several large reservoirs that supply urban centers. Surface water for non-potable use in this area is commonly withdrawn from small stream impoundments that release directly into the tidal James River or other estuarine water bodies.

Table 39: Population Trend by Locality in Lower James Basin

Localities	20 Year % Change
Charles City	-2.38
Chesterfield	22.51
Hanover	16.94
Henrico	17.18
Isle of Wight	18.17
James City	34.48
New Kent	37.48
Prince George	8.14
Surry	-7.83
York	15.44
Chesapeake	15.51
Hampton	-12.36
Hopewell	-1.83
Newport News	-3.20
Norfolk	1.16
Portsmouth	-10.13
Richmond City	9.70
Suffolk	29.21
Virginia Beach	2.84
Williamsburg	18.39

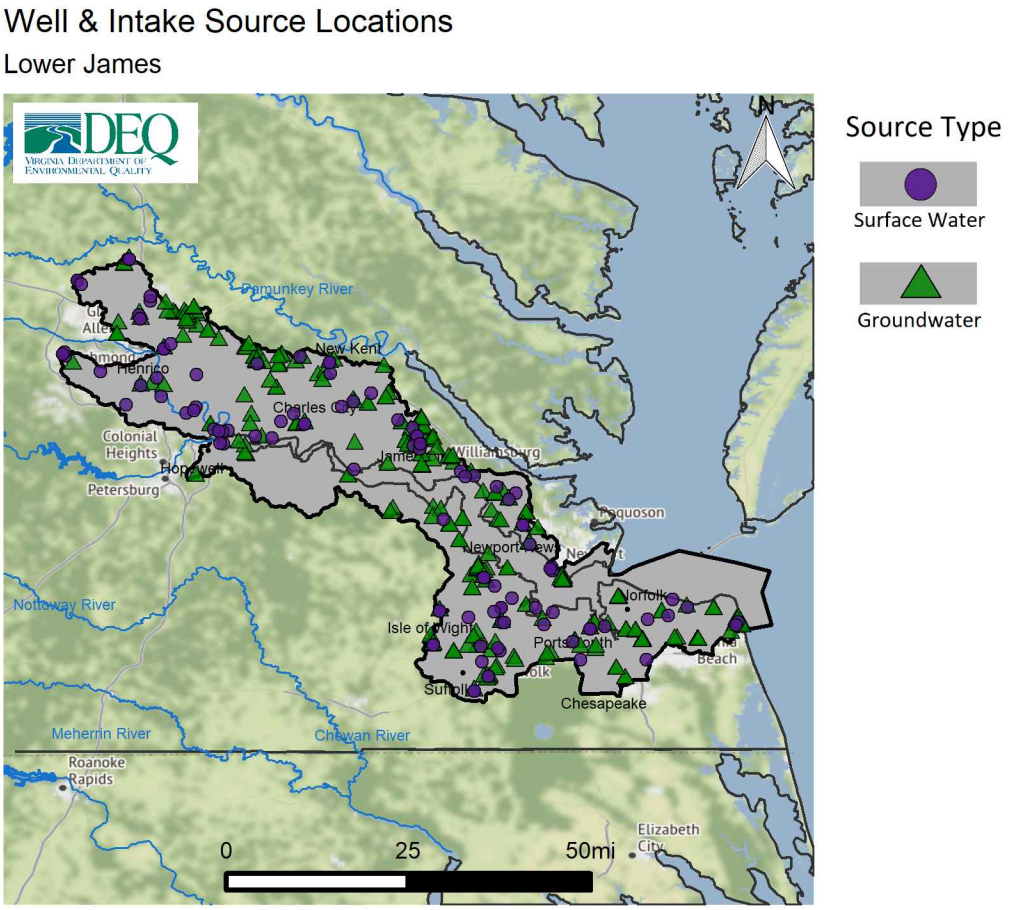

Figure 156: Spatial distribution of groundwater wells and intakes in the Lower James Minor Basin

A.6.3 Existing Water Use

The following section discusses existing (current) water use within the basin, which is based on existing demand information submitted to DEQ in the water supply plans. Table 40 provides a summary of all demands within the basin by system type and source type including power generation. It also provides a count of surface water or groundwater sources associated with each system type. Note that withdrawals related to power are often significantly higher than other demand categories and can therefore make evaluating trends for other categories more challenging. Many power generation withdrawals are also largely non-consumptive; water is withdrawn for cooling purposes and then discharged back into the source stream with minimal loss. To ensure other categories of use are adequately represented, summary Table 41 excludes power generation facilities and will be referenced throughout the following section.

Table 40: Summary of Lower James Minor Basin Water Demand by Source Type and System Type (including Power Generation)

System Type	Source Count	2020 Demand (MGD)	2030 Demand (MGD)	2040 Demand (MGD)	20 Year Percent Change
Surface Water					
Agriculture	32	1.34	1.38	1.43	7.12
CWS	14	120.40	124.92	129.44	7.51
Large SSU	60	2011.39	2020.43	2029.46	0.90
Small SSU	N/A	0.00	0.00	0.00	0.00
Total SW	**106**	**2133.13**	**2146.73**	**2160.33**	**1.28**
Groundwater					
Agriculture	9	0.03	0.03	0.03	0.00
CWS	132	15.00	22.41	29.82	98.80
Large SSU	141	4.37	4.48	4.59	4.96
Small SSU	N/A	11.09	12.39	13.69	23.46
Total GW	**282**	**30.49**	**39.31**	**48.13**	**57.86**
Total (SW + GW)					
Agriculture	41	1.37	1.42	1.46	6.95
CWS	146	135.39	147.32	159.25	17.62
Large SSU	201	2015.76	2024.91	2034.05	0.91
Small SSU	N/A	11.09	12.39	13.69	23.46
Minor Basin Total	**388**	**2163.61**	**2186.04**	**2208.45**	**2.07**

* Small SSU demands are county-wide estimates of private well usage below 300,000 gallons a month. The number of private wells is not known.

Table 41: Summary of Lower James Minor Basin Water Demand by Source Type and System Type (excluding Power Generation)

System Type	Source Count	2020 Demand (MGD)	2030 Demand (MGD)	2040 Demand (MGD)	20 Year Percent Change
Surface Water					
Agriculture	32	1.34	1.38	1.43	7.12
CWS	14	120.40	124.92	129.44	7.51
Large SSU	51	187.90	195.00	202.10	7.56
Small SSU	N/A	0.00	0.00	0.00	0.00
Total SW	**97**	**309.64**	**321.30**	**332.97**	**7.53**
Groundwater					
Agriculture	9	0.03	0.03	0.03	0.00
CWS	132	15.00	22.41	29.82	98.80
Large SSU	126	4.04	4.15	4.26	5.36
Small SSU	N/A	11.09	12.39	13.69	23.46
Total GW	**267**	**30.16**	**38.98**	**47.80**	**58.49**
Total (SW + GW)					
Agriculture	41	1.37	1.42	1.46	6.95
CWS	146	135.39	147.32	159.25	17.62
Large SSU	177	191.93	199.14	206.35	7.51
Small SSU	N/A	11.09	12.39	13.69	23.46
Minor Basin Total	**364**	**339.78**	**360.27**	**380.75**	**12.06**

* Small SSU demands are county-wide estimates of private well usage below 300,000 gallons a month. The number of private wells is not known.

The total existing demand from all surface and groundwater sources excluding power generation is approximately 339.78 MGD, with groundwater supplying approximately 30.16 MGD or 9% of total water demands. Surface water demand within the basin totals approximately 309.64 MGD, or 91% of current demands. Surface water demand is primarily comprised of Large Self-Supplied Users (Large SSUs) and Community Water System (CWS) facilities. Groundwater demand is primarily comprised of Community Water Systems and Small Self-Supplied Users (Small SSUs) that rely on private wells for water supply.

The five largest facility demands for each source type including power generation are provided in Table 42. The five largest facility demands for each source type excluding power generation are provided in Table 43. The largest groundwater demands include the James City Service Authority, Western Tidewater Water Authority, and the Lake Kilby Water Treatment facility. CWS demand is the largest use category in the basin and makes up four of the five largest groundwater demands. The Smithfield Meat Corp. is also a significant source of groundwater demand in the basin as the fifth largest user. When excluding power generation, the largest surface water demands are primarily from Large SSUs with the AdvanSix Resins and Chemical Hopewell Plant being the greatest surface water user. The Western Branch Reservoir operated by the City of Norfolk is the only CWS within the five largest surface water users. Significant manufacturing and industrial users dominate surface water demands in the basin.

Table 42: Top 5 Users in 2040 by Source Type in the Lower James Minor Basin (including Power Generation)

Facility Name	System Type	Locality	2020 Demand (MGD)	2030 Demand (MGD)	2040 Demand (MGD)	20 Year Percent Change	% of Total Surface Water
Surface Water							
Surry Power Station	Large SSU	Surry	1815.39	1815.39	1815.39	0.00	84.03
Hopewell Plant	Large SSU	Hopewell	110.76	106.65	102.54	-7.42	4.75
Western Branch Reservoir	CWS	Suffolk	62.58	62.58	62.58	0.00	2.9
Spruance Plant	Large SSU	Chesterfield	28.72	29.67	30.63	6.65	1.42
Chesterfield Plant	Large SSU	Chesterfield	21.27	25.69	30.11	41.56	1.39
Total SW			2038.72	2039.98	2041.25	0.12	94.49
Groundwater							**% of Total Groundwater**
JCSA - Central System	CWS	James City	4.57	7.12	9.67	111.6	20.09
Western Tidewater Water Authority	CWS	Suffolk	3.92	6.17	8.42	114.8	17.49
Lake Kilby Water Treatment Facility	CWS	Suffolk	2.32	2.39	2.47	6.47	5.13
Northwest River/Western Branch Systems	CWS	Chesapeake	1.15	1.52	1.9	65.22	3.95
Smithfield Fresh Meats Corp. - Smithfield Va	Large SSU	Isle of Wight	1.69	1.69	1.69	0.00	3.51
Total GW			13.65	18.89	24.15	76.92	50.18

Table 43: Top 5 Users in 2040 by Source Type in the Lower James Minor Basin (excluding Power Generation)

Facility Name	System Type	Locality	2020 Demand (MGD)	2030 Demand (MGD)	2040 Demand (MGD)	20 Year Percent Change	% of Total Surface Water
Surface Water							
AdvanSix Resins and Chemicals	Large SSU	Hopewell	110.76	106.65	102.54	-7.42	30.8
Western Branch Reservoir	CWS	Suffolk	62.58	62.58	62.58	0.00	18.79
Dupont Spruance Plant	Large SSU	Chesterfield	28.72	29.67	30.63	6.65	9.2
AdvanSix Chesterfield Plant	Large SSU	Chesterfield	21.27	25.69	30.11	41.56	9.04
WestRock CP	Large SSU	Hopewell	12.42	17.98	23.54	89.53	7.07
Total SW			235.75	242.57	249.4	5.79	74.9
Groundwater							**% of Total Groundwater**
JCSA - Central System	CWS	James City	4.57	7.12	9.67	111.6	20.23
Western Tidewater Water Authority	CWS	Suffolk	3.92	6.17	8.42	114.8	17.62
Lake Kilby Water Treatment Facility	CWS	Suffolk	2.32	2.39	2.47	6.47	5.17
Northwest River/Western Branch Systems	CWS	Chesapeake	1.15	1.52	1.9	65.22	3.97
Smithfield Fresh Meats Corp. - Smithfield Va	Large SSU	Isle of Wight	1.69	1.69	1.69	0.00	3.54
Total GW			13.65	18.89	24.15	76.92	50.52

Table 41 also provides the proportion of each use category that is supplied by either surface water or groundwater. Use categories include Community Water System (CWS), Large Self-Supplied User (Large SSU), Small Self-Supplied User (Small SSU), and Agricultural Self-Supplied User (AG). These categories are defined below. Surface water demand is primarily comprised of Large SSUs and CWS facilities. Groundwater demand is driven primarily by CWS and significant Small SSU demands from domestic well users.

The CWS category includes any public and private waterworks that serve at least 15 service connections used by year-round residents or regularly serve at least 25 year-round residents, and are regulated under the Virginia Department of Health's Waterworks Regulation (12VAC5-590). In the Lower James Basin, approximately 15 MGD of groundwater demand and 120.4 MGD of surface water demand is from CWS. Significant groundwater users within this category include James City County, Western Tidewater Water Authority, and the Lake Kilby Water Treatment facility as the primary demands. Surface water is the primary water source for CWS with significant water users including the cities of Newport News, Norfolk, and Portsmouth. With the Western Branch, Lee Hall, Diascund, and Meade reservoirs as the primary water sources.

Large SSUs include any non-CWS or AG users who withdraw more than 300,000 gallons per month from a well or surface water intake. In the Lower James Basin, approximately 4.04 MGD of groundwater demand and 187.90 MGD of surface water demand is from Large SSUs. Significant groundwater users within this category include the Smithfield Meat Corp, Colonial Williamsburg, Dupont Hopewell Plant, and the Surry Power Station. Demands from Large SSUs represent the greatest use category for surface water in the

watershed demanding more than 60% of current surface water withdrawals. Significant users excluding power generation, include two AdvanSix facilities in the City of Hopewell and Chesterfield County, Dupont, and WestRock. Each of the largest surface water demands primarily rely on the James River for supply and represent more than 54% of current surface water demands in the basin.

Small SSUs include any users who withdraw less than 300,000 gallons per month from wells. Small SSUs generally consist of residential or domestic use for those who lives outside service areas and provide their own water. Small SSU demand is generally met with groundwater. In the Lower James Basin, approximately 11.09 MGD of groundwater demand is from Small SSUs. With significant population centers and suburban areas in the basin, reliance on domestic wells is common throughout the basin. The largest demands from domestic well users are within Hanover County, Henrico County, the City of Suffolk, and Isle of Wight County.

The AG category includes crop farms, livestock operations, aquaculture and other agricultural facilities. In the Lower James Basin, approximately 0.03 MGD of groundwater demand and 1.34 MGD of surface water demand is from AG. Significant groundwater users within the category are largely comprised of cumulative withdrawals from agricultural estimates in Isle of Wight County, the City of Suffolk, and Charles City County. Surface water is the primary source of supply for the AG category with the largest demands from Bennett's Creek Nursery, Varina on the James, and Renwood Farms. AG demands are the smallest use category in the basin.

A.6.4 Projected Population and Water Use

Projected Population: Trends in water use are generally driven by trends in population change or economic development. Increasing population within an area generally means increased connections for community water systems or additional groundwater demand from homeowners that construct wells. Increasing population in an area also tends to incentivize both new and expanded industrial and commercial water use.

Table 39 shows the projected change in population by 2040 for each locality located partly or wholly within this minor basin. With much of the basin including or near major urban centers such as the City of Richmond and Hampton Roads region, significant increases in population are projected as urban areas continue to expand. The fastest growing localities include New Kent, James City, Suffolk, and Chesterfield, as economic opportunity and growth continue to attract individuals to these key areas in the basin. In addition to significant increases, population declines are expected within the cities of Hampton and Portsmouth, largely driven by limited economic opportunity and recruitment.

Projected Water Use: The following section discusses projected water use through 2040 within the Lower James basin, based on projections provided in local and regional water supply plans. Table 41, included in the existing demand section above, is the basis for information discussed in this section.

Total demand within the basin is projected to increase from 339.78 MGD in 2020 to approximately 380.75 MGD in 2040. Increases in demand are primarily focused within increased surface water demands for Large Self-Supplied Users, and groundwater demands by Community Water Systems. Surface water demand is projected to increase by 23.3 MGD or 7.5%, by 2040. Groundwater demand is projected to increase by 17.6 MGD, or 58.4%, by 2040. The largest contributors to this trend in total projected demand include significant increases in demand from the AdvanSix Resins & Chemical facilities in the City of Hopewell and Chesterfield County, the City of Newport News, and the DuPont Spruance Plant.

Demand from CWS users within the basin is projected to increase by 17.6% by 2040. Within this category, surface water use is projected to increase by 7.5%, while groundwater use is projected to increase by 98.8%. The largest increases in demand are projected for the cities of Newport News and Portsmouth service areas that are supplied by surface water. Significant increases in groundwater demands are projected for the Western Tidewater Water Authority and the James City County Central System. Increased reliance on groundwater sources for CWS over the planning period is similar to other watersheds within the GWMA.

Demand from Large SSUs within the basin is projected to increase by 7.5% by 2040. Within this category, surface water use is projected to increase by 7.5%, while groundwater use is projected to increase by 5.3%. The largest increases in demands are from surface water sources and are driven by AdvanSix, DuPont, and Veolia North America facilities that rely on the James River.

Demand from Small SSUs within the basin is projected to increase by 23.4% by 2040. As noted previously, Small SSU demand is entirely met with groundwater and represents domestic well use. Increased demands in the category are primarily driven by significant increases within Hanover County. Additionally, Isle of Wight, Charles City, and New Kent counties are projecting large increases in domestic well use over the planning period. Projected increases in water demand align with the expected increases in population in the watershed.

Demand from Agriculture Users within the basin is projected to increase by 6.9% by 2040. Within this category, surface water use is projected to increase by 7.1%. Groundwater demands are minimal and are expected to remain constant over the planning period. Projected increases in demand are entirely comprised by increased surface water demands for the Bacon Castle Farm.

A.6.5 Cumulative Impact Analysis

The following section provides a brief summary of the Cumulative Impact Analysis (CIA) modeling results in the Lower James Minor Basin. Discussion of these results will primarily be found in the Trends and Goals section of this appendix. However a brief overview of the VAHydro model and the scenarios and metrics is provided below.

The VAHydro surface water model simulates streamflow using inputs such as precipitation, climate, land use, and topography, combined with data on all known withdrawals and discharges, and operational rules of major hydrologic features such as reservoirs. Each minor basin is broken into smaller hydrologic subsections, or river segments. The model simulates the water balance on a daily basis for each individual river segment, with each downstream segment being affected by the "cumulative impact" of streamflow changes occurring in upstream segments. The following figures help analyze this cumulative impact within the Lower James Minor Basin. Note that this section is not intended to document in detail the methods and assumptions for the VAHydro model or for the scenarios and metrics discussed. Detailed documentation of the model and assumptions can be found in Chapter 4.

The VAHydro surface water model was used to simulate streamflow under a variety of scenarios. Demand scenarios examine how streamflow is impacted under 2030 or 2040 demands as compared to current (2020) demands. Demands were calculated based on current and future demand information submitted through local and regional water supply plans. Climate change scenarios examine how streamflow is impacted when 2040 demands are simulated in conjunction with a range of precipitation and temperature conditions that may occur in the future due to changing climate (Dry, Median, Wet scenarios). Finally, the exempt user scenario examines impacts from users excluded, or exempt, from VWP permit requirements per Va. Code § 62.1-44.15:22 B. Exempt users were simulated at the maximum possible demand identified through a review of demand justification values commonly asserted by exempt users, including but not limited to VDH pump capacity, maximum pre-1989 withdrawal, and maximum intake capacity. In order to effectively manage surface water resources and address the uncertainty related to these demands, DEQ determined the most conservative, or maximum possible, demand should be evaluated in this scenario. However, DEQ does not agree that the maximum values used in this scenario represent an allocation for, or the expectation of, a future withdrawal of that volume; nor does DEQ concede that any particular exempt user is necessarily entitled to withdraw any particular maximum value used in this scenario. The methods and assumptions for each of these modeling scenarios are discussed in more detail in Chapter 4.

For each scenario described above, different metrics can be used to evaluate the simulated streamflow. A metric is a method for measuring or evaluating a given set of data; different metrics can be evaluated to answer different questions. Within this section the following metrics will be discussed: the lowest 30 day flow (L30), the lowest 90 day flow (L90), 7Q10, and overall change in flow. The L30 describes the lowest

consecutive 30 day average daily streamflow over the simulation period. This metric is a representation of a short-term, or acute drought, and is a good metric for evaluating impacts to direct withdrawals without storage. Similarly, the lowest 90 day flow represents the lowest consecutive 90 day average daily streamflow over the simulation period. This would represent a prolonged drought and is often used to evaluate impacts to reservoirs. The 7Q10 is the lowest 7-day average flow that occurs (on average) once every 10 years. 7Q10 is generally used in the evaluations of in-stream beneficial uses such as waste assimilative capacity. Overall change in flow describes the net loss of water from the riverine system as a result of off-stream use not otherwise returned through point source discharges, or losses due to evapotranspiration. This metric is useful for evaluating impacts to aquatic life and is discussed in more detail in Chapter 4.

Demand Scenarios: 2020 demand or current demand, 2030 demand, and 2040 demand scenarios were simulated. The following series of figures compares the 2030 and 2040 demand scenarios to the current demand scenario. The change in flow depicted on each map is the change expected when comparing two scenarios - in this case future demands compared to current demands. Each page includes two figures comparing either the 2030 or 2040 demand scenario to current demand using the L30, L90, and 7Q10 metrics. This allows for comparisons of simulated impacts between the 2030 and 2040 demand scenarios. The scenarios and metrics are identified in the paragraph below and in the figure captions.

Figures 157 and 158 compare the lowest 30 day flow simulated with the current demand scenario with the lowest 30 day flow simulated in the 2030 and 2040 demand scenarios respectively. Figures 159 and 160 compare the lowest 90 day low flow simulated with the current demand scenario with the lowest 90 day flow simulated in the 2030 and 2040 demand scenarios respectively. Figures 161 and 162 compare the 7Q10 simulated with the current demand scenario with the 7Q10 simulated in the 2030 and 2040 demand scenarios respectively.

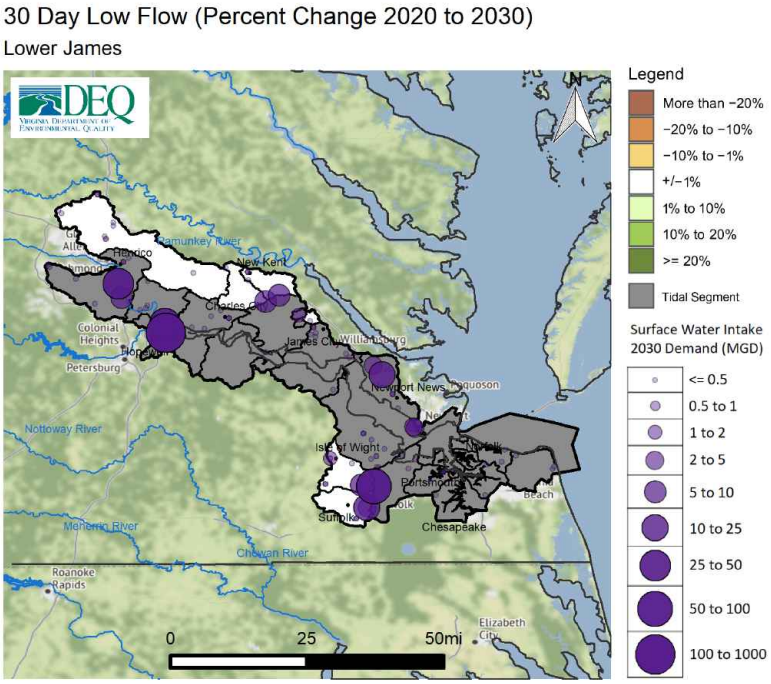

Figure 157: Change in 30 day low flow between 2020 and 2030 demand scenarios within the Lower James Minor Basin

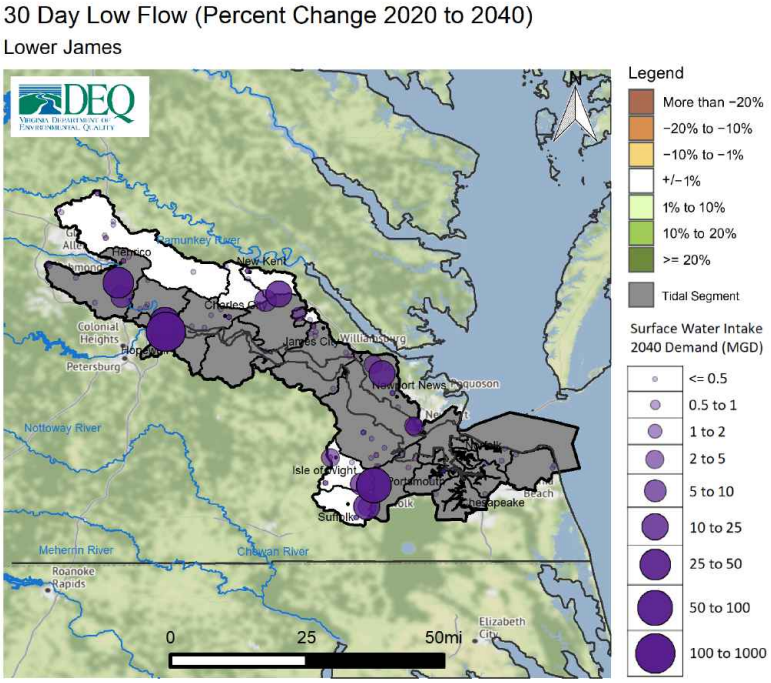

Figure 158: Change in 30 day low flow between 2020 and 2040 demand scenarios within the Lower James Minor Basin

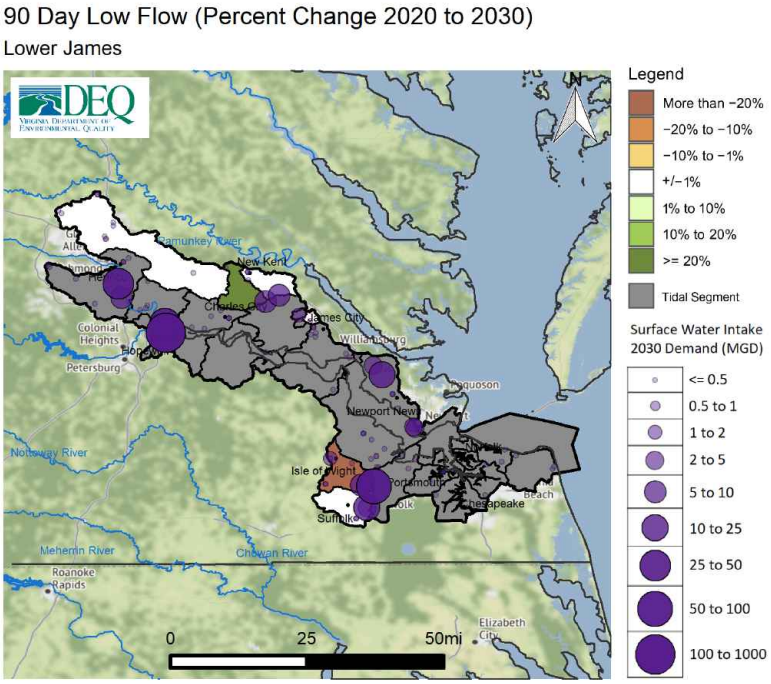

Figure 159: Change in 90 day low flow between 2020 and 2030 demand scenarios within the Lower James Minor Basin

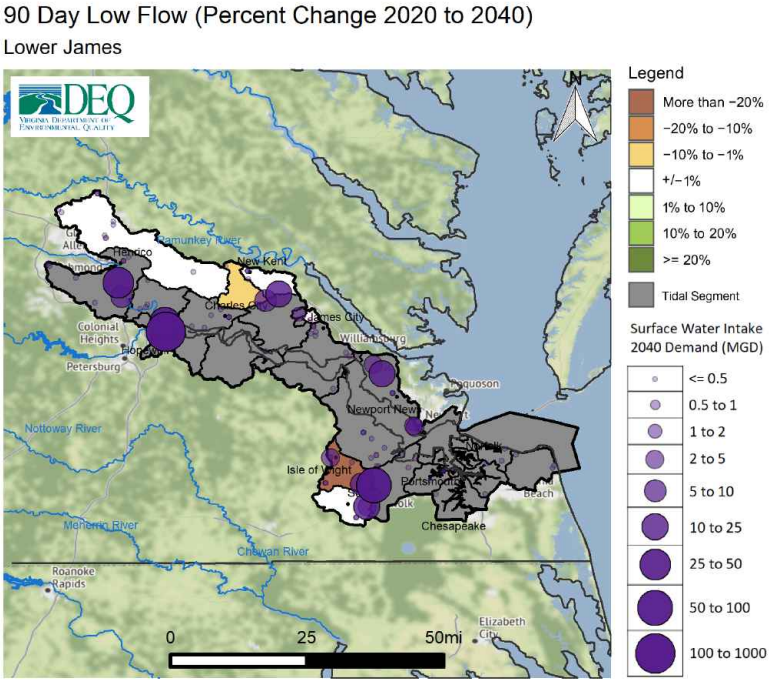

Figure 160: Change in 90 day low flow between 2020 and 2040 demand scenarios within the Lower James Minor Basin

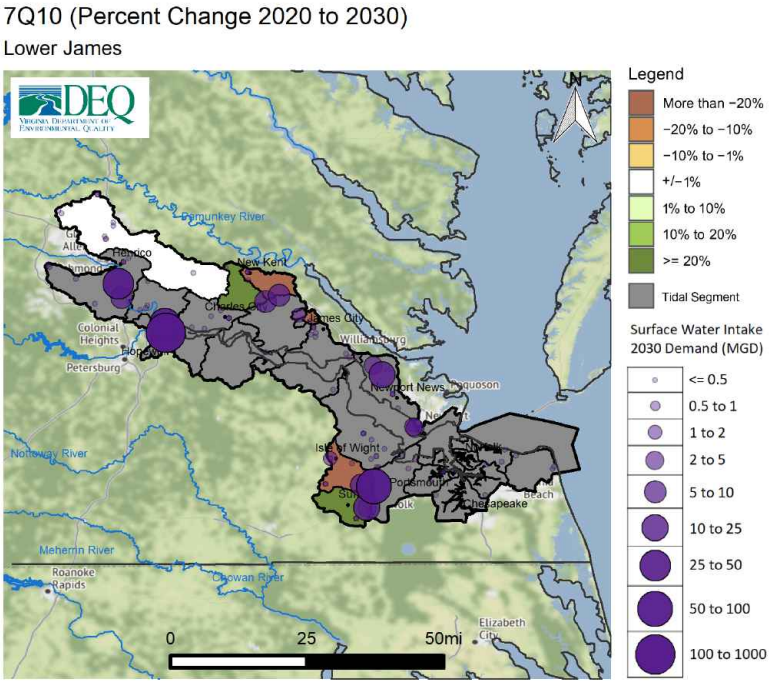

Figure 161: Change in 7Q10 between 2020 and 2030 demand scenarios within the Lower James Minor Basin

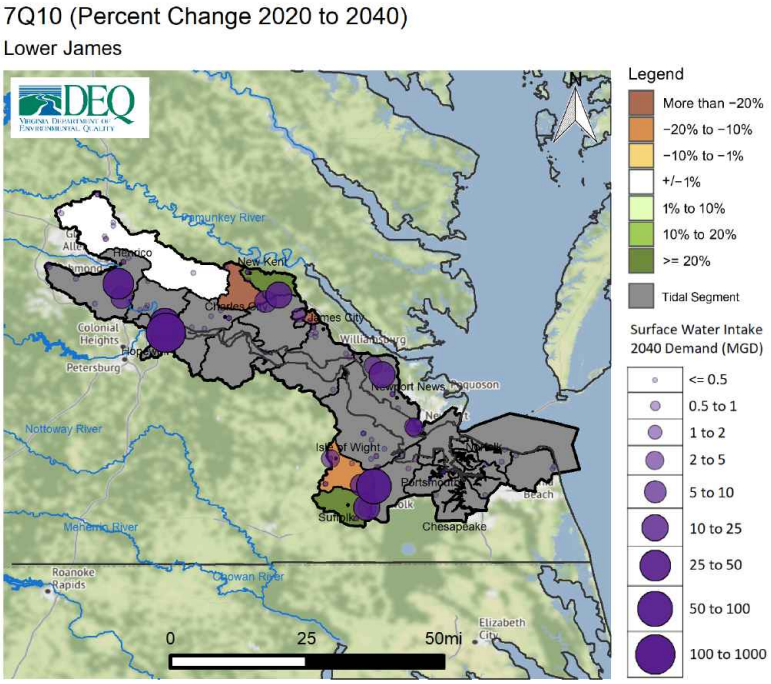

Figure 162: Change in 7Q10 between 2020 and 2040 demand scenarios within the Lower James Minor Basin

The figures above show a comparison between two scenarios. An additional way to evaluate impacts to streamflow is to examine the total reduction in streamflow resulting from all withdrawals within a river segment, as well as losses due to evapotranspiration, while taking into consideration any discharges back to the source. To use a common industry term, the overall change in flow metric evaluates "consumptive use", or the amount of water removed from the river that is not returned through discharges. This can help describe potential impacts to downstream withdrawals, while also providing a basis for evaluating impacts to aquatic life. In general, total reductions in streamflow can result in a reduction in aquatic biodiversity[84]. The relationship between streamflow and aquatic biodiversity is discussed in more detail in Chapter 4. Figure 163 shows the overall change in streamflow for the 2030 Demand Scenario, while Figure 164 shows the overall change in streamflow for the 2040 Demand Scenario.

[84]Rapp, J.L., R. Burgholzer, J. Kleiner, D. Scott, and E. Passero. 2020. "Application of a New Species-Richness Based Flow Ecology Framework for Assessing Flow Reduction Effects on Aquatic Communities." Journal of the American Water Resources Association 1–14.https://doi.org/10.1111/1752-1688.12877.

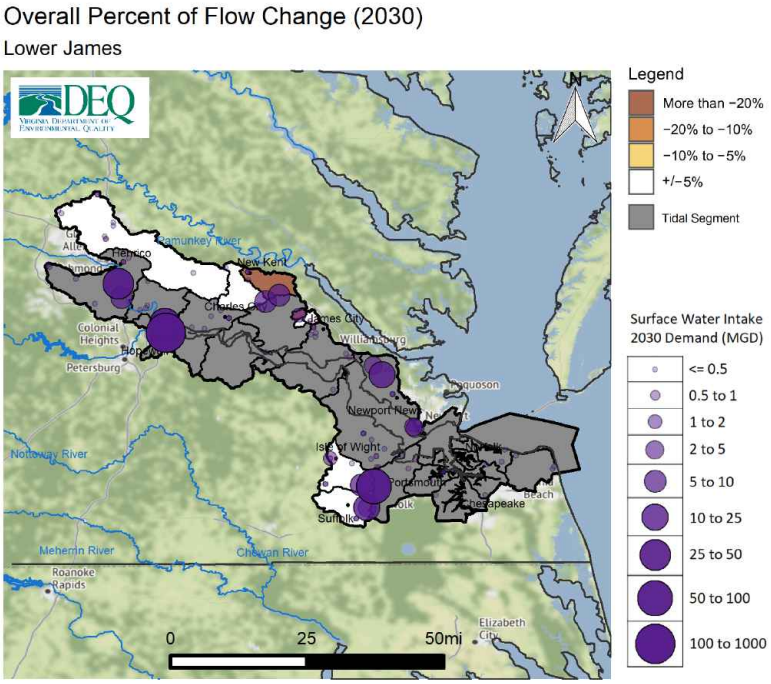

Figure 163: Overall change in flow in percent for 2030 demand scenario within the Lower James Minor Basin

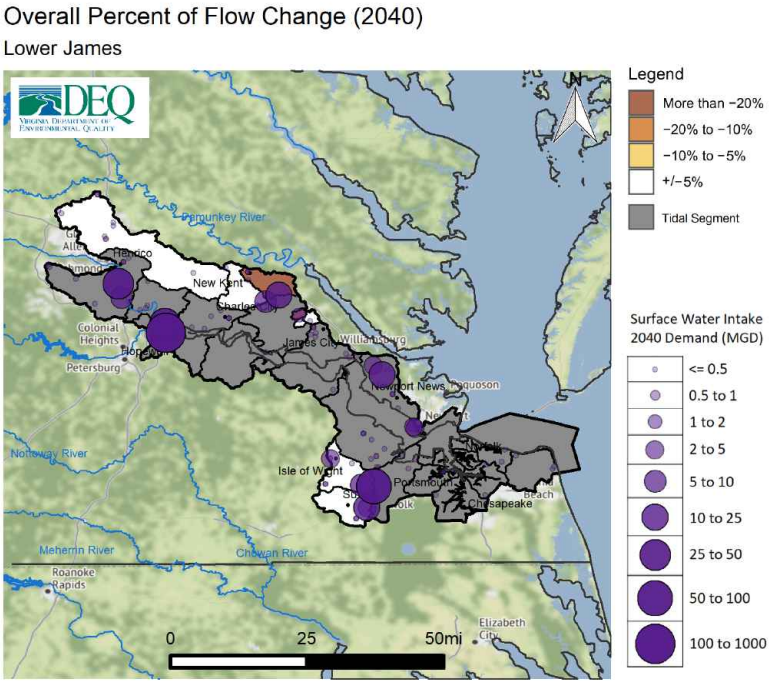

Figure 164: Overall change in flow in percent for 2040 demand scenario within the Lower James Minor Basin

Climate Scenarios: Three scenarios that simulate impacts to streamflow in response to changes in temperature and climate were completed for areas in the state where climate data was available, which includes the portions of the Commonwealth located in the Chesapeake Bay watershed. Details on the methods and assumptions employed for these scenarios can be found in Appendix B. The three scenarios can be described as dry, median, and wet scenarios. Virginia is expected to experience a range of precipitation and temperature changes that may vary spatially and from year to year. The potential for both more severe and prolonged droughts as well as for higher intensity and more frequent rain events must be considered. These three scenarios are not intended as predictions of future climate conditions, but as representations of several possibilities that climate change models indicate could occur. Should they occur, these results provide an evaluation of how streamflows may be impacted. Their purpose is to build upon existing climate modeling to provide a foundation for state and local government, as well as other stakeholders, to better evaluate what practical water resource challenges may be associated with the range of climate conditions Virginia could experience.

Figure 165 depicts the percent change in the L30 for the dry climate scenario in conjunction with 2040 demands, as compared to the current climate and demand scenario. Reductions in streamflow in this scenario may be caused by reduced precipitation, increased demand, or as is generally the case, a combination of both. Figures 166 and 167 depict the L30 for the median and wet climate scenarios (in conjunction with 2040 demands) as compared to the current climate and demand scenario.

Figure 168 depicts the percent change in the L90 for the dry climate scenario in conjunction with 2040 demands, as compared to the current climate and demand scenario. Figures 169 and 170 depict the L30 for the median and wet climate scenarios (in conjunction with 2040 demands) as compared to the current climate and demand scenario.

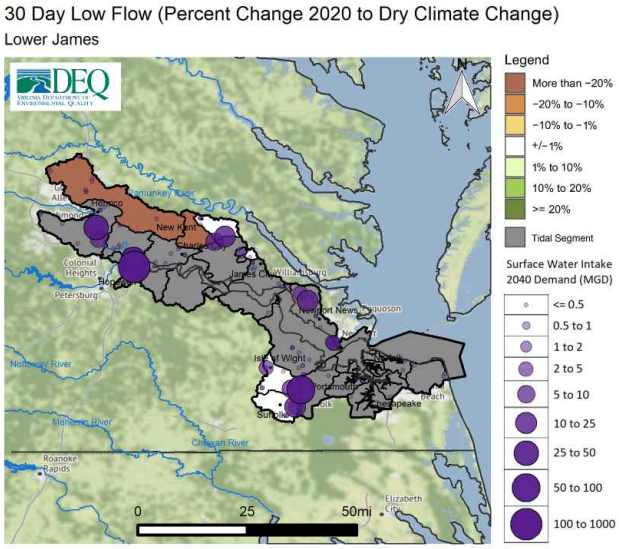

Figure 165: Change in 30 day low flow between current climate/demand scenario and the dry climate/2040 demand scenario within the Lower James Minor Basin

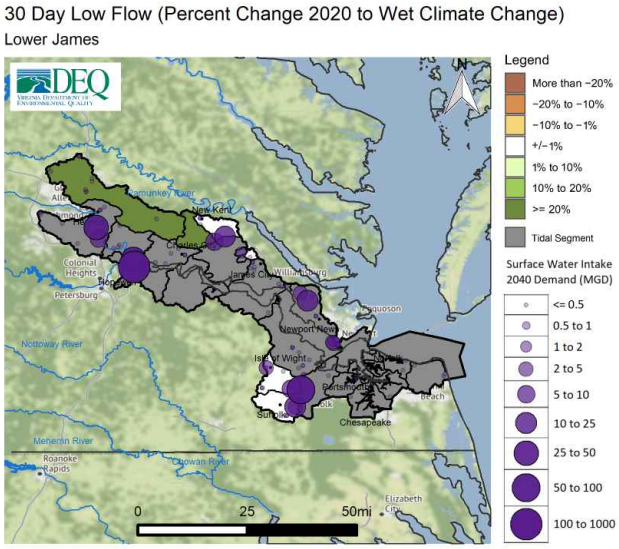

Figure 167: Change in 30 day low flow between current climate/demand scenario and the wet climate/2040 demand scenario within the Lower James Minor Basin

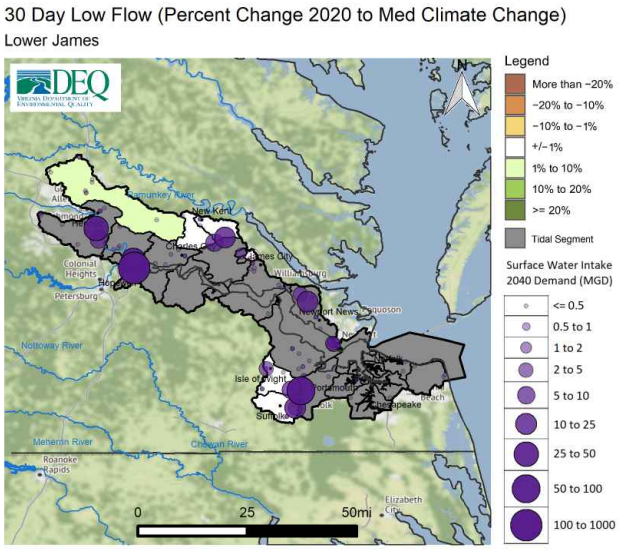

Figure 166: Change in 30 day low flow between current climate/demand scenario and the median climate/2040 demand scenario within the Lower James Minor Basin

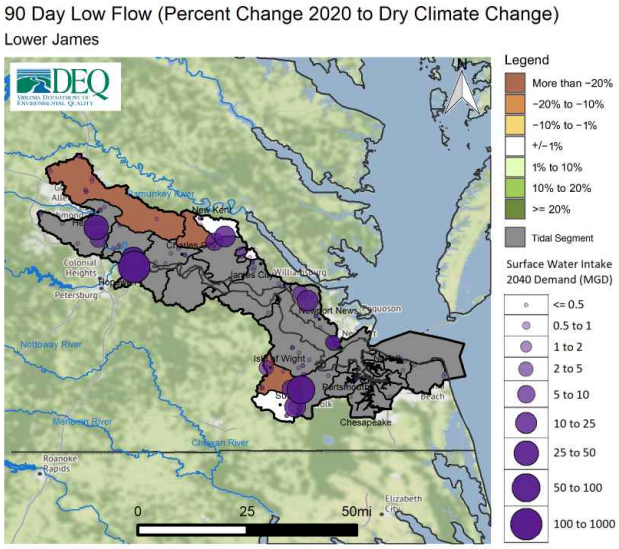

Figure 168: Change in 90 day low flow between current climate/demand scenario and the dry climate/2040 demand scenario within the Lower James Minor Basin

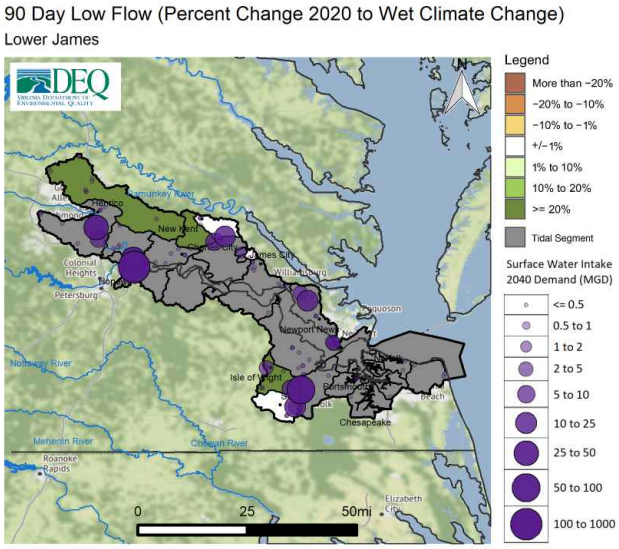

Figure 170: Change in 90 day low flow between current climate/demand scenario and wet climate/2040 demand scenario within the Lower James Minor Basin

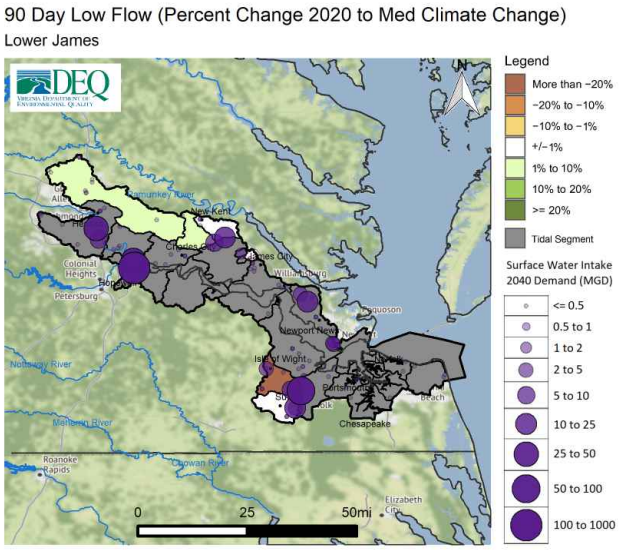

Figure 169: Change in 90 day low flow between current climate/demand scenario and median climate/2040 demand scenario within the Lower James Minor Basin

Exempt User Scenario: The exempt user scenario simulates the maximum possible exempt demand for users excluded from Virginia Water Protection permitting requirements per Va. Code § 62.1-44.15:22 B, in combination with the permitted withdrawal limits for those users that are permitted. A more detailed discussion of the data and assumptions used in this scenario can be found in Appendix B. Note that this scenario uses current climate conditions. Figure 171 depicts the percent change in 30 day low flow between the exempt user scenario and current (2020) demand. Figure 172 depicts the percent change in 90 day low flow between the exempt user scenario and current (2020) demand. Figure 173 depicts the percent change in the 7Q10 between the exempt user scenario and current (2020) demand. Finally, figure 174 depicts the overall change in flow in percent (consumptive use) for the exempt user scenario.

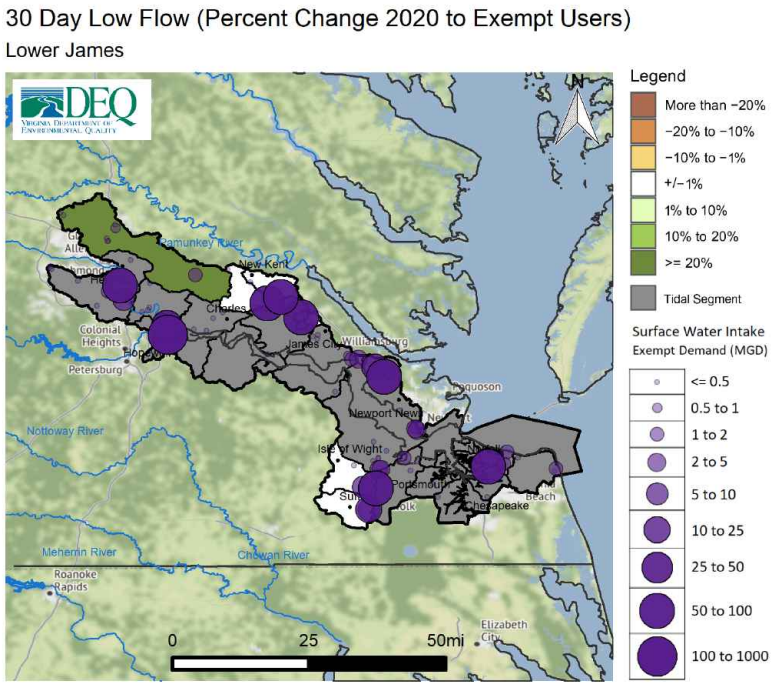

Figure 171: Change in 30 day low flow between current demand scenario and exempt user scenario within the Lower James Minor Basin

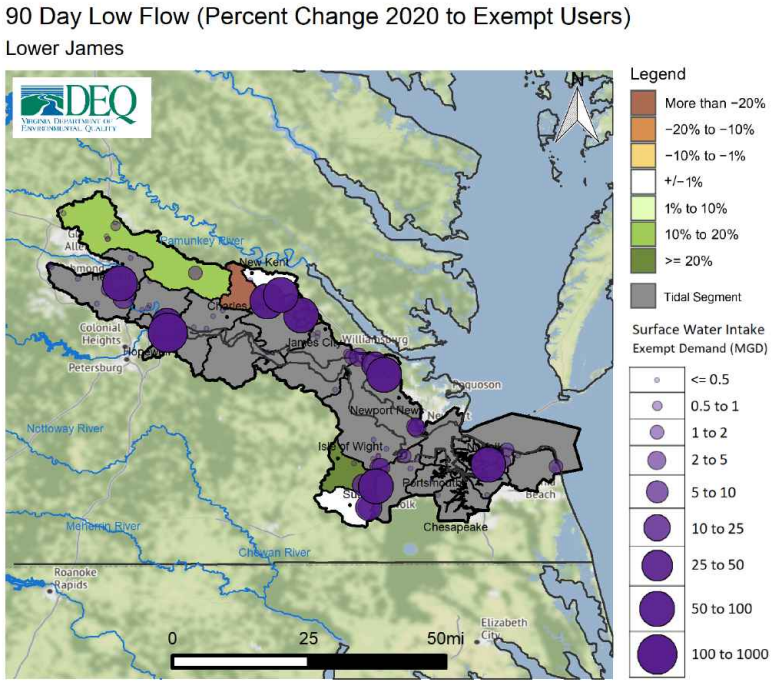

Figure 172: Change in 90 day low flow between current demand scenario and exempt user scenario within the Lower James Minor Basin

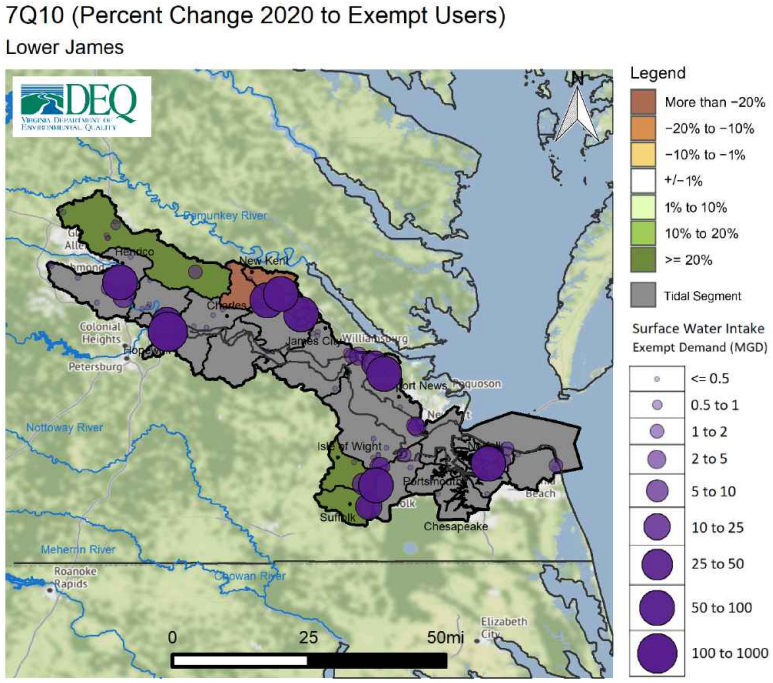

Figure 173: Change in 7Q10 between current demand scenario and exempt user scenario within the Lower James Minor Basin

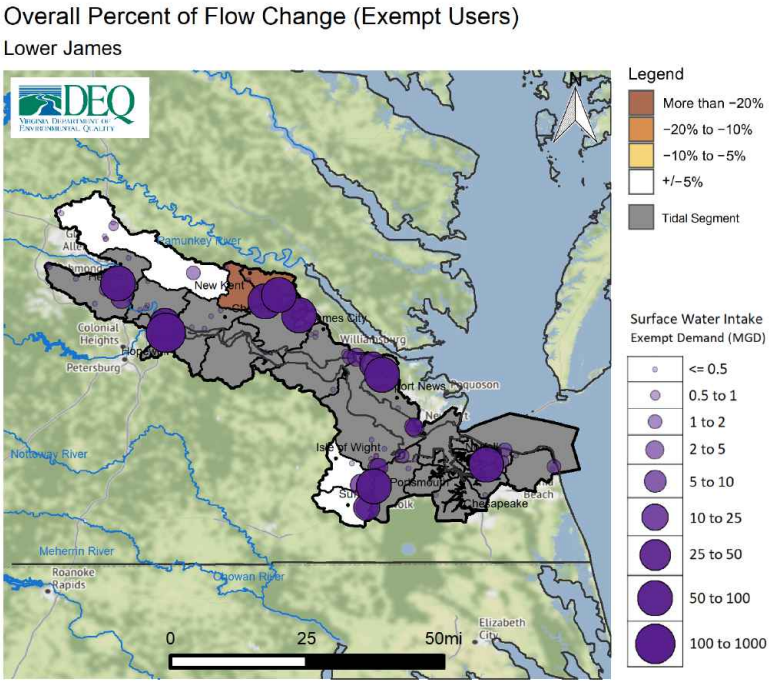

Figure 174: Overall change in flow in percent for exempt user scenario within the Lower James Minor Basin

Potential Unmet Demand: Potential unmet demand was evaluated for all facilities within the basin for each scenario. Potential unmet demand is the portion of surface water demand for a specific facility that is limited by available streamflow as simulated in a given model scenario, including any known operational limits such as flow-by requirements. This unmet demand, if realized, could be managed through water conservation, through alternative sources, operational changes, or from available storage. Absent of these or other options, this portion of demand could remain unmet. As with all scenarios, demand requirements were determined using demand projections provided in the water supply plans. In the case of the exempt user scenario, the highest possible withdrawal amount was used for users exempt from VWP permitting requirements.

This metric is useful for evaluating where the results seen in the above figures may result in challenges in meeting future demands under a variety of conditions including increasing demands in the basin, changing climate, or withdrawals from users exempt from permitting requirements. Table 44 provides for each facility the highest average daily potential unmet demand over a 30 day period over the course of the simulation for the following scenarios: 2020 demand, 2030 demand, 2040 demand, dry climate, and exempt user. Only facilities showing potential unmet demand in at least one scenario appear on this table. The dry climate scenario is selected among the climate scenarios as the dry scenario represents the potential for increased drought intensity and frequency, and therefore poses the greatest challenge for water supply.

Table 44: Change in Highest 30 Day Potential Unmet Demand (MGD) in Lower James Minor Basin

Facility	**2020 Demand**	**2030 Demand**	**2040 Demand**	**Dry Climate**	**Exempt User**
Chickahominy River	0.00	0.00	0.00	0.00	70.11
Little Creek Reservoir	0.00	0.00	2.96	0.00	60.04
Diascund Reservoir	0.00	0.00	0.00	0.94	60.01
Lake Kilby Water Treatment Facility	13.58	14.01	13.5	-	31.75
Brookwoods Golf Club	0.00	0.00	0.00	0.00	0.54
The Crossings Golf Course	0.00	0.00	0.00	0.00	0.5
Belmont Golf Course	0.00	0.00	0.00	0.00	0.08
Berkeley Pump Co. Golf Course	0.00	0.00	0.00	0.00	0.03
Jefferson-Lakeside Country Clb	0.00	0.00	0.00	0.00	0.03
Deer Lake Estates (Colonial Heritage)	0.22	0.22	0.22	0.1	0.00
John T Butler Jr	0.00	0.03	0.00	-	0.00

* Climate scenarios were not completed in areas located outside of the Chesapeake Bay watershed

Note: Potential unmet demand is the portion of surface water demand for a specific facility that is limited by available streamflow as simulated in a given model scenario, including any known operational limits such as flow-by requirements. This unmet demand, if realized, could be managed through water conservation, alternative sources, operational changes, or from available storage.

A.6.6 Spatial Overview of Groundwater Demands

The cumulative impact analysis figures above provide an overview of surface water demands in the basin but did not include groundwater demands. A substantial portion of the demands in this basin are supplied by groundwater. Figure 175 identifies the location and size of projected groundwater demands in the basin for 2040 based on information provided by localities in water supply plans.

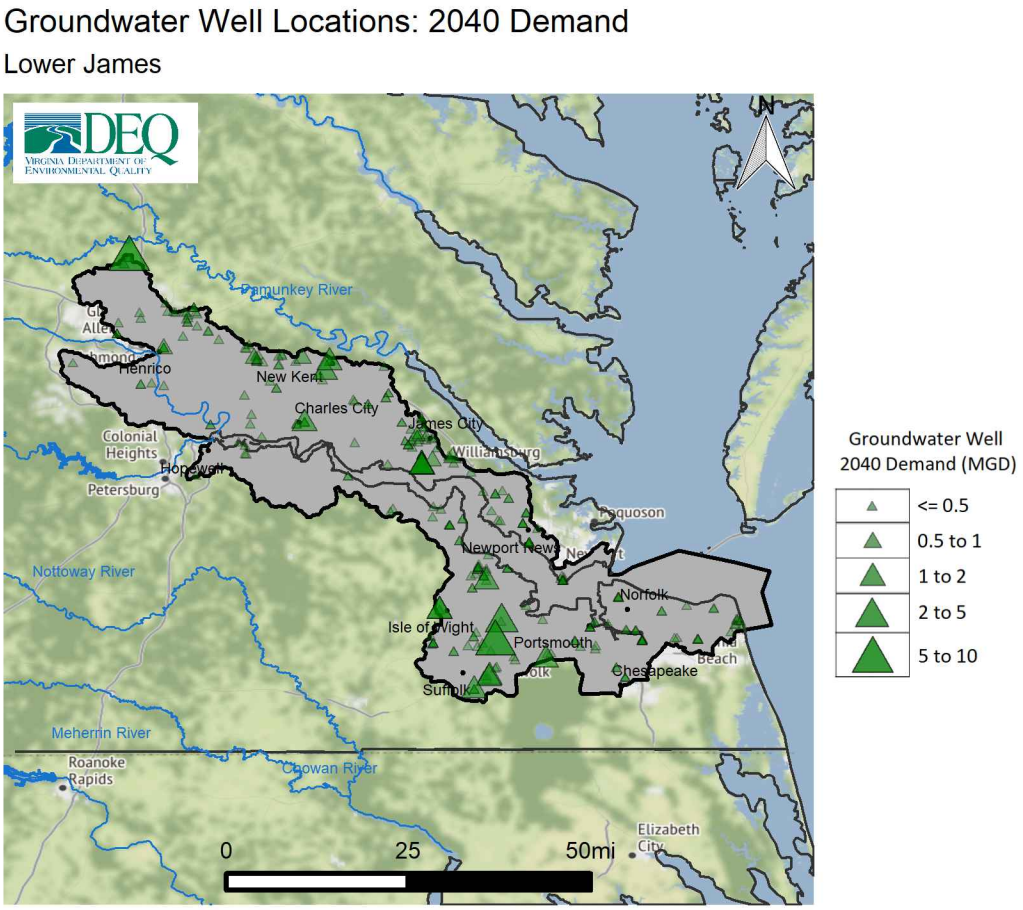

Figure 175: Projected 2040 Groundwater Demands in the Lower James Minor Basin

A.6.7 Trends and Goals

The Code of Virginia mandates that the State Water Control Board should take into consideration the principle that "adequate and safe supplies shall be preserved and protected for human consumption, while conserving maximum supplies for other beneficial uses". [85] This principle is the key driver of the challenges in water resource management, which is that all beneficial uses must be adequately considered when evaluating impacts to surface water resources. The State Water Control Board is tasked with ensuring that water supply quantity needs are met at all times while also protecting Virginia's natural resources, and furthermore, ensuring equitable allocation during a time of shortage .[86] While evaluating and planning for the long-term sustainability of water supply for Virginia is the primary goal for the State Plan, evaluating and limiting impacts to in-stream beneficial uses such as aquatic habitat life is also part of DEQ's responsibility.

The primary purpose of this section is to identify where the most significant challenges to long-term sustainability of water supply and other beneficial uses are indicated based on the CIA and information collated from local water supply plans within this basin. Goals for future planning and areas for additional data collection or analysis are also suggested where appropriate.

The CIAs were completed using the best available data and methods known to DEQ. This discussion focuses on the evaluation of trends - in other words the prevailing tendency or inclination. This means evaluating whether streamflow is simulated to increase or decrease in a given scenario, and by how much. A relative trend indicating reductions of greater than or equal to 10% in streamflow, whether driven by demand increases, changing climate conditions, or exempt user demands was considered a threshold for potential impacts to beneficial uses. The following summarize the key trends or goals for this basin:

- **Demand Scenarios:** Surface water modeling was completed in the Lower James Minor Basin for the non-tidal portions of this basin, which largely consists of the freshwater portion of the Chickahominy River. The majority of the Lower James is tidal (indicated in grey on the above figures), and as noted in the sections on existing sources, these areas rely increasingly on groundwater from the Coastal Plain aquifers such as the Potomac Aquifer and surface water impoundments. Surface water demands across the basin are projected to increase in the Lower James by approximately 7.5% between 2020 and 2040, or by around 23 MGD total. However, the majority of these demand increases occur outside of the non-tidal portion of the basin. No significant reductions in streamflow are simulated when comparing the 2040 demand scenario with the 2020 demand scenario in either the short-term (L30) or long term drought (L90). However, reductions in overall flow of more than 10% are simulated in the 2040 demand scenario below Chickahominy Lake and the Diascund Reservoir; although the Chickahominy is tidal below these points, reductions in freshwater inflow can impact salinity and therefore downstream beneficial uses. Evaluating the extent of these potential salinity changes is not within the scope of the non-tidal model, but will need to be an area of increasing focus as withdrawals in and upstream of freshwater tidal rivers becomes more common. Potential unmet demand is simulated in the current and 2040 demand scenarios for Chickahominy Lake, Little Creek Reservoir, and Diascund Reservoir. The City of Norfolk operates these reservoirs as part of a larger system and in general where unmet demand occurs in one it is likely the demand could be met using other sources. Simulated changes in streamflow below the Western Branch Dam for all scenarios are very small in volume (less than 1 cfs) although by percentage they appear significant.
- **Climate Scenarios:** The dry climate scenario shows reductions greater than 20% in simulated streamflow in every non-tidal river segment in the main stem of the Chickahominy River both during a short-term (L30) and long-term (L90) drought when compared to current climate. The potential for more severe droughts must be considered by localities and users when evaluating existing sources and alternatives, as well as for broader planning and resource management efforts by all stakeholders whether state or local. Additionally, more severe droughts could impact water quality in tidal fresh portions of

[85] § 62.1-44.36 of the Code of Virginia
[86] 9VAC25-390-20.1

rivers, like the Chickahominy due to reduced freshwater inflows, particularly in conjunction with projected sea level rise resulting from climate change. As sea level rises generally, the freshwater/saltwater interface can move further upstream. As proposals for tidal freshwater withdrawals are becoming more common, investing resources in evaluating potential impacts from both climate change and increasing surface water demands on these systems is increasingly necessary.

- **Exempt User Scenario:** The exempt user scenario models the cumulative maximum possible exempt demands from all users exempt from VWP permitting requirements within the basin. The users with the most significant maximum possible exempt demands within this basin are located outside of the non-tidal portions of this basin. Streamflows are simulated to increase moderately in the exempt user scenario in the headwaters of the Chickahominy due to a VWP permitted facility which is modeled at its permit limit in the exempt user scenario, which is lower than its projected 2040 demands in the 2040 demand scenario. However, maximum possible exempt demands in the Chickahominy Lake, Diascund Reservoir, and Little Creek Reservoir result in a reduction in overall flow (consumptive use) between 40-50%, resulting in diminished freshwater releases into the tidal segments below the reservoirs. Additionally, with significant draw down of major water supply reservoirs, the potential for unmet demand is greatest under the exempt user scenario. Preserving water supply and other beneficial uses may require managing these demands with respect to their cumulative impacts and in the context of the available resources in the basin.

- **Coastal Plain Groundwater Demand Scenarios:** The majority of the Lower James Minor Basin is located within the Eastern Virginia Groundwater Management Area. This includes portions of Henrico County, New Kent County, Charles City County, Surry County, Prince George County, Isle of Wight County, James City County, the City of Newport News, the City of Suffolk, the City of Norfolk, the City of Chesapeake, and the City of Virginia Beach. Many of these localities meet a significant portion of their demands from wells constructed in confined aquifers such as the Potomac Aquifer. To evaluate sustainability of groundwater resources with increasing demands, cumulative impact analysis groundwater modeling of the 2020 and 2040 demand scenarios was completed using the VAHydro Virginia Coastal Plain Groundwater Model for the State Plan. The methods and assumptions for these scenarios as well as the resulting simulated water levels and simulated critical cells are provided in Chapter 4, section 4.3.3, VCPM Model Results. These figures inform this discussion.

- With respect to this basin, the following are the key trends from the groundwater scenarios. In the 2020 demand scenario, water levels across the management area in the Potomac Aquifer are simulated to recover gradually from 2020 through 2050, before marginally declining through 2070. However, in the 2040 demand scenario, due to the increased domestic (Small SSU) and permitted demands, water levels decline consistently from 2020 to 2070. This results in portions of this basin where water levels fall below the critical surface, and critical cells are simulated to occur. In the 2020 scenario, Potomac Aquifer critical cells are primarily simulated along the fall-line in Henrico and Chesterfield counties, although these are areas where demands are primarily met through surface water. In the 2040 scenario, Potomac Aquifer critical cells expand into New Kent County and along the western edge of Charles City County, Prince George County, and into Sussex County near the border with Surry County. Existing or proposed withdrawals in the vicinity of these critical cells could face challenges in meeting the regulatory criteria for permit issuance if demands were to increase to those modeled in the 2040 scenario. It should be noted that large withdrawals that are distant from these cells can still be large enough to influence these areas. Critical cells in the Aquia Aquifer and Piney Point Aquifer are also simulated to occur in or near these localities, although these aquifers make up far less of the total groundwater demands than does the Potomac Aquifer. Some groundwater users in these areas have already encountered challenges meeting the regulatory criteria for a groundwater withdrawal permit. Additionally, any large groundwater withdrawal (over 2 MGD for example) can have a regional impact, and therefore can contribute to or be impacted by critical cells several localities away. This underscores the importance for localities in this basin, particularly those identified above, of evaluating and pursuing alternative sources and regional planning where possible.

A.7 Meherrin Nottoway Minor Basin

A.7.1 Watershed Overview

The Meherrin Nottoway Minor Basin is primarily comprised of the Meherrin, Nottoway, and Blackwater river basins, which ultimately drain into the Chowan River. The Chowan River begins at the confluence of the Nottoway and Blackwater rivers near the North Carolina and Virginia border and flows through flat terrain characterized by swamps and wetlands before eventually draining into the Albemarle Sound. The Meherrin River begins in Virginia's Piedmont and flows southeast into North Carolina where it meets the Chowan. The Nottoway River begins in Prince Edward County and flows generally southeast towards the confluence with the Blackwater River. The rolling hills of the Piedmont transition to Coastal Plain portions of this basin including the Great Dismal Swamp. The basin is largely rural characterized by forest and agricultural cover, with significant estuary systems along the coast. Development increases in areas near and along the coast and in the vicinity of large urban areas such as the cities of Norfolk, Chesapeake, and Virginia Beach.

The total spatial area of the basin occupies 4,380 sq. miles and includes all or portions of the localities listed in Table 45.

A.7.2 Existing Water Sources

Major surface water sources within the basin include the Nottoway, Meherrin, and Blackwater rivers. West of the fall-line (or interstate highway 95), groundwater is primarily withdrawn from bedrock aquifers; east of the fall-line in the groundwater management area, wells are generally constructed in confined aquifers like the Potomac Aquifer. Withdrawals within the basin are used for public water supply as well as for agriculture, irrigation, commercial, and industrial/manufacturing.

The location of wells and surface water intakes identified to DEQ within the basin are shown in figure 176. This figure does not include private or domestic wells. The majority of wells are located east of the fall-line in the Eastern Virginia Groundwater Management Area. Surface water intakes are located throughout the basin.

Table 45: Population Trend by Locality in Meherrin Nottoway Basin

Localities	20 Year % Change
Brunswick	-16.56
Charlotte	-7.85
Dinwiddie	11.12
Greensville	-4.60
Isle of Wight	18.17
Lunenburg	-11.86
Mecklenburg	-8.67
Nottoway	-4.23
Prince Edward	12.54
Prince George	8.14
Southampton	-1.54
Surry	-7.83
Sussex	-13.54
Chesapeake	15.51
Emporia	-6.42
Franklin City	-4.27
Petersburg	-10.55
Suffolk	29.21
Virginia Beach	2.84

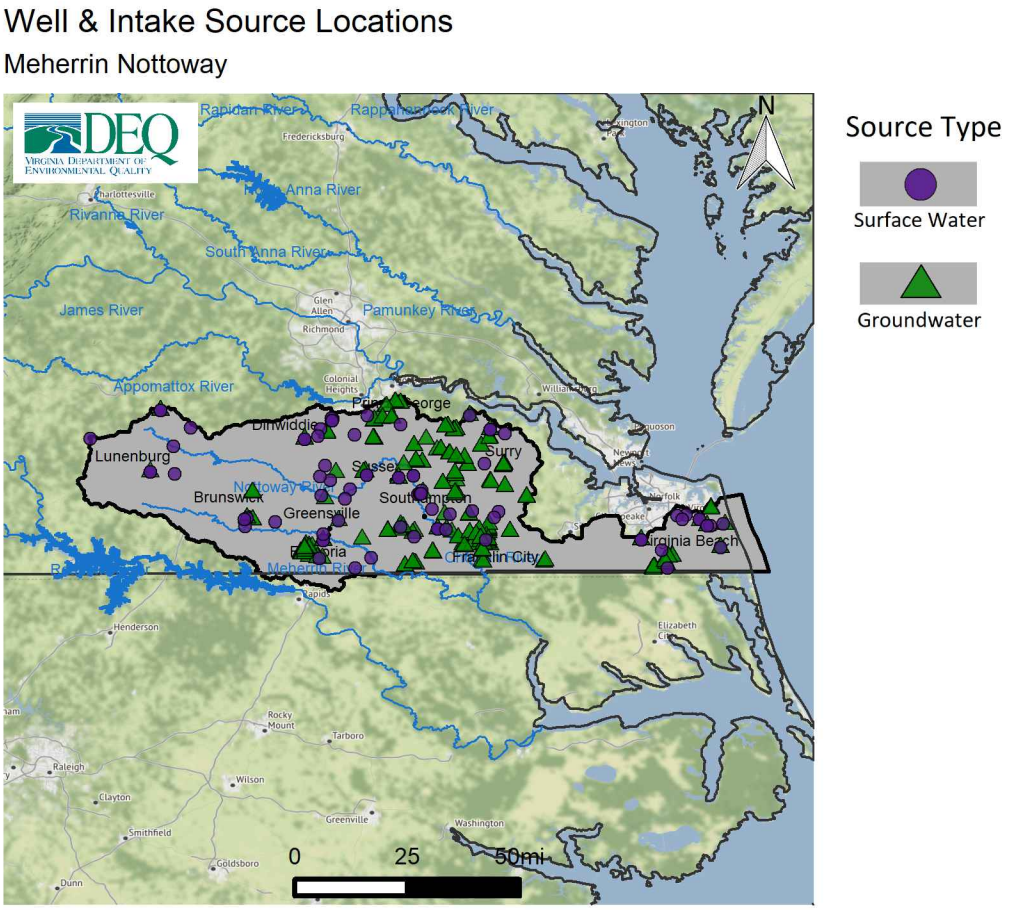

Figure 176: Spatial distribution of groundwater wells and intakes in the Meherrin Nottoway Minor Basin

A.7.3 Existing Water Use

The following section discusses existing (current) water use within the basin, which is based on existing demand information submitted to DEQ in the water supply plans. Table 46 provides a summary of all demands within the basin by system type and source type including power generation. It also provides a count of surface water or groundwater sources associated with each system type.

Table 46: Summary of Meherrin Nottoway Minor Basin Water Demand by Source Type and System Type (including Power Generation)

System Type	Source Count	2020 Demand (MGD)	2030 Demand (MGD)	2040 Demand (MGD)	20 Year Percent Change
Surface Water					
Agriculture	46	1.09	1.60	2.12	94.87
CWS	12	10.05	12.43	14.80	47.29
Large SSU	15	5.65	5.68	5.71	1.11
Small SSU	N/A	0.00	0.00	0.00	0.00
Total SW	**73**	**16.79**	**19.71**	**22.63**	**34.78**
Groundwater					
Agriculture	57	0.35	0.39	0.43	25.74
CWS	93	3.92	4.69	5.45	39.00
Large SSU	85	17.22	17.28	17.34	0.68
Small SSU	N/A	8.16	8.51	8.86	8.68
Total GW	**235**	**29.65**	**30.87**	**32.08**	**8.20**
Total (SW + GW)					
Agriculture	103	1.43	1.99	2.55	78.21
CWS	105	13.97	17.11	20.25	44.97
Large SSU	100	22.87	22.96	23.05	0.78
Small SSU	N/A	8.16	8.51	8.86	8.68
Minor Basin Total	**308**	**46.43**	**50.57**	**54.71**	**17.83**

* Small SSU demands are county-wide estimates of private well usage below 300,000 gallons a month. The number of private wells is not known.

The total existing demand from all surface and groundwater sources is approximately 46.43 MGD, with groundwater supplying approximately 29.65 MGD or 63% of total water demands. Surface water demand within the basin totals approximately 16.79 MGD, or 37% of current demands. Groundwater supplies the majority of demands in the Meherrin Nottoway Minor Basin, as most of the basin is able to make use of the high capacity and high quality Coastal Plain Aquifer system.

The five largest facility demands for each source type are provided in Table 47. The largest groundwater demands include International Paper's Franklin Mill, which currently represents approximately 14.31 MGD, or 48% of current groundwater demand in the basin. The Solenis Chemical Plant and several smaller Community Water System (CWS) facilities represent the remaining top 5 groundwater users. The largest surface water users include the City of Chesapeake's Northwest River/Western Branch System, Greensville County's Jarrat WTP, and the International Paper Company Franklin Mill. Surface water is the primary water source for the largest CWS facilities, while groundwater primarily supplies Large Self-Supplied Users (Large SSUs).

Table 47: Top 5 Users in 2040 by Source Type in the Meherrin Nottoway Minor Basin (including Power Generation)

Facility Name	System Type	Locality	2020 Demand (MGD)	2030 Demand (MGD)	2040 Demand (MGD)	20 Year Percent Change	% of Total Surface Water
Surface Water							
Jarratt WTP	CWS	Greensville	1.51	2.97	4.44	194.04	19.62
Northwest River/Western Branch Systems	CWS	Chesapeake	2.21	2.93	3.66	65.61	16.17
Franklin Virginia Mill	Large SSU	Isle of Wight	2.32	2.32	2.32	0.00	10.25
Lawrenceville Quarry	Large SSU	Brunswick	2.04	2.07	2.09	2.45	9.24
City Of Norfolk's Blackwater Pumping Station	CWS	Isle of Wight	1.32	1.32	1.32	0.00	5.83
Total SW			9.4	11.61	13.83	47.13	61.11
Groundwater							**% of Total Groundwater**
Franklin Virginia Mill	Large SSU	Isle of Wight	14.31	14.31	14.31	0.00	44.61
Solenis Llc	Large SSU	Southampton	2.66	2.66	2.66	0.00	8.29
Northwest River/Western Branch Systems	CWS	Chesapeake	1.35	1.79	2.23	65.19	6.95
Franklin Water System	CWS	Franklin City	0.8	0.93	1.05	31.25	3.27
VDOC Saint Brides / Indian Creek Correctional Center	CWS	Chesapeake	0.28	0.38	0.47	67.86	1.47
Total GW			19.4	20.07	20.72	6.8	64.59

Table 46 also provides the proportion of each use category that is supplied by either surface water or groundwater. Use categories include Community Water System (CWS), Large Self-Supplied User (Large SSU), Small Self-Supplied User (Small SSU), and Agricultural Self-Supplied User (AG). These categories are defined below. Surface water demand is primarily comprised of CWS and Large SSU demands. Groundwater demand is primarily comprised of Large SSU and Small SSU demands.

The CWS category includes any public and private waterworks that serve at least 15 service connections used by year-round residents or regularly serve at least 25 year-round residents, and are regulated under the Virginia Department of Health's Waterworks Regulation (12VAC5-590). In the Meherrin Nottoway Minor Basin, approximately 3.92 MGD of groundwater demand and 10.05 MGD of surface water demand is from CWS users. Significant groundwater users within this category include the groundwater wells from the City of Chesapeake's Northwest River/Western Branch System and the City of Franklin's Water System. Significant surface water users from this category include Greensville County's Jarrat WTP and the City of Chesapeake's Northwest River/Western Branch System. Surface water is currently the most viable water source for CWS.

Large SSUs include any non-CWS or AG who withdraw more than 300,000 gallons per month from a well or surface water intake. In the Meherrin Nottoway Minor Basin, approximately 17.22 MGD of groundwater demand and 5.65 MGD of surface water demand is from Large SSUs. International Paper's Franklin Mill

makes up the majority of Large SSU demands for groundwater, and the facility's intake in the Backwater River is also the most significant Large SSU surface water demand. Groundwater is currently the most relied upon water source for Large SSUs.

Small SSUs include any users who withdraw less than 300,000 gallons per month from wells. Small SSUs generally consist of residential or domestic use for those who live outside service areas and provide their own water. Small SSU demand is generally met with groundwater. In the Meherrin Nottoway Minor Basin, approximately 8.16 MGD of groundwater demand is estimated for Small SSUs. Localities within the basin with the greatest demands from Small SSUs include the City of Chesapeake and Southampton County.

The AG category includes crop farms, livestock operations, aquaculture and other agricultural facilities. In the Meherrin Nottoway Minor Basin, approximately 0.35 MGD of groundwater demand and 1.09 MGD of surface water demand is estimated for AG. The City of Chesapeake and Southampton County have the highest estimated agricultural demands, the majority of which is groundwater.

A.7.4 Projected Population and Water Use

Projected Population: Trends in water use are generally driven by trends in population change or economic development. Increasing population within an area generally means increased connections for community water systems or additional groundwater demands from homeowners that construct wells. Increasing population in an area also tends to incentivize both new and expanded industrial and commercial water use.

Table 45 shows the projected change in population by percent between 2020 and 2040 for each locality located partly or wholly within this minor basin. Projected population change varies significantly throughout the basin. Localities such as Brunswick, Sussex, and Lunenburg counties are projected to decrease by more than 10% in population between 2020 and 2040. However, localities in the Tidewater and greater Hampton Roads region are projected to have significant population growth including the City of Suffolk, City of Chesapeake, and Isle of Wight County. With limited economic opportunity or development in more rural portions of the basin, population trends follow increased growth within urban and suburban areas.

Projected Water Use: The following section discusses projected water use through 2040 within the Meherrin Nottoway Minor Basin, based on projections provided in local and regional water supply plans. Table 46, included in the existing demand section above, is the basis for information discussed in this section.

Total demand within the basin is projected to increase from 46.43 MGD in 2020 to 54.71 MGD in 2040, or approximately 17.8%. Surface water demand is projected to increase by 5.84 MGD, or 34.7%, by 2040. Groundwater demand is projected to increase by 2.43 MGD, or 8.2%, by 2040. The projected demand increases for surface water are driven primarily by CWS facilities like the City of Chesapeake's Northwest River system and Greensville County's Jarrat WTP, while groundwater demand increases are primarily driven by estimated increases in CWS and Small SSU demands. While total groundwater demands are higher in 2020, surface water demands are projected to grow at a much faster rate than groundwater between 2020 and 2040 to meet growing public water supply demands.

Demand from CWS users within the basin is projected to increase by 44% by 2040. Within this category, surface water use is projected to increase by 47.2%, while groundwater use is projected to increase by 39.0%. Surface water is the primary source for CWS facilities operated by the City of Chesapeake, Greensville County, and the City of Emporia. Significant groundwater users in the category include the City of Chesapeake, City of Franklin, and Sussex County.

Demand from Large SSUs within the basin is not projected to change significantly by 2040. Large SSU demands make up a large portion of existing demands due to facilities like International Paper's Franklin Mill, but these facilities are not projecting significant increases over the planning period. Minimal increases in surface water demands are projected with an increase of 1.1% , or 0.1 MGD by 2040. Major water users in the category include International Paper, Solenis LLC, and Vulcan Construction Materials.

Demand from Small SSUs within the basin is projected to increase by 8% by 2040. As noted previously, Small SSU demand is entirely met with groundwater and represents domestic and private well use. Southampton and Surry counties have the highest estimated growth in Small SSU demands. Projected increases in population over the planning period align with the expected increases in domestic and private well use by 2040.

Demand from Agriculture users within the basin is projected to increase by 78% by 2040. Within this category, surface water use is projected to increase by 95%, while groundwater use is projected to increase by 25%. Despite this projected increase, the volume of estimated agricultural use is not a significant portion of the total demands in the basin; farms in Southampton and Surry counties drive the substantial projected increases in demand by percentage.

A.7.5 Cumulative Impact Analysis

The following section provides a brief summary of the Cumulative Impact Analysis (CIA) modeling results in the Meherrin Nottoway Minor Basin. Discussion of these results will primarily be found in the Trends and Goals section of this appendix. However a brief overview of the VAHydro model and the scenarios and metrics is provided below.

The VAHydro surface water model simulates streamflow using inputs such as precipitation, climate, land use, and topography, combined with data on all known withdrawals and discharges, and operational rules of major hydrologic features such as reservoirs. Each minor basin is broken into smaller hydrologic subsections, or river segments. The model simulates the water balance on a daily basis for each individual river segment, with each downstream segment being affected by the cumulative impact of streamflow changes occurring in upstream segments. The following figures help analyze this cumulative impact within the Meherrin Nottoway Minor Basin (model results summarized by river segment). Note that this section is not intended to document in detail the methods and assumptions for the VAHydro model or for the scenarios and metrics discussed. More documentation of the model and assumptions can be found in Chapter 4.

The VAHydro surface water model was used to simulate streamflow under a variety of scenarios. Demand scenarios examine how streamflow is impacted under 2030 or 2040 demands as compared to current (2020) demands. Demands were calculated based on current and future demand information submitted through local and regional water supply plans. Climate change scenarios examine how streamflow is impacted when 2040 demands are simulated in conjunction with a range of precipitation and temperature conditions that may occur in the future due to changing climate (Dry, Median, Wet scenarios). Finally, the exempt user scenario examines impacts from users excluded, or exempt, from VWP permit requirements per Va. Code § 62.1-44.15:22 B. Exempt users were simulated at the maximum possible demand identified through a review of demand justification values commonly asserted by exempt users, including but not limited to VDH pump capacity, maximum pre-1989 withdrawal, and maximum intake capacity. In order to effectively manage surface water resources and address the uncertainty related to these demands, DEQ determined the most conservative, or maximum possible, demand should be evaluated in this scenario. However, DEQ does not agree that the maximum values used in this scenario represent an allocation for, or the expectation of, a future withdrawal of that volume; nor does DEQ concede that any particular exempt user is necessarily entitled to withdraw any particular maximum value used in this scenario. The methods and assumptions for each of these modeling scenarios are discussed in more detail in Chapter 4.

For each scenario described above, different metrics can be used to evaluate the simulated streamflow. A metric is a method for measuring or evaluating a given set of data; different metrics can be evaluated to answer different questions. Within this section the following metrics will be discussed: the lowest 30 day flow (L30), the lowest 90 day flow (L90), 7Q10, and overall change in flow. The L30 describes the lowest consecutive 30 day average daily streamflow over the simulation period. This metric is a representation of a short-term, or acute drought, and is a good metric for evaluating impacts to direct withdrawals without storage. Similarly, the lowest 90 day flow represents the lowest consecutive 90 day average daily streamflow over the simulation period. This would represent a prolonged drought and is often used to evaluate impacts to reservoirs. The 7Q10 is the lowest 7-day average flow that occurs (on average) once every 10 years.

7Q10 is generally used in the evaluations of in-stream beneficial uses such as waste assimilative capacity. Overall change in flow describes the net loss of water from the riverine system as a result of off-stream use not otherwise returned through point source discharges, or losses due to evapotranspiration. This metric is useful for evaluating impacts to aquatic life and is discussed in more detail in Chapter 4.

Demand Scenarios: 2020 demand or current demand, 2030 demand, and 2040 demand scenarios were simulated. The following series of figures compares the 2030 and 2040 demand scenarios to the current demand scenario. The change in flow depicted on each map is the change expected when comparing two scenarios - in this case future demands compared to current demands. Each page includes two figures comparing either the 2030 or 2040 demand scenario to current demand using the L30, L90, and 7Q10 metrics. This allows for comparisons of simulated impacts between the 2030 and 2040 demand scenarios. The scenarios and metrics are identified in the paragraph below and in the figure captions.

Figures 177 and 178 compare the lowest 30 day flow simulated with the current demand scenario with the lowest 30 day flow simulated in the 2030 and 2040 demand scenarios respectively. Figures 179 and 180 compare the lowest 90 day low flow simulated with the current demand scenario with the lowest 90 day flow simulated in the 2030 and 2040 demand scenarios respectively. Figures 181 and 182 compare the 7Q10 simulated with the current demand scenario with the 7Q10 simulated in the 2030 and 2040 demand scenarios respectively.

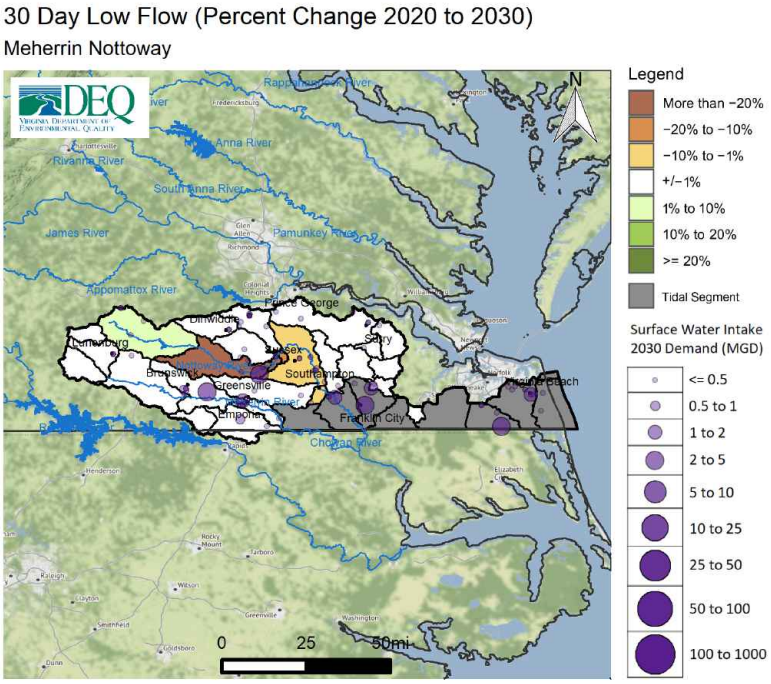

Figure 177: Change in 30 day low flow between 2020 and 2030 demand scenarios within the Meherrin Nottoway Minor Basin

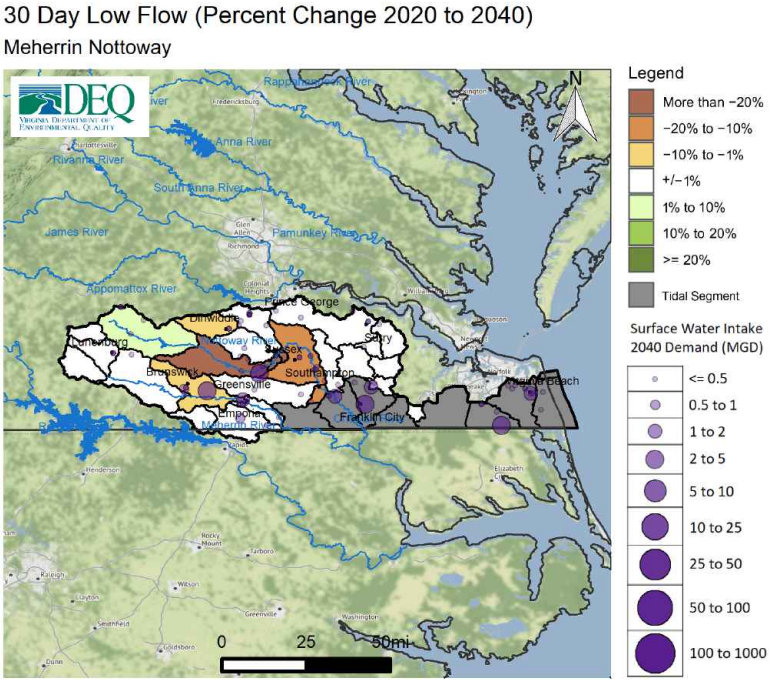

Figure 178: Change in 30 day low flow between 2020 and 2040 demand scenarios within the Meherrin Nottoway Minor Basin

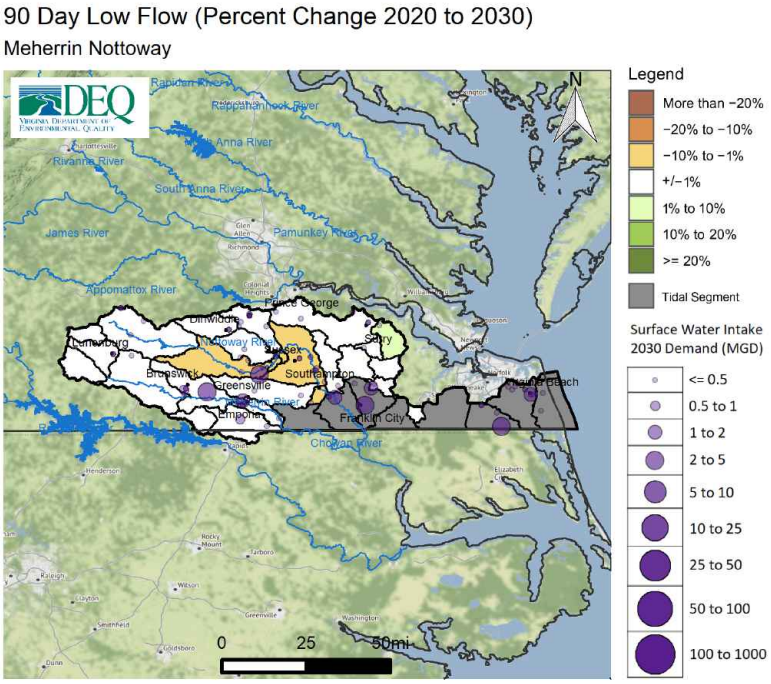

Figure 179: Change in 90 day low flow between 2020 and 2030 demand scenarios within the Meherrin Nottoway Minor Basin

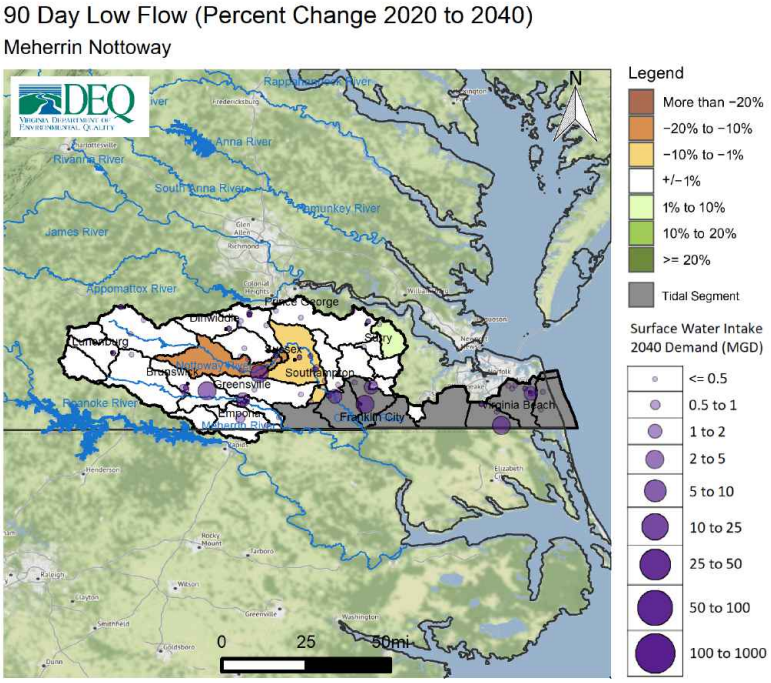

Figure 180: Change in 90 day low flow between 2020 and 2040 demand scenarios within the Meherrin Nottoway Minor Basin

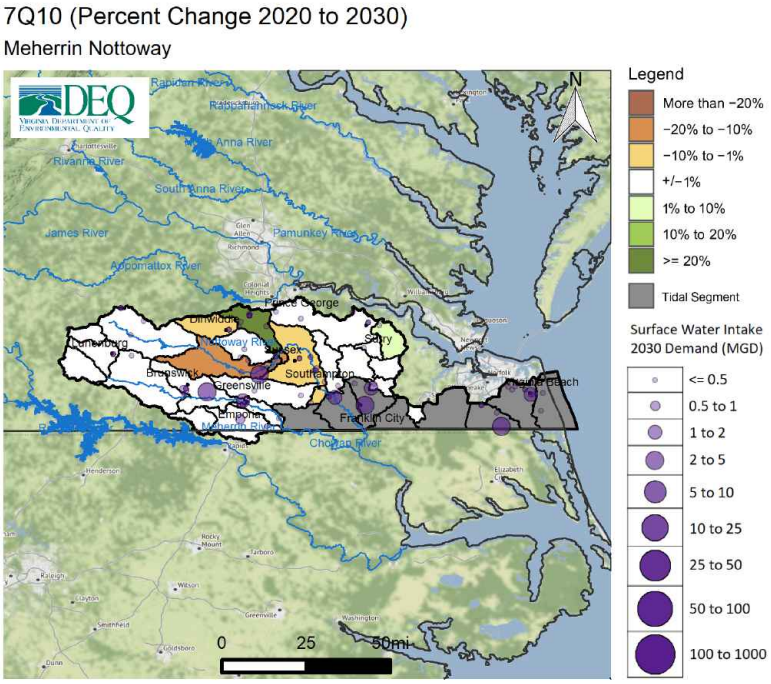

Figure 181: Change in 7Q10 between 2020 and 2030 demand scenarios within the Meherrin Nottoway Minor Basin

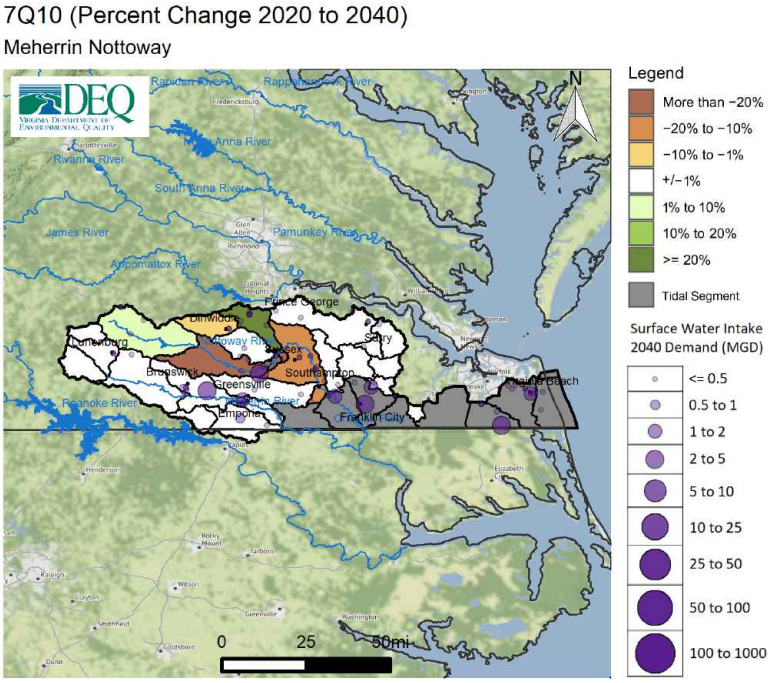

Figure 182: Change in 7Q10 between 2020 and 2040 demand scenarios within the Meherrin Nottoway Minor Basin

The figures above show a comparison between two scenarios. An additional way to evaluate impacts to streamflow is to examine the total reduction in streamflow resulting from all withdrawals within a river segment, as well as losses due to evapotranspiration, while taking into consideration any discharges back to the source. To use a common industry term, the overall change in flow metric evaluates "consumptive use", or the amount of water removed from the river that is not returned through discharges. This can help describe potential impacts to downstream withdrawals, while also providing a basis for evaluating impacts to aquatic life. In general, total reductions in streamflow can result in a reduction in aquatic biodiversity[87]. The relationship between streamflow and aquatic biodiversity is discussed in more detail in Chapter 4. Figure 183 shows the overall change in streamflow for the 2030 Demand Scenario, while figure 184 shows the overall change in streamflow for the 2040 Demand Scenario.

[87]Rapp, J.L., R. Burgholzer, J. Kleiner, D. Scott, and E. Passero. 2020. "Application of a New Species-Richness Based Flow Ecology Framework for Assessing Flow Reduction Effects on Aquatic Communities." Journal of the American Water Resources Association 1–14.https://doi.org/10.1111/1752-1688.12877.

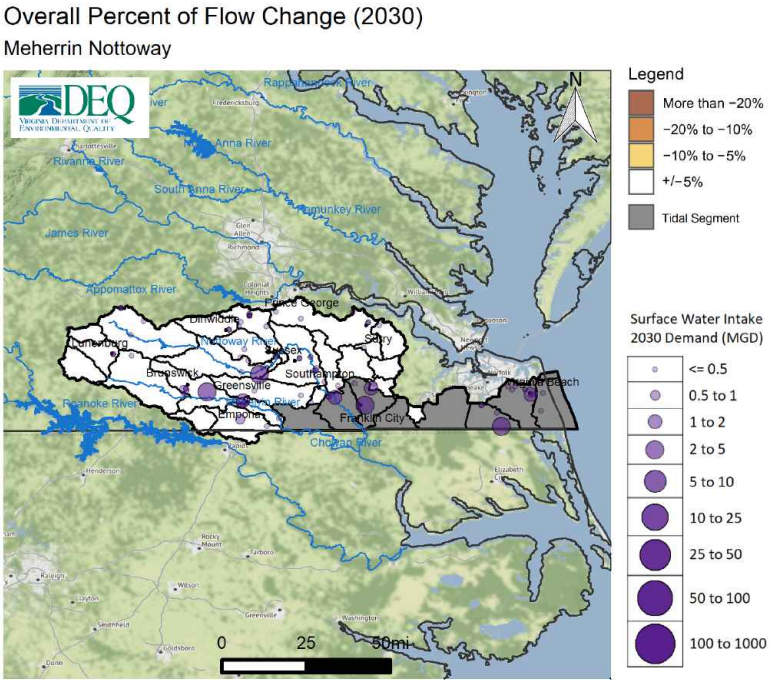

Figure 183: Overall change in flow in percent for 2030 demand scenario within the Meherrin Nottoway Minor Basin

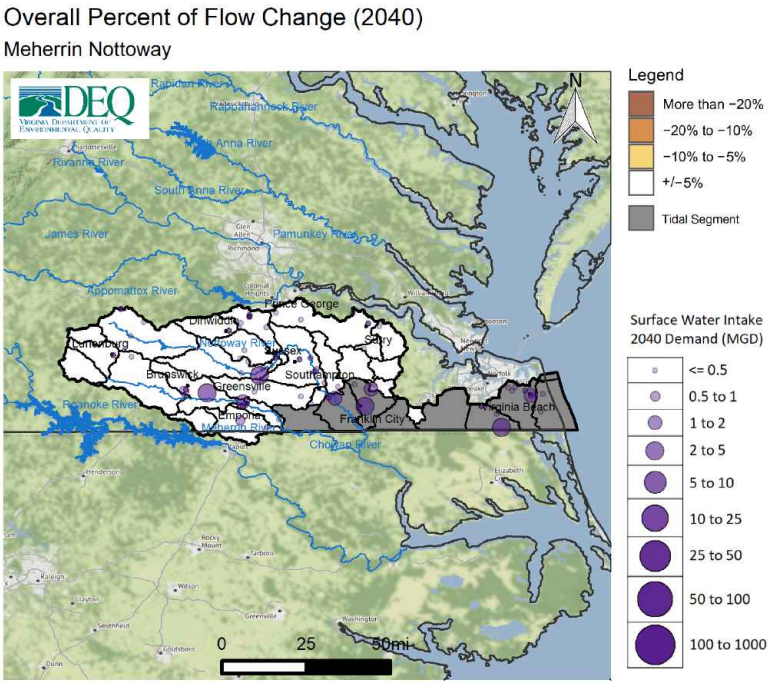

Figure 184: Overall change in flow in percent for 2040 demand scenario within the Meherrin Nottoway Minor Basin

Climate Scenarios:Three scenarios that simulate impacts to streamflow in response to changes in temperature and climate were completed for areas in the state where climate data was available, which includes the portions of the Commonwealth located in the Chesapeake Bay watershed. Details on the methods and assumptions employed for these scenarios can be found in Chapter 4. Three scenarios can be described as dry, median, and wet scenarios. Virginia is expected to experience a range of precipitation and temperature changes that may vary spatially and from year to year. The potential for both more severe and prolonged droughts as well as for higher intensity and more frequent rain events must be considered. This Basin is located outside of the Chesapeake Bay watershed and therefore climate scenarios were not completed at this time. DEQ is working to expand these climate scenarios to cover the entire state for future planning efforts.

Exempt User Scenario: The exempt user scenario simulates the maximum possible exempt demand for users excluded from Virginia Water Protection permitting requirements per Va. Code § 62.1-44.15:22 B, in combination with the permitted withdrawal limits for those users that are permitted. A more detailed discussion of the data and assumptions used in this scenario can be found in Appendix B. Note that this scenario uses current climate conditions. Figure 185 depicts the percent change in the Lowest 30 Day Flow between the exempt user scenario and current (2020) demand. Figure 186 depicts the percent change in the Lowest 90 Day Flow between the exempt user scenario and current (2020) demand. Figure 187 depicts the percent change in the 7Q10 between the exempt user scenario and current (2020) demand. Finally, figure 188 depicts the overall change in flow in percent (consumptive use) for the exempt user scenario.

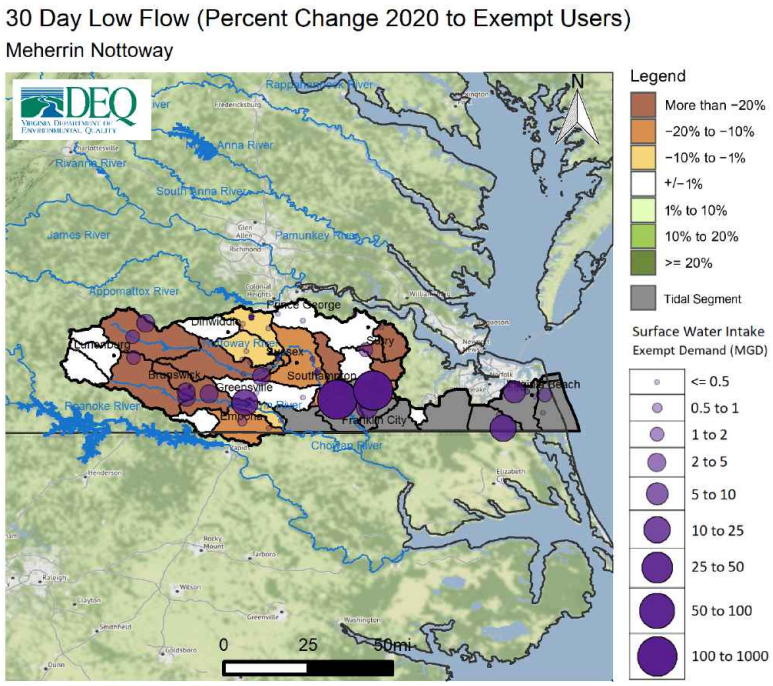

Figure 185: Change in 30 day low flow between current demand scenario and exempt user scenario within the Meherrin Nottoway Minor Basin

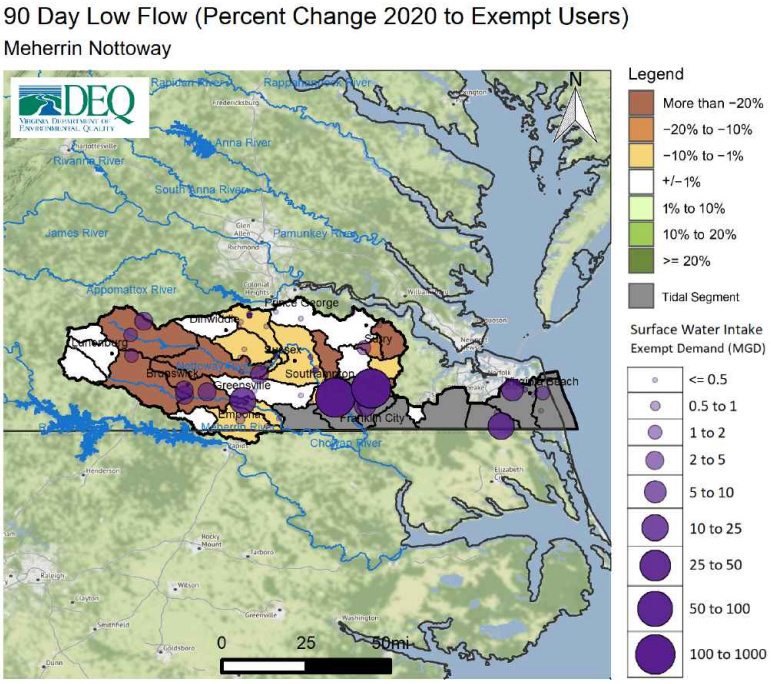

Figure 186: Change in 90 day low flow between current demand scenario and exempt user scenario within the Meherrin Nottoway Minor Basin

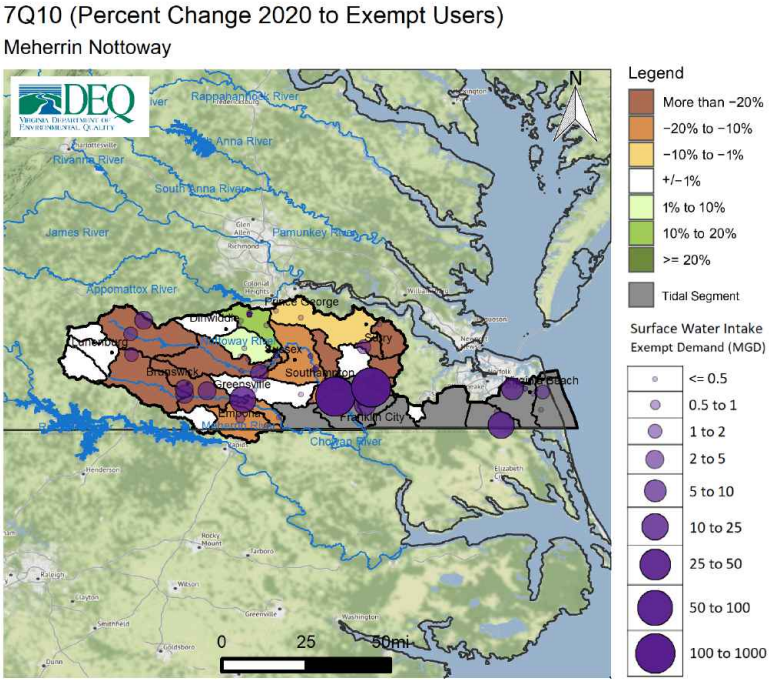

Figure 187: Change in 7Q10 between current demand scenario and exempt user scenario within the Meherrin Nottoway Minor Basin

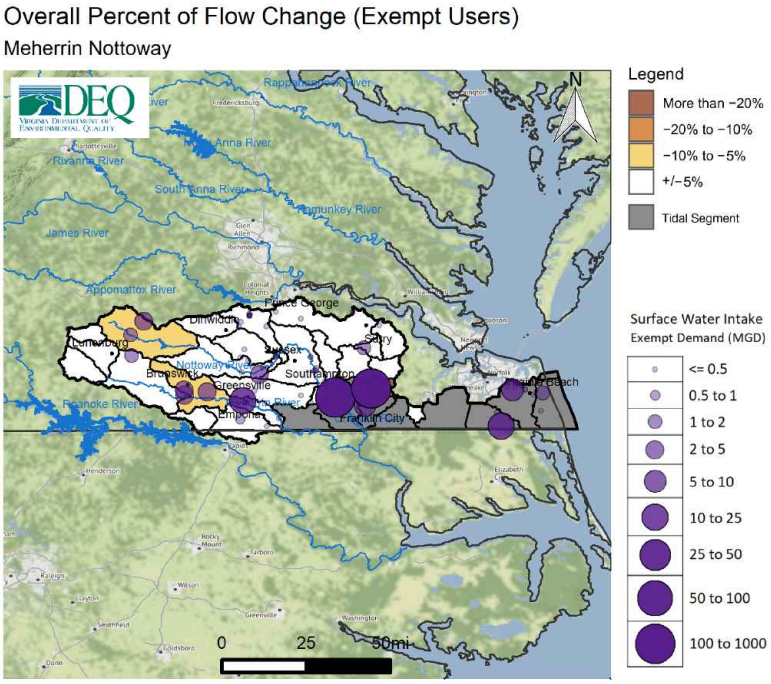

Figure 188: Overall change in flow in percent for exempt user scenario within the Meherrin Nottoway Minor Basin

Potential Unmet Demand: Potential unmet demand was evaluated for all facilities within the basin for each scenario. Potential unmet demand is the portion of surface water demand for a specific facility that is limited by available streamflow as simulated in a given model scenario, including any known operational limits such as flow-by requirements. This unmet demand, if realized, could be managed through water conservation, through alternative sources, operational changes, or from available storage. Absent of these or other options, this portion of demand could remain unmet. As with all scenarios, demand requirements were determined using demand projections provided in the water supply plans. In the case of the exempt user scenario, the highest possible withdrawal amount was used for users exempt from VWP permitting requirements.

This metric is useful for evaluating where the results seen in the above figures may result in challenges in meeting future demands under a variety of conditions including increasing demands in the basin, changing climate, or withdrawals from users exempt from permitting requirements. Table 48 provides for each facility the highest average daily potential unmet demand over a 30 day period over the course of the simulation for the following scenarios: 2020 demand, 2030 demand, 2040 demand, and exempt user. Only facilities showing potential unmet demand in at least one scenario appear on this table. Additional information on the potential unmet demand metric can be found in Appendix B.

Table 48: Change in Highest 30 Day Potential Unmet Demand (MGD) in Meherrin Nottoway Minor Basin

Facility	2020 Demand	2030 Demand	2040 Demand	Dry Climate	Exempt User
Blackwater Pumping Station	1.96	1.96	1.96	-	131.08
Emporia WTP	0.00	0.00	0.00	-	18.09
Greensville County Raw Water Reservoir And Intake	0.00	0.00	0.00	-	7.22
Blackstone Water Utilities	0.28	0.27	0.27	-	4.45
Jarratt WTP	0.14	0.26	0.37	-	3.81
Victoria WTP	0.08	0.08	0.08	-	2.85
Bacons Castle Farm	0.00	0.00	0.00	-	1.74
Crewe WTP	0.16	0.15	0.13	-	1.47
Lawrenceville WTP	0.00	0.00	0.00	-	1.46
Vicks Plantation (Farm)	0.00	0.00	0.00	-	1.08
Skippers Plant	0.39	0.39	0.39	-	0.64
Concord Concentrator Site	0.01	0.05	0.07	-	0.3
Lawrenceville Quarry	0.00	0.00	0.00	-	0.21
Center Pivot	0.00	0.00	0.00	-	0.14
Lawrenceville WTP	0.00	0.00	0.00	-	0.12
Cox Farms	0.02	0.03	0.04	-	0.09
Prince George Golf Course	0.00	0.00	0.01	-	0.02
Pierce Farm	0.01	0.01	0.01	-	0.01
Nottoway River Country Club	0.00	0.00	0.00	-	0.01
Polar Water Company	0.00	0.00	0.00	-	0.01
Yarden Farm	0.00	0.01	0.03	-	0.00

* Climate scenarios were not completed in areas located outside of the Chesapeake Bay Basin

Note: Potential unmet demand is the portion of surface water demand for a specific facility that is limited by available streamflow as simulated in a given model scenario, including any known operational limits such as flow-by requirements. This unmet demand, if realized, could be managed through water conservation, alternative sources, operational changes, or from available storage.

A.7.6 Spatial Overview of Groundwater Demands

The cumulative impact analysis figures above provide an overview of surface water demands in the basin but did not include groundwater demands. A substantial portion of the demands in this basin are supplied by groundwater. Figure 189 identifies the location and size of projected groundwater demands in the basin for 2040 based on information provided by localities in water supply plans.

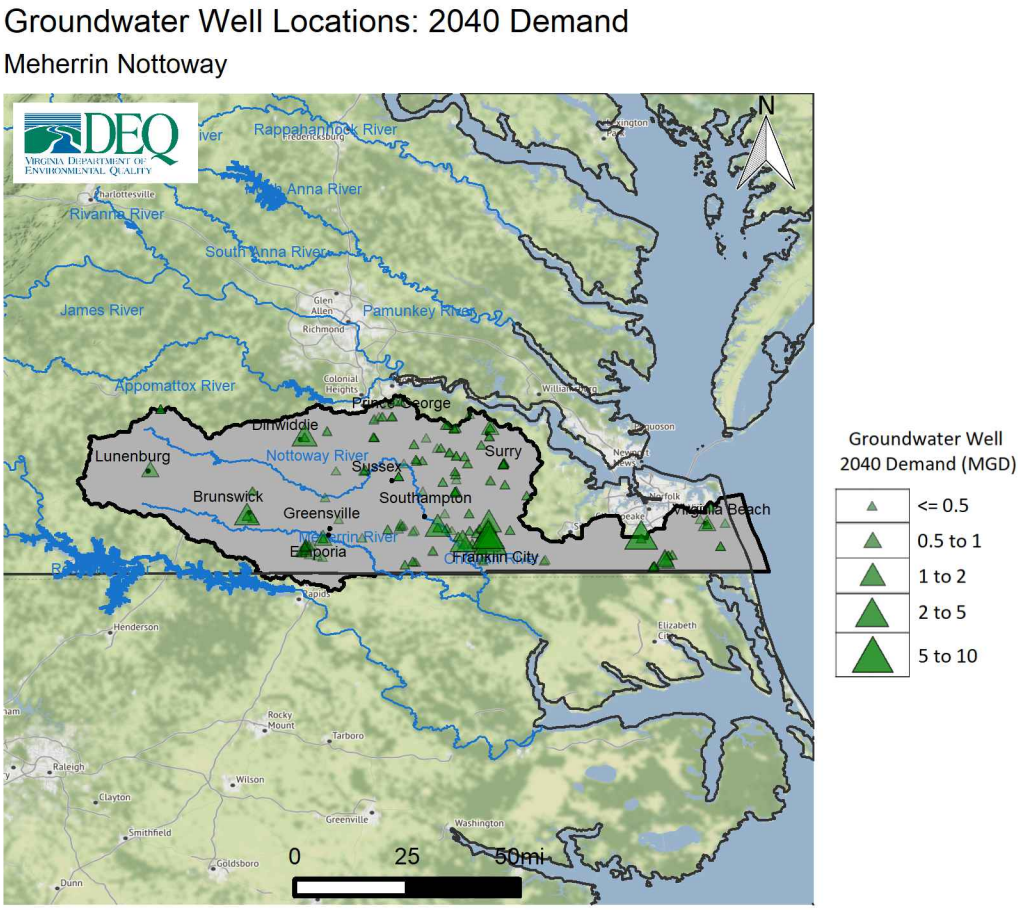

Figure 189: Projected 2040 Groundwater Demands in the Meherrin Nottoway Minor Basin

A.7.7 Trends and Goals

The Code of Virginia mandates that the State Water Control Board take into consideration the principle that "adequate and safe supplies shall be preserved and protected for human consumption, while conserving maximum supplies for other beneficial uses".[88] This principle is the key driver of the challenges in water resource management, which is that all beneficial uses must be adequately considered when evaluating impacts to surface water resources. The State Water Control Board is tasked with ensuring that water supply quantity needs are met at all times while also protecting Virginia's natural resources, and furthermore, ensuring equitable allocation during a time of shortage.[89] While evaluating and planning for the long-term sustainability of water supply for Virginia is the primary goal for the State Plan, evaluating and limiting impacts to in-stream beneficial uses such as aquatic habitat life is also part of DEQ's responsibility.

The primary purpose of this section is to identify where the most significant challenges to long-term sustainability of water supply and other beneficial uses are indicated based on the CIA and information collated from local water supply plans within this basin. Goals for future planning and areas for additional data collection or analysis are also suggested where appropriate.

The CIAs were completed using the best available data and methods known to DEQ. This discussion focuses on the evaluation of trends - in other words the prevailing tendency or inclination. This means evaluating whether streamflow is simulated to increase or decrease in a given scenario, and by how much. A relative trend indicating reductions of greater than or equal to 10% in streamflow, whether driven by demand increases, changing climate conditions, or exempt user demands was considered a threshold for potential impacts to beneficial uses. The following summarize the key trends or goals for this basin:

- **Demand Scenarios:** The surface water modeling in the Meherrin Nottoway Minor Basin primarily focuses on the non-tidal Meherrin and Nottoway River drainage area. Surface water demands across the basin are projected to increase in the Meherrin Nottoway Minor Basin by approximately 34% between 2020 and 2040, or by around 6 MGD. Demand increases in the non-tidal portions are driven primarily by projected increases from Greensville County's Jarratt WTP. The 2040 demand scenario shows a more than 20% reduction in streamflow in the L30 and more than 10% reduction in the L90 in the Nottoway River beginning in the Jarratt area when compared to the 2020 demand scenario. Similar but lesser reductions are simulated in the Nottoway River from Jarratt through to the confluence with the Chowan River in both the short-term (L30) and long-term drought (L90) metrics. Greensville County has recently constructed an off-stream pump storage reservoir and a new intake in the Nottoway River which once fully operational will replace the current direct intake in supplying the Jarratt WTP. This storage will likely mitigate some of the impacts to streamflow. Potential unmet demand is simulated for the Jarratt WTP in both the current and 2040 demand scenarios. Potential unmet demand is also simulated for several other CWS facilities including the Town of Blackstone WTP, Town of Crewe WTP, and the City of Norfolk's Blackwater Pumping Station in both the current and future demand scenarios. The City of Norfolk operates a multiple sources and is able to load balance and meet demands as needed if the Blackwater River flows are not sufficient to meet demands. However this results suggests that simulated drought flows are not sufficient in portions of the Nottoway and Blackwater drainage to meet existing or future demands without storage or alternatives.
- **Climate Scenarios:** As climate change data was not available in this basin, climate change scenarios were not completed for this basin. The overall trend in climate change simulations statewide suggests the potential for higher average temperatures and higher average precipitation totals. However, the simulations also suggest the potential for more significant droughts than have been historically experienced in Virginia. Simulations completed elsewhere in the Commonwealth show short-term and long-term droughts with 20-50% reductions in streamflow compared to previous droughts. The potential for more severe droughts must be considered by localities and users when evaluating existing sources and alternatives, as well as for broader planning and resource management efforts by all stakeholders whether state or local.

[88] § 62.1-44.36 of the Code of Virginia
[89] 9VAC25-390-20.1

- **Exempt User Scenario:** The exempt user scenario, which models the cumulative maximum possible exempt demands from all users exempt from VWP permitting requirements, shows widespread reductions in streamflow with 14 river segments showing reductions of more than 10% in a short term drought (L30) compared to the 2020 demand scenario. During a long-term drought (L90), eight river segments show a reduction of more than 10% when comparing the exempt user scenario to 2020 demands. The most significant reductions by percentage are simulated in the Meherrin River near the Town of Lawrenceville, driven by the maximum possible exempt demands for the City of Emporia and the Town of Lawrenceville. Reductions in the headwaters of the Nottoway River are driven by the maximum possible exempt demands from the Town of Crewe and the Town of Victoria. Significant reductions are simulated in the Nottoway and Blackwater rivers before the confluence with the Chowan River driven by the maximum possible exempt demand from the City of Norfolk's intakes in those rivers. The maximum possible exempt demand from International Paper's Blackwater intake also contributes to simulated reductions in the exempt user scenario in the Blackwater River. These segments of the Blackwater River and the Meherrin River are also simulated to have reductions in overall flow (consumptive use) of more than 20%, which would suggest the potential for impacts to aquatic life and habitat if withdrawals were in line with the maximum possible exempt demands. Finally, the exempt user scenario also results in potential unmet demand for numerous facilities including the City of Emporia, the Town of Lawrenceville, Greensville County's Jarratt intake and pump storage operation, and several smaller municipal systems including the towns of Blackstone, Crewe, and Victoria. In summary, the cumulative maximum possible exempt demands in the basin exceed the water budget in many river segments. Preserving water supply and other beneficial uses may require managing these potential demands with respect to their cumulative impacts and in the context of the available resources in the basin.

- **Coastal Plain Groundwater Demand Scenarios:** Much of the eastern portion of the Meherrin Nottoway Minor Basin is located within the Eastern Virginia Groundwater Management Area. A large portion of demand in this area is met through groundwater withdrawals from confined aquifers such as the Potomac, Aquia, and Virginia Beach aquifers. This includes portions of localities such as Sussex and Southampton counties, and the cities of Suffolk, Norfolk, and Virginia Beach. This basin also includes a number of the largest groundwater withdrawals in the state. Cumulative impact analysis groundwater modeling of the 2020 and 2040 demand scenarios was completed using the VAHydro Virginia Coastal Plain Groundwater Model for the State Plan. The results of these simulations are covered in detail with figures displaying simulated water levels and simulated critical cells provided in Chapter 4, Section 4.3.3 for each scenario. These figures inform this discussion.

- Key trends identified during the groundwater scenarios within the Meherrin Nottoway Minor Basin included gradual water level recovery within the Potomac Aquifer from 2020-2050. However, aquifers are simulated to marginally decline through 2070. In the 2040 demand scenario, due to the increased domestic (Small SSU) and permitted demands, water levels continue to decline from 2020 to 2070. This results in portions of this basin where water levels fall below the critical surface and critical cells are simulated. In the 2020 scenario, a small number of Potomac Aquifer critical cells are simulated in Southampton and Sussex counties. In the 2040 scenario, the number of Potomac Aquifer critical cells greatly increases and the area impacted expands to cover most of central Southampton County and eastern Sussex County. Similar results are seen in the 2020 and 2040 scenarios for the Aquia Aquifer. These simulations indicate that even as permitted demands decrease, projected domestic increases as estimated could off-set reductions in permitted demands. The majority of groundwater users in this area rely on withdrawals from the Potomac Aquifer. If demands were to increase in line with the 2040 demand scenario, users in this area may not be able to meet the regulatory criteria for issuance of a groundwater withdrawal permit. This could impact both new or proposed withdrawals as well as existing permits during re-issuance. Several users in Southampton and Sussex counties have already encountered challenges meeting the regulatory criteria for a groundwater withdrawal permit in the region. This underscores the importance of continuing to evaluate and pursue alternative sources, interconnection opportunities, and more robust conservation for groundwater users in this basin.

A.8 New River Basin

A.8.1 Watershed Overview

The New River Basin is located in southwestern Virginia. The New River begins in North Carolina and flows northeast into Virginia, before flowing northwest and draining into the Gauley River in West Virginia. The New River Minor Basin includes all or a portion of the localities listed in Table 49. The topography of the basin includes both mountainous areas as well as narrow valleys with land cover that is widely rural and forested. Urban development is generally located within large localities such as the towns of Blacksburg and Christiansburg, and the City of Radford.

Major tributaries to the New River within Virginia include: the Little River, Walker Creek, Cripple Creek, Elk Creek, Rock Creek, Reed Creek, Big Reed Island Creek, Little Reed Island Creek, and Fox Creek. Claytor Lake, which is an impounded portion of the New River, is the major reservoir located within the basin.

Table 49: Population Trend by Locality in New River Basin

Localities	20 Year % Change
Bland	-11.20
Carroll	-4.16
Craig	-3.72
Floyd	8.31
Franklin County	13.14
Giles	-2.03
Grayson	-21.95
Montgomery	13.10
Patrick	-13.62
Pulaski	-6.76
Smyth	-13.07
Tazewell	-10.60
Washington	1.99
Wythe	0.18
Galax	-7.91
Radford	8.95

A.8.2 Existing Water Sources

Major surface water sources within the basin include the New River, Little River, Bluestone River, Reed Creek, Little Reed Island Creek, Walker Creek, and Claytor Lake. Groundwater within the basin is withdrawn from wells constructed in bedrock or fractured rock aquifers.

Withdrawals within the basin are used for public water supply as well as for agriculture, irrigation, commercial, mining, and industrial/manufacturing uses.

The location and spatial distribution of wells and surface water intakes identified to DEQ within the basin are shown in Figure 190. This figure does not include private or domestic wells. This map also shows locations of any Instream Flow Incremental Method (IFIM) studies completed in the basin. Surface water intakes are distributed throughout the basin with a greater concentration on the New River within the northern portion of the basin. Groundwater wells are located primarily in the central and southern portions of the basin, and rely on fractured rock aquifers for supply.

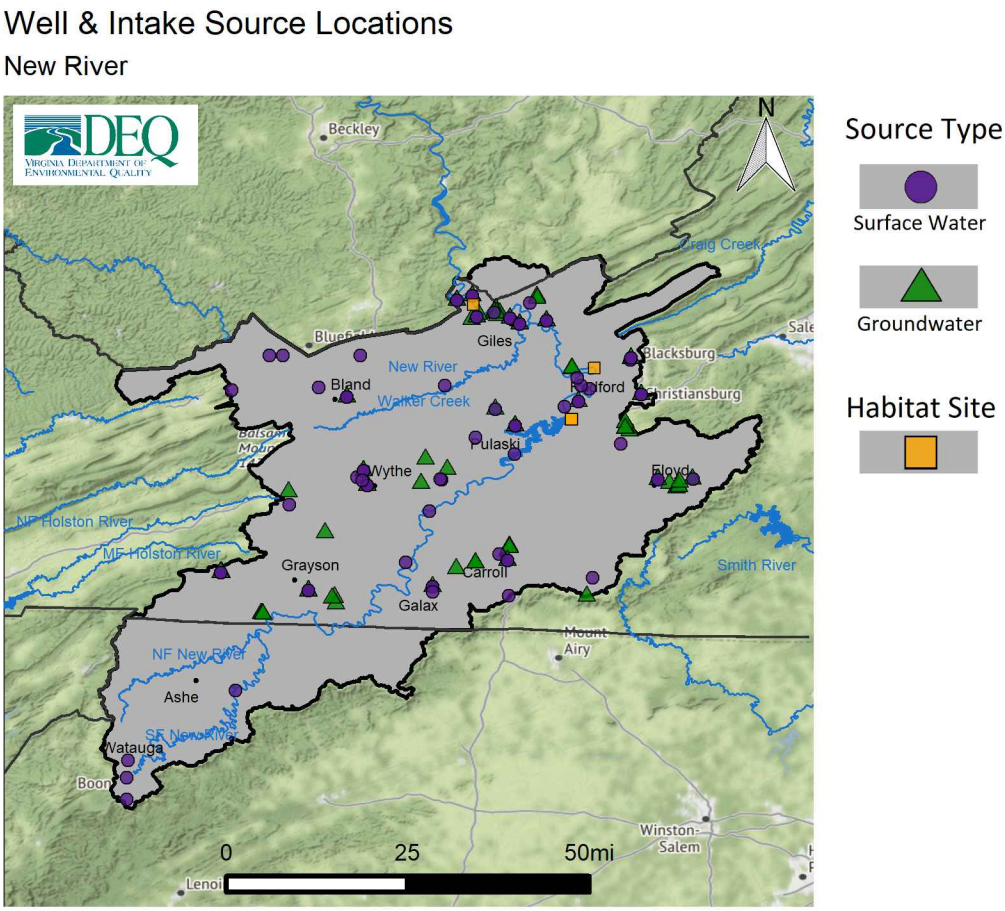

Figure 190: Locations of surface water intakes and groundwater wells within the New River Basin

A.8.3 Existing Water Use

The following section discusses existing (current) water use within the basin, which is based on existing demand provided in the Water Supply Plans. Table 50 provides a summary of all demand within the basin including demand associated with power generation. Note that withdrawals related to power generally dwarf other demand categories and can therefore make evaluating trends for other categories more challenging. Most power generation withdrawals are also largely non-consumptive; water is withdrawn for cooling purposes and then discharged back into the source stream with minimal loss. Note that this basin does not include any withdrawals classified as power generation. This table also includes the number of sources, whether groundwater or surface water, corresponding with each use category.

Table 50: Summary of New River Minor Basin Water Demand by Source Type and System Type (including Power Generation)

System Type	Source Count	2020 Demand (MGD)	2030 Demand (MGD)	2040 Demand (MGD)	20 Year Percent Change
Surface Water					
Agriculture	3	9.05	9.47	9.90	9.45
CWS	16	24.66	27.03	29.39	19.17
Large SSU	16	67.78	68.98	70.18	3.55
Small SSU	N/A	0.00	0.00	0.00	0.00
Total SW	**35**	**101.49**	**105.48**	**109.47**	**7.86**
Groundwater					
Agriculture	4	3.35	3.54	3.72	11.09
CWS	44	1.87	1.94	2.02	7.91
Large SSU	16	15.50	15.87	16.24	4.76
Small SSU	N/A	5.96	6.28	6.60	10.85
Total GW	**64**	**26.68**	**27.63**	**28.58**	**7.12**
Total (SW + GW)					
Agriculture	7	12.40	13.01	13.63	9.89
CWS	60	26.53	28.97	31.41	18.38
Large SSU	32	83.28	84.85	86.42	3.77
Small SSU	N/A	5.96	6.28	6.60	10.85
Minor Basin Total	**99**	**128.17**	**133.11**	**138.06**	**7.72**

* Small SSU demands are county-wide estimates of private well usage below 300,000 gallons a month. The number of private wells is not known.

The total existing demand from all surface and groundwater sources is approximately 128.17 MGD, with groundwater supplying approximately 26.68 MGD or 21% of total water demands. Surface water demand within the basin totals approximately 101.49 MGD, or 79% of current demands. As with most basins, surface water accounts for the majority of current demands.

The five largest facility demands for each source type including power generation are provided in Table 51. The largest groundwater demands include two Kimballton limestone mines, as well as the Celanese Celco plant, all located in Giles County. Giles County Public Service Authority is the largest municipal groundwater demand in the basin. The largest surface water demands include the Celanese Celco Plant (which uses groundwater and surface water), the Radford Ammunition Plant's New River intake, and the New River Regional Water Authority's New River intake, both located in Montgomery County.

Table 51: Top 5 Users in 2040 by Source Type in the New River Minor Basin (including Power Generation)

Facility Name	System Type	Locality	2020 Demand (MGD)	2030 Demand (MGD)	2040 Demand (MGD)	20 Year Percent Change	% of Total Surface Water
Surface Water							
Celco Plant	Large SSU	Giles	51.88	53.08	54.28	4.63	49.58
Radford Ammunitions WTP 1	Large SSU	Montgomery	15.52	15.51	15.49	-0.19	14.15
New River WTP	CWS	Montgomery	6.71	8.07	9.42	40.39	8.61
Wytheville Fish Hatchery	AG	Wythe	3.28	3.52	3.76	14.63	3.43
Wytheville WTP	CWS	Wythe	2.86	2.86	2.86	0.00	2.61
Total SW			80.25	83.04	85.81	6.93	78.39
Groundwater							**% of Total Groundwater**
Kimballton Plant 1	Large SSU	Giles	9.4	9.62	9.84	4.68	34.43
Celco Plant	Large SSU	Giles	4.33	4.43	4.53	4.62	15.85
Kimballton Plant 2	Large SSU	Giles	1.67	1.71	1.75	4.79	6.12
Giles County Public Service Authority	CWS	Giles	1.1	1.12	1.15	4.55	4.02
Independence Service Area	CWS	Grayson	0.15	0.15	0.16	6.67	0.56
Total GW			16.65	17.03	17.43	4.68	60.99

Table 50 also provides the proportion of each use category that is supplied by either surface water or groundwater. Use categories include Community Water System (CWS), Large Self-Supplied User (Large SSU), Small Self-Supplied User (Small SSU), and Agricultural Self-Supplied User (AG). These categories are defined below. Surface water demand is primarily comprised of Large SSUs (67.78 MGD), CWS (24.66 MGD), and AG demand. Groundwater demand is primarily comprised of Large SSUs (15.50 MGD), Small SSUs (5.96 MGD) and AG. Consistent with much of the state, surface water is the primary source for CWS, while groundwater supplies the majority of domestic or residential use.

The CWS category includes any public and private waterworks that serve at least 15 service connections used by year-round residents or regularly serve at least 25 year-round residents, and are regulated under the Virginia Department of Health's Waterworks Regulation (12VAC5-590). In the New River Basin, approximately 1.87 MGD of groundwater demand and 24.66 MGD of surface water demand is from CWS. Significant groundwater users within this category include groundwater wells operated by the Giles County Public Service Authority as well as wells operated by the Town of Independence. Significant surface water users from this category include the previously mentioned New River intake operated by the New River Regional Water Authority, as well as the Town of Wytheville's Reed Creek intake.

Large SSUs include any non-CWS or AG who withdraw more than 300,000 gallons per month from a well or surface water intake. In the New River Basin, approximately 15.50 MGD of groundwater demand and 67.68 MGD of surface water demand is from Large SSUs. Significant groundwater users within this category include the two previously mentioned Kimballton mines and the Celanese Celco Plant. Significant surface water users from this category include the Celanese Celco New River intake and the Radford Army Ammunition Plant's New River intake. Surface water comprises the majority source for Large SSUs with more than four times the groundwater demands associated with Large SSUs.

Small SSUs include any users who withdraw less than 300,000 gallons per month from wells. Small SSUs generally consist of residential or domestic use for those who live outside service areas and provide their own water. Small SSU demand is generally met with groundwater. In the New River Basin, approximately 5.96 MGD of current groundwater demand is from Small SSUs. No surface water demand is associated with Small SSUs in the New River Basin. Localities within the basin with the greatest contribution from Small SSUs include Floyd, Carroll, and Pulaski counties.

The AG category includes crop farms, livestock operations, aquaculture and other agricultural facilities. In the New River Basin, approximately 3.35 MGD of groundwater demand and 9.05 MGD of surface water demand is from AG. Significant surface water users from this category include the Wytheville Fish Hatchery. There are no significant AG facilities using groundwater reported to DEQ, but several localities provided locality-wide estimates of AG groundwater use. Floyd, Carroll, and Grayson counties have the highest county-wide AG estimates within the basin.

A.8.4 Projected Water Use

Projected Population: Trends in water use are generally driven by trends in population change or economic development. Increasing population within an area generally means increased connections for community water systems or additional demands from homeowners that construct wells. Increasing population in an area also tends to incentivize both new and expanded industrial and commercial water use. Alternatively, the addition of new economic opportunities such as a large employer may include additional water demands for operational needs. Reviewing short and long term population projections can inform water supply planning efforts.

Table 49 shows the projected change in population by percent between 2020 and 2040 for each locality located partly or wholly within this minor basin. As with other areas in the Commonwealth that are comprised of mostly rural areas, many localities within the New River basin are projected to experience some decline in population from 2020 to 2040. Grayson County is projected to have the largest decrease in population (-21.95%). Localities projected to increase in population by 2040 include Franklin County (13.14%), Floyd County (8.31%), Montgomery County (13.10%), City of Radford (8.95%) Wythe County (0.18%), and Washington County (1.99%). Increases in domestic water use by Small SSUs as well as increasing CWS demands generally aligns with where the greatest population growth is projected.

Projected Water Use: The following section discusses projected water use through 2040 within the New River basin, based on projections provided in local and regional water supply plans. Table 50, included in the existing demand section above, is the basis for information discussed in this section.

Total demand within the basin is projected to increase from 128.17 MGD in 2020 to 138.06 MGD in 2040, or an increase of 7.72%. Surface water demand is projected to increase by 7.98 MGD, or approximately 7.86%, by 2040. Groundwater demand is projected to increase by 1.9 MGD, or 7.12%, by 2040. CWS is the major driver of increasing surface water demands in the basin while Large and Small SSUs are the major drivers of increasing groundwater demands.

The largest contributors to this trend are the New River Regional Valley Authority's New River intake, which is projected to increase by over 40% from 2020 to 2040, and the Wytheville Fish Hatchery in Wythe County, which is projected to increase by approximately 14%.

Demands from CWS users within the basin is projected to increase by 18.38% by 2040. Within this category, surface water use is projected to increase by 19.17%, while groundwater use is projected to increase by 7.91%. Expected increases in surface water demand are largely driven by projected increases in demand from the New River Regional Valley Authority's New River WTP in Montgomery County. The New River is the primary source of withdrawal for the water treatment plant and is projected to increase from 6.71 MGD to 9.43 MGD by 2040.

Demands from Large SSUs within the basin is projected to increase by 3.77% by 2040. Within this category, surface water use is projected to increase by 3.55%, while groundwater use is projected to increase by 4.76%. Demand increases in the category are primarily driven by increase demands expected from the Celanse Acetate and Kimballton Mining Plants. Celanse Acetate is the largest water user in the basin and is projecting an additional 2.60 MGD in demand by 2040. Celanse is unique in the New River basin with reliance on both a surface water intake from the New River and a network of five groundwater wells. Demands are projected to be met primarily from increased withdrawals from the New River. The Kimballton Mine operation are also reliant on surface water and groundwater sources, however the expected 0.52 MGD increase in demand is expected to be met by increases in withdrawal from quarry pits.

Demands from Small SSUs within the basin is projected to increase by 10.85% by 2040. Within this category, groundwater is the only known source of supply. This category represents the cumulative withdrawals from individual private well owners. Increases in home construction and population in the basin is the largest contributor to expected increases in demand for the category.

Demands from Agriculture Users within the basin is projected to increase by 9.89% by 2040. Within this category, surface water use is projected to increase by 9.45%, while groundwater use is projected to increase by 11.09%. Expected increases in demand across the category are primarily driven by increases in countywide agricultural demand from small farm operations in Floyd County. The Wytheville Fish Hatchery is the largest individual withdrawal in the category and is expected to increase by approximately 0.47 MGD by 2040.

A.8.5 Cumulative Impact Analysis

The following section provides a brief summary of the Cumulative Impact Analysis (CIA) modeling results in the New River Basin. Discussion of these results will primarily be found in the Trends and Goals section of this Appendix. However a brief overview of the VAHydro model and the scenarios and metrics is provided below.

The VAHydro surface water model simulates streamflow using inputs such as precipitation, climate, land use, and topography, combined with data on all known withdrawals and discharges, and operational rules of major hydrologic features such as reservoirs. Each minor basin is broken into smaller hydrologic subsections, or river segments. The model simulates the water balance on a daily basis for each individual river segment, with each downstream segment being affected by the "cumulative impact" of streamflow changes occurring in upstream segments. The following figures help analyze this cumulative impact within the New River Basin (model results summarized by river segment). Note that this section is not intended to document in detail the methods and assumptions for the VAHydro model or for the scenarios and metrics discussed. Detailed documentation of the model and assumptions can be found in Chapter 4.

The VAHydro surface water model was used to simulate streamflow under a variety of scenarios. Demand scenarios examine how streamflow is impacted under 2030 or 2040 demands as compared to current (2020) demands. Demands were calculated based on current and future demand information submitted through local and regional water supply plans. Climate change scenarios examine how streamflow is impacted when 2040 demands are simulated in conjunction with a range of precipitation and temperature conditions that may occur in the future due to changing climate (Dry, Median, Wet scenarios). Finally, the exempt user scenario examines impacts from users excluded, or exempt, from VWP permit requirements per Va. Code § 62.1-44.15:22 B. Exempt users were simulated at the maximum possible demand identified through a review of demand justification values commonly asserted by exempt users, including but not limited to VDH pump capacity, maximum pre-1989 withdrawal, and maximum intake capacity. In order to effectively manage surface water resources and address the uncertainty related to these demands, DEQ determined the most conservative, or maximum possible, demand should be evaluated in this scenario. However, DEQ does not agree that the maximum values used in this scenario represent an allocation for, or the expectation of, a future withdrawal of that volume; nor does DEQ concede that any particular exempt user is necessarily entitled to withdraw any particular maximum value used in this scenario. The methods and assumptions for each of these modeling scenarios are discussed in more detail in Chapter 4.

For each scenario described above, different metrics can be used to evaluate the simulated streamflow. A metric is a method for measuring or evaluating a given set of data; different metrics can be evaluated to answer different questions. Within this section the following metrics will be discussed: the lowest 30 day flow (L30), the lowest 90 day flow (L90), 7Q10, and overall change in flow. The L30 describes the lowest consecutive 30 day average daily streamflow over the simulation period. This metric is a representation of a short-term, or acute drought, and is a good metric for evaluating impacts to direct withdrawals without storage. Similarly the lowest 90 day flow represents the lowest consecutive 90 day average daily streamflow over the simulation period. This would represent a prolonged drought and is often used to evaluate impacts to reservoirs. The 7Q10 is the lowest 7-day average flow that occurs (on average) once every 10 years. 7Q10 is generally used in the evaluations of in-stream beneficial uses such as waste assimilative capacity. Overall change in flow describes the net loss of water from the riverine system as a result of off-stream use not otherwise returned through point source discharges, or losses due to evapotranspiration. This metric is useful for evaluating impacts to aquatic life and is discussed in more detail in Chapter 4.

Demand Scenarios: 2020 demand or "current demand", 2030 demand, and 2040 demand scenarios were simulated. The following series of figures compares the 2030 and 2040 demand scenarios to the current demand scenario. The change in flow depicted on each map is the change expected when comparing two scenarios - in this case future demands compared to current demands. Each page includes two figures comparing either the 2030 or 2040 demand scenario to current demand using the L30, L90, and 7Q10 metrics. This allows for comparisons of simulated impacts between the 2030 and 2040 demand scenarios. The scenarios and metrics are identified in the paragraph below and in the figure captions.

Figures 191 and 192 compare the lowest 30 day low flow simulated with the current demand scenario (2020) with the lowest 30 day flow simulated in the 2030 and 2040 demand scenarios respectively. Figures 193 and 194 compare the lowest 90 day low flow simulated with the current demand scenario (2020) with the lowest 90 day flow simulated in the 2030 and 2040 demand scenarios respectively. Figures 195 and 196 compare the 7Q10 simulated with the current demand scenario (2020) with the 7Q10 simulated in the 2030 and 2040 demand scenarios respectively.

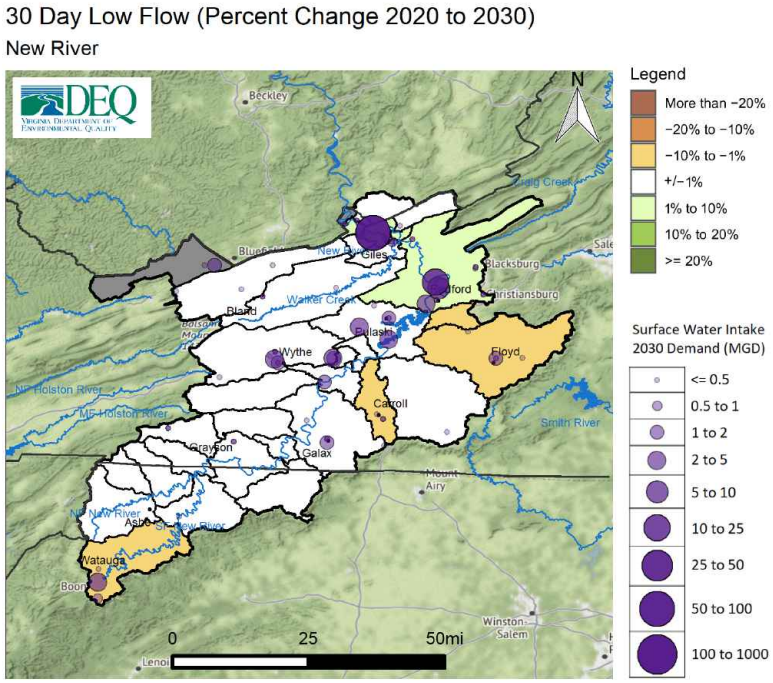

Figure 191: Change in 30 day low flow between 2020 and 2030 demand scenarios within the New River Basin

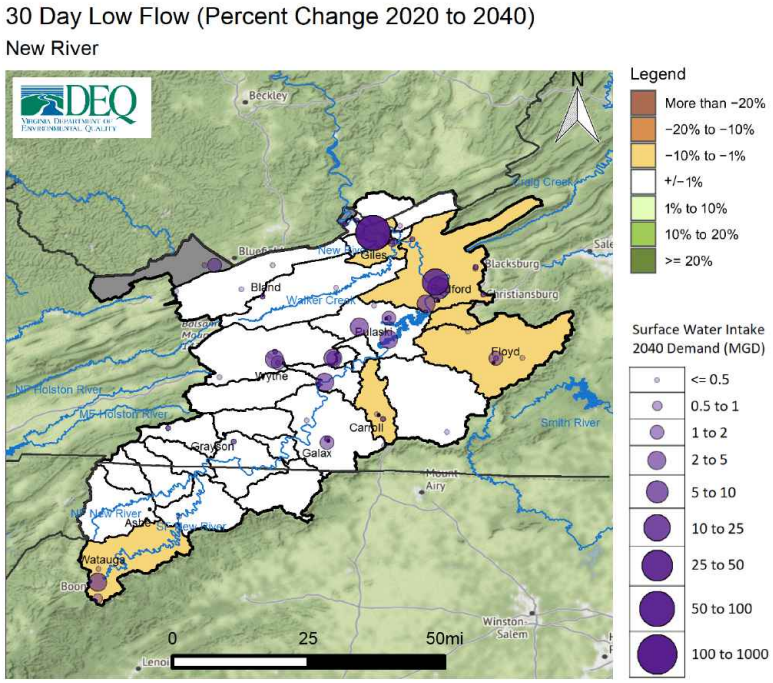

Figure 192: Change in 30 day low flow between 2020 and 2040 demand scenarios within the New River Basin

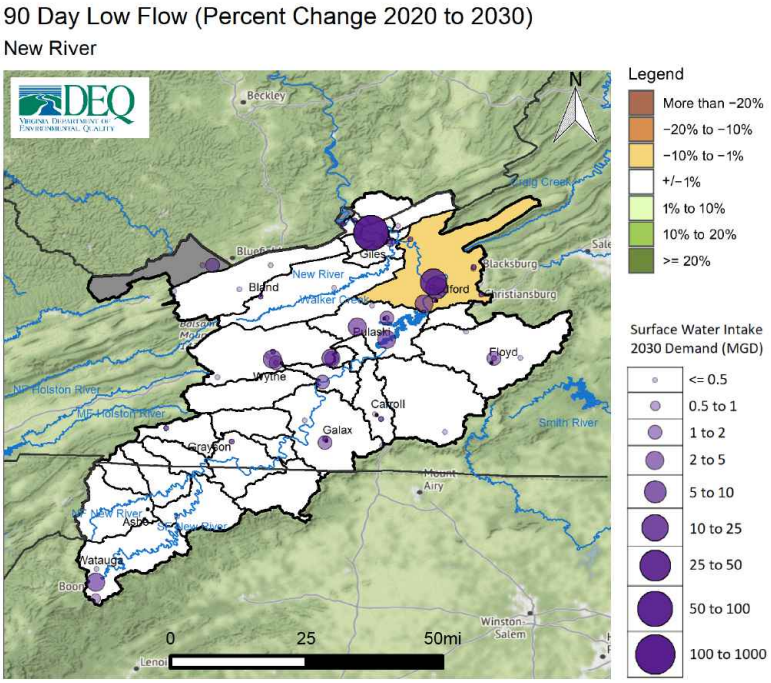

Figure 193: Change in 90 day low flow between 2020 and 2030 demand scenarios within the New River Basin

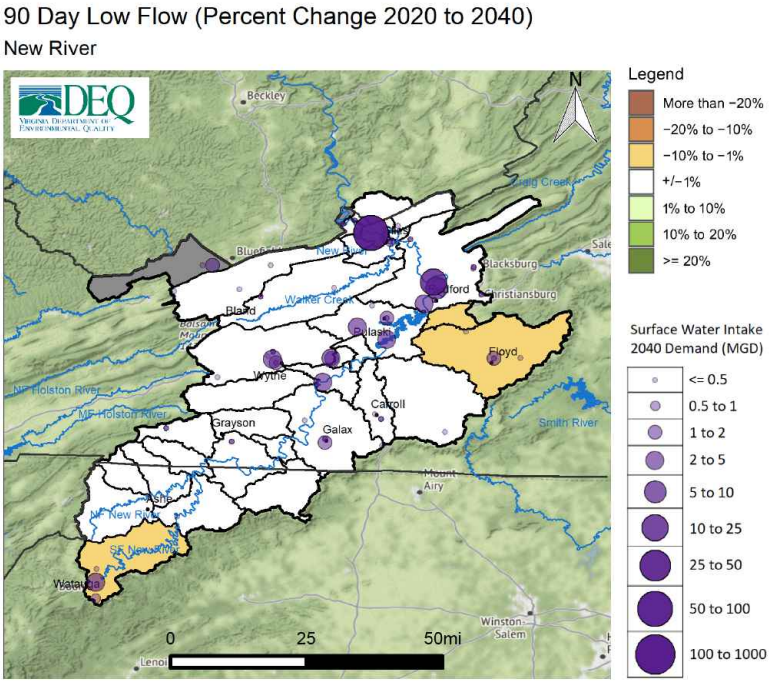

Figure 194: Change in 90 day low flow between 2020 and 2040 demand scenarios within the New River Basin

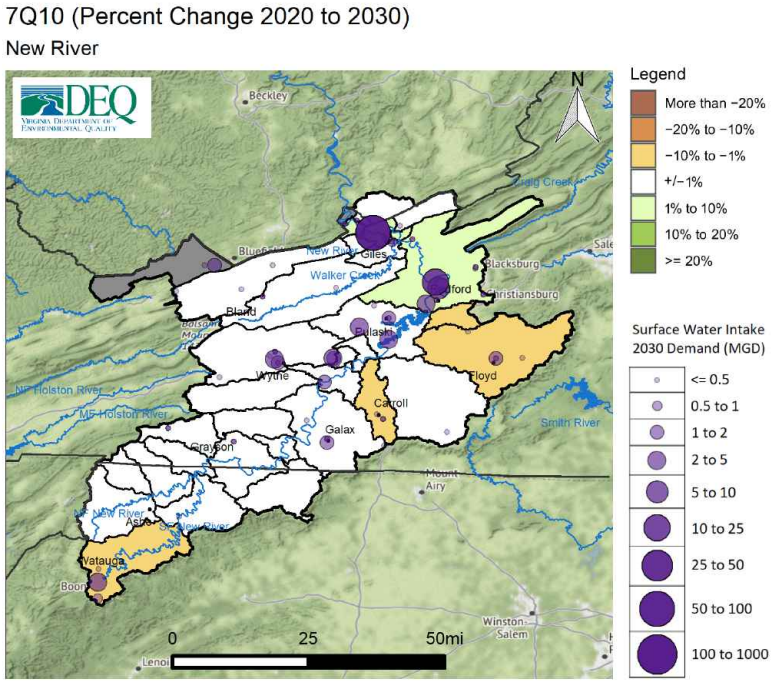

Figure 195: Change in 7Q10 between 2020 and 2030 demand scenarios within the New River Basin

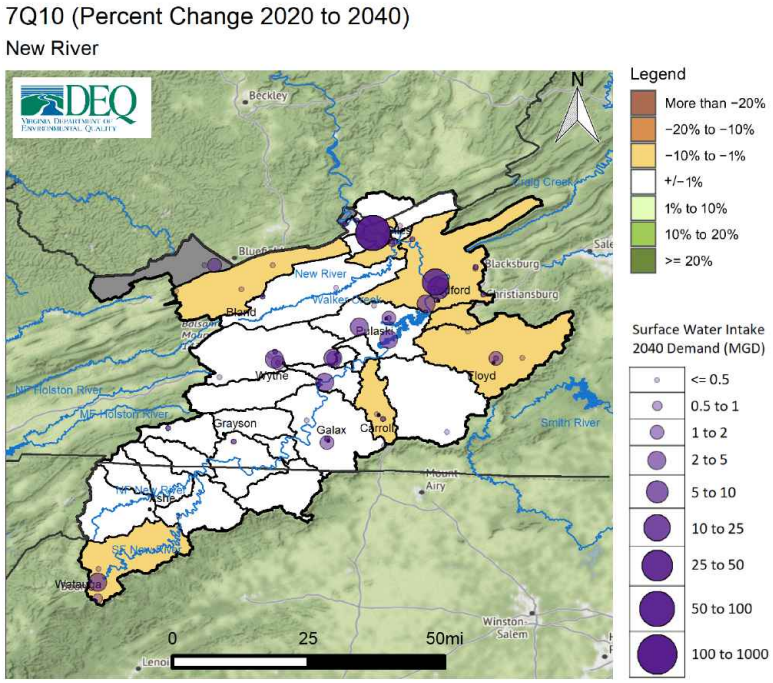

Figure 196: Change in 7Q10 between 2020 and 2040 demand scenarios within the New River Basin

The figures above show a comparison between two scenarios. An additional way to evaluate impacts to streamflow is to examine the total reduction in streamflow resulting from all withdrawals within a river segment, as well as losses due to evapotranspiration, while taking into consideration any discharges back to the source. To use a common industry term, the overall change in flow metric evaluates "consumptive use", or the amount of water removed from the river that is not returned through discharges. This can help describe potential impacts to downstream withdrawals, while also providing a basis for evaluating impacts to aquatic life. In general, total reductions in streamflow can result in a proportional reduction in aquatic biodiversity [90]. The relationship between streamflow and aquatic biodiversity is discussed in more detail in Chapter 4. Figure 197 shows the overall change in streamflow for the 2030 Demand Scenario, while figure 198 shows the overall change in streamflow for the 2040 Demand Scenario.

[90] Rapp, J.L., R. Burgholzer, J. Kleiner, D. Scott, and E. Passero. 2020. "Application of a New Species-Richness Based Flow Ecology Framework for Assessing Flow Reduction Effects on Aquatic Communities." Journal of the American Water Resources Association 1–14.https://doi.org/10.1111/1752-1688.12877.

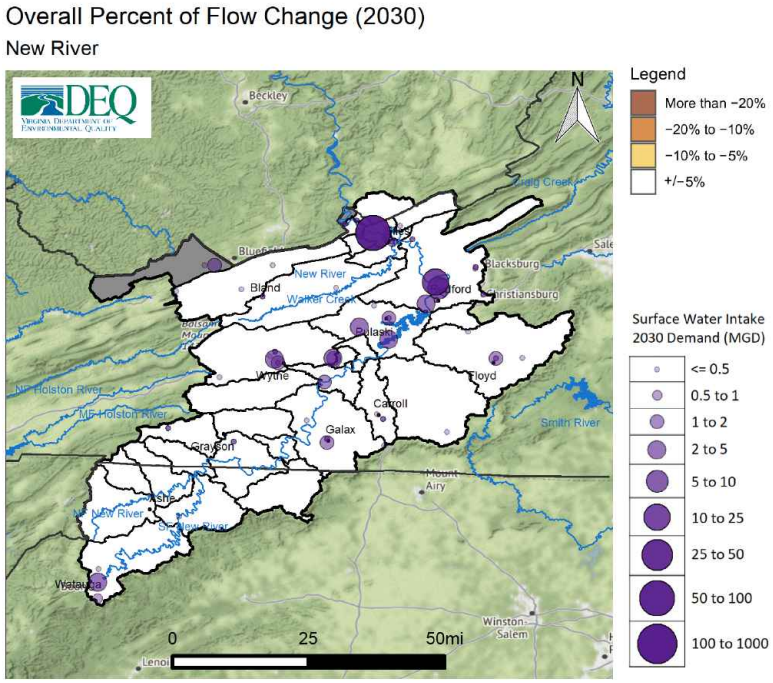

Figure 197: Overall change in flow in percent for 2030 demand scenario within the New River Basin

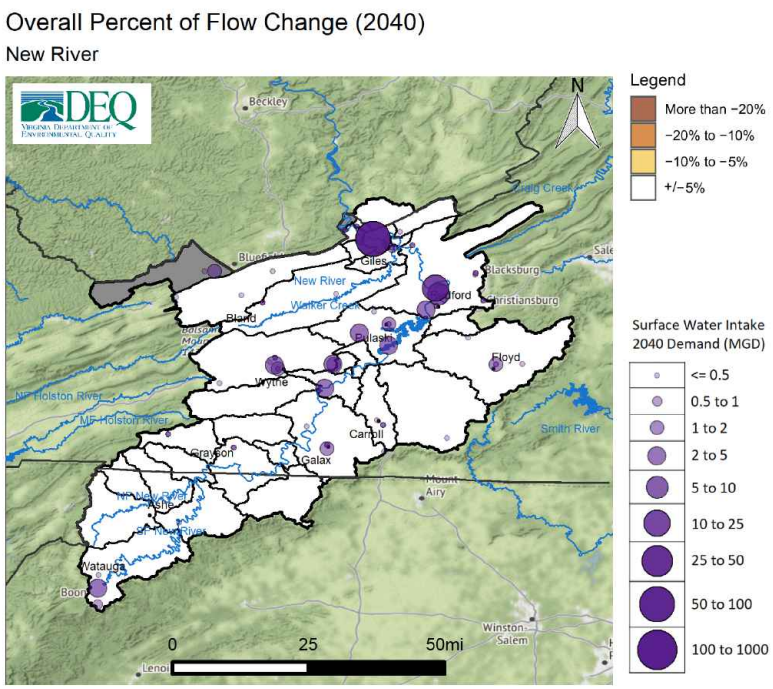

Figure 198: Overall change in flow in percent for 2040 demand scenario within the New River Basin

Climate Scenarios:Three scenarios that simulate impacts to streamflow in response to changes in temperature and climate were completed for areas in the state where climate data was available, which includes the portions of the Commonwealth located in the Chesapeake Bay watershed. Details on the methods and assumptions employed for these scenarios can be found in Appendix B. In short, the three scenarios can be described as dry, median, and wet scenarios. Virginia is expected to experience a range of precipitation and temperature changes that may vary spatially and from year to year. The potential for both more severe and prolonged droughts as well as for higher intensity and more frequent rain events must be considered. These three scenarios are not intended as predictions of future climate conditions, but as representations of several possibilities that climate change models indicate could occur. Should they occur, these results provide an evaluation of how streamflows may be impacted. Their purpose is to build upon existing climate modeling to provide a foundation for state and local government, as well as other stakeholders, to better evaluate what practical water resource challenges may be associated with the range of climate conditions Virginia could experience.Note that this Basin is located outside of the Chesapeake Bay watershed and therefore climate scenarios were not completed at this time. DEQ is working to expand these climate scenarios to cover the entire state for future planning efforts.

Exempt User Scenario: The exempt user scenario simulates the maximum possible exempt demand for users excluded from Virginia Water Protection permitting requirements per Va. Code § 62.1-44.15:22 B., in combination with the permitted withdrawal limits for those users that are permitted. A more detailed discussion of the data and assumptions used in this scenario can be found in Appendix B. Note that this scenario uses current climate conditions. Figure 199 depicts the percent change in the Lowest 30 Day Flow between the exempt user scenario and current (2020) demand. Figure 200 depicts the percent change in the Lowest 90 Day Flow between the exempt user scenario and current (2020) demand. Figure 201 depicts the percent change in the 7Q10 between the exempt user scenario and current (2020) demand. Finally, figure 202 depicts the overall change in flow in percent (consumptive use) for the exempt user scenario.

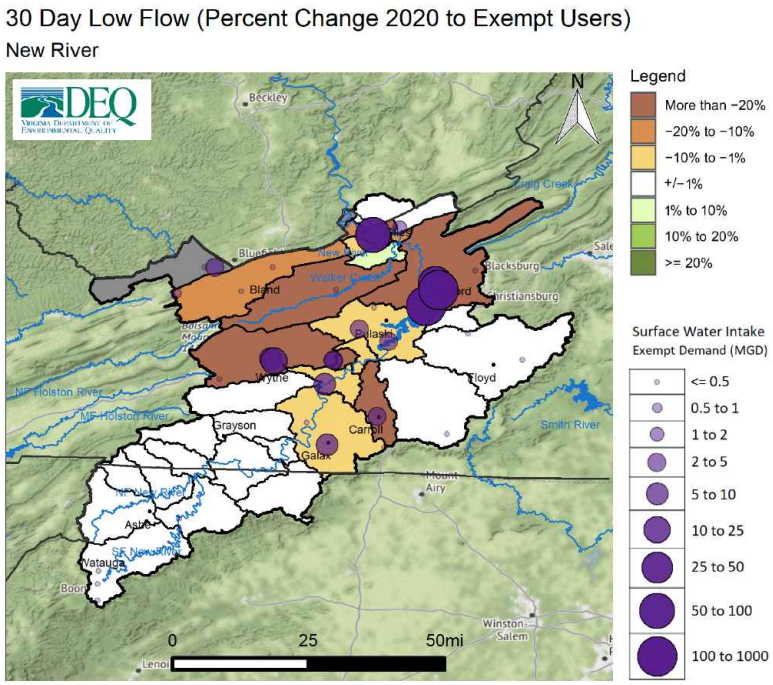

Figure 199: Change in 30 day low flow between current demand scenario and exempt user scenario within the New River Basin

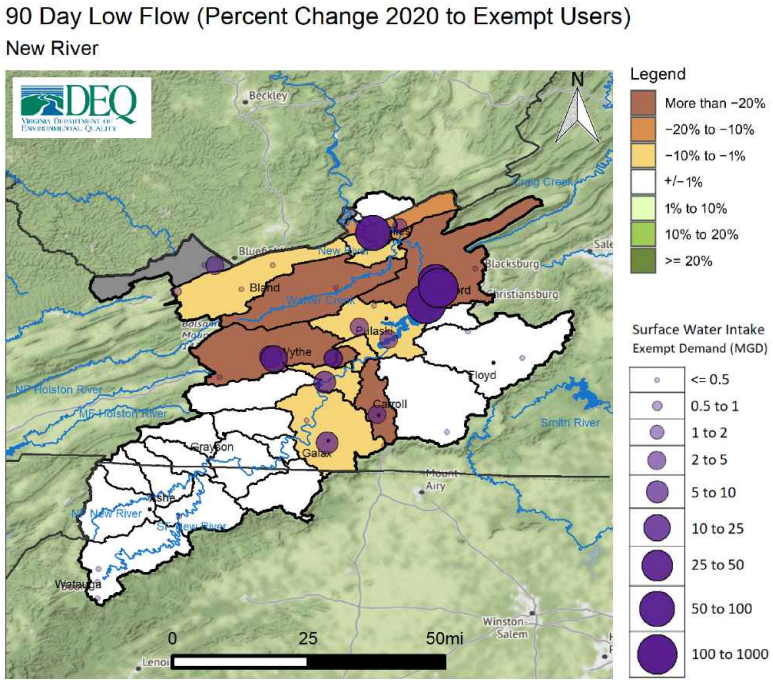

Figure 200: Change in 90 day low flow between current demand scenario and exempt user scenario within the New River Basin

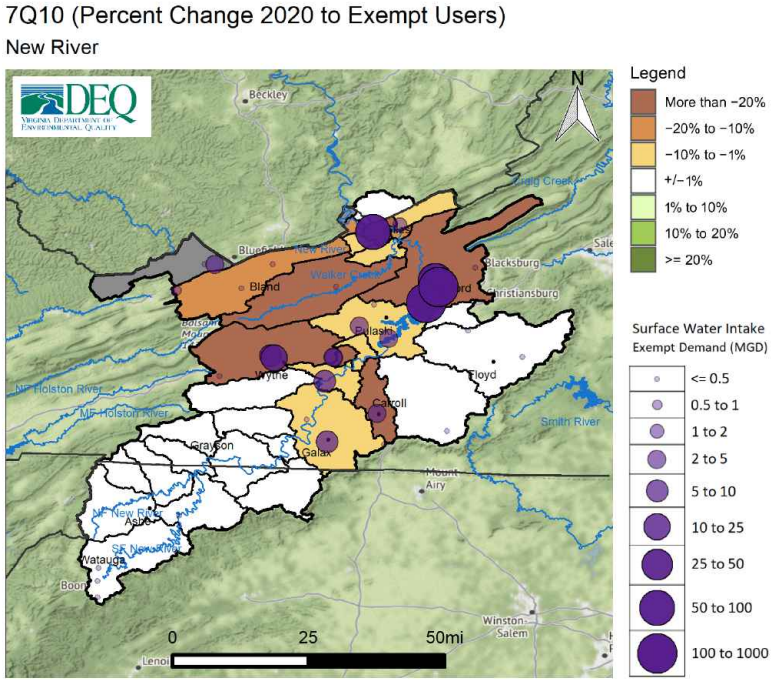

Figure 201: Change in 7Q10 between current demand scenario and exempt user scenario within the New River Basin

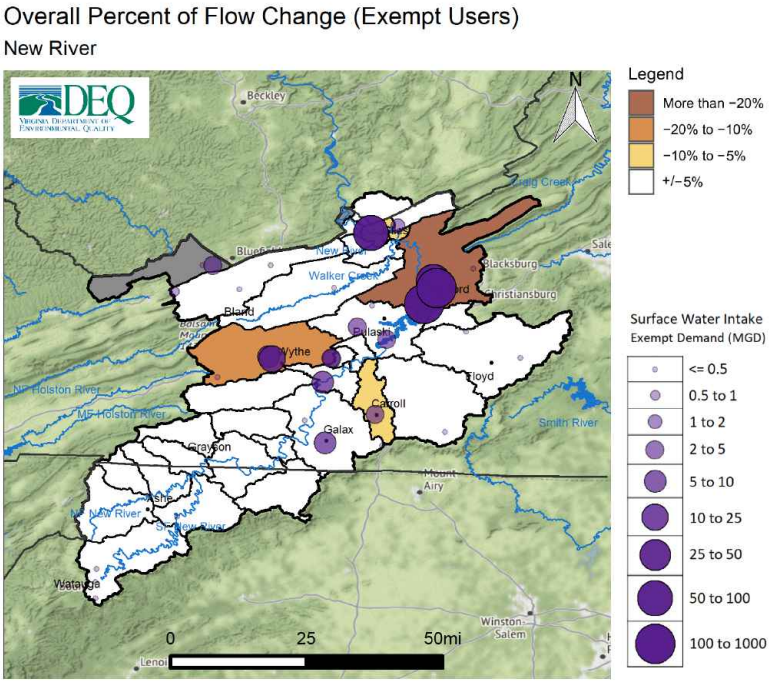

Figure 202: Overall change in flow in percent for exempt user scenario within the New River Basin

Potential Unmet Demand: Potential unmet demand was evaluated for all facilities within the basin for each scenario. Potential unmet demand is the portion of surface water demand for a specific facility that is limited by available streamflow as simulated in a given model scenario, including any known operational limits such as flow-by requirements. This unmet demand, if realized, could be managed through water conservation, through alternative sources, operational changes, or from available storage. Absent of these or other options, this portion of demand could remain unmet. As with all scenarios, demand requirements were determined using demand projections provided in the water supply plans. In the case of the exempt user scenario, the highest possible withdrawal amount was used for users exempt from VWP permitting requirements.

This metric is useful for evaluating where the results seen in the above figures may result in challenges in meeting future demands under a variety of conditions including increasing demands in the basin, changing climate, or withdrawals from users exempt from permitting requirements. Table 52 provides for each facility the highest average daily potential unmet demand over a 30 day period over the course of the simulation for the following scenarios: 2020 demand, 2030 demand, 2040 demand, and exempt User. Only facilities showing potential unmet demand in at least one scenario appear on this table. Additional information on the potential unmet demand metric can be found in B.

Table 52: Change in Highest 30 Day Potential Unmet Demand (MGD) in New River Minor Basin

Facility	**2020 Demand**	**2030 Demand**	**2040 Demand**	**Dry Climate**	**Exempt User**
New River WTP	0.00	0.00	0.00	-	301.14
Radford WTP	0.00	0.00	0.00	-	291.14
Wytheville WTP	0.22	0.22	0.23	-	9.86
Wytheville Golf Club	0.00	0.00	0.00	-	3.28
Wytheville Fish Hatchery	0.42	0.52	0.63	-	3.19
Hillsville WTP	0.00	0.00	0.00	-	2.14
Kimballton Plant 2	0.23	0.24	0.24	-	1.01
Bland (Town) WTP	0.00	0.00	0.00	-	0.88
Radford Ammunitions WTP 1	0.00	0.00	0.00	-	0.51
Greater Tazwell Regional WTP	0.01	0.01	0.01	-	0.08
Bland Correctional Center WTP	0.00	0.00	0.00	-	0.08

* Climate scenarios were not completed in areas located outside of the Chesapeake Bay Basin

Note: Potential unmet demand is the portion of surface water demand for a specific facility that is limited by available streamflow as simulated in a given model scenario, including any known operational limits such as flow-by requirements. This unmet demand, if realized, could be managed through water conservation, alternative sources, operational changes, or from available storage.

A.8.6 Trends and Goals

The Code of Virginia mandates that the State Water Control Board should take into consideration the principle that "adequate and safe supplies shall be preserved and protected for human consumption, while conserving maximum supplies for other beneficial uses."[91] This principle is the key driver of the challenges in water resource management, which is that all beneficial uses must be adequately considered when evaluating impacts to surface water resources. The State Water Control Board is tasked with ensuring that water supply quantity needs are met at all times while also protecting Virginia's natural resources, and furthermore, ensuring equitable allocation during a time of shortage.[92] While evaluating and planning for the long-term sustainability of water supply for Virginia is the primary goal for the State Plan, evaluating and limiting impacts to in-stream beneficial uses such as aquatic habitat life is also part of DEQ's responsibility.

The primary purpose of this section is to identify where the most significant challenges to long-term sustainability of water supply and other beneficial uses are indicated based on the CIA and information collated from local water supply plans within this basin. Goals for future planning and areas for additional data collection or analysis are also suggested where appropriate.

The CIAs were completed using the best available data and methods known to DEQ. This discussion focuses on the evaluation of trends - in other words the prevailing tendency or inclination. This means evaluating whether streamflow is simulated to increase or decrease in a given scenario, and by how much. A relative trend indicating reductions of greater than or equal to 10% in streamflow, whether driven by demand increases, changing climate conditions, or exempt user demands was considered a threshold for potential impacts to beneficial uses. The following summarize the key trends or goals for this basin:

- **Demand Scenarios:** The 2040 demand scenario in the New River basin resulted in no reductions in simulated streamflow in excess of 10% within any river segment for any of the metrics in the New River Basin. The projected demands as presented in the regional and local water supply plans do not indicate any additional impacts to future water supply availability and in-stream beneficial uses within the basin. This is not entirely unexpected given demand in the basin is only projected to increase approximately 7% between 2020 and 2040. This does not suggest that impacts to water supply are not already occurring during a drought, but that increased impacts due to demand alone are not expected. However, three facilities do show potential unmet demand in the 2040 demand scenario: Town of Wytheville's water treatment plant, Wytheville Fish Hatchery, and the Kimballton Plant 2 in Giles County.

- **Climate Scenarios:** As climate change data was not available in this basin, climate change scenarios were not completed for this basin. The overall trend in climate change simulations statewide suggests the potential for higher average temperatures and higher average precipitation totals. However, the simulations also suggest the potential for more significant droughts than have been historically experienced in Virginia. Simulations completed elsewhere in the Commonwealth show short-term and long-term droughts with 20-50% reductions in streamflow compared to previous droughts. The potential for more severe droughts must be considered by localities and users when evaluating existing sources and alternatives, as well as for broader planning and resource management efforts by all stakeholders whether state or local.

- **Exempt User Scenario:**The exempt user scenario models the cumulative maximum possible exempt demands from all users exempt from VWP permitting requirements. In the New River Basin, nine river segments showed reductions of at least 10% in simulated stream flow compared to 2020 demands when evaluating short term drought (30 day low flow) and long term drought (90 day low flow). The most severe reductions were in the New River between Claytor Lake Dam, Walker, and Reed creeks. A number of public water supplies are simulated to have potential unmet demand in the highest cumulative exempt user scenario including the New River Valley Regional Authority, the City of

[91] § 62.1-44.36 of the Code of Virginia
[92] 9VAC25-390-20.1

Radford, Town of Wytheville, and Hillsville facilities. Two river segments showed an overall reduction of stream flow of greater than 10%, the threshold at which the probability of impacts to aquatic species richness increases significantly. These river segments include the New River from Claytor Lake Dam to Walker Creek, and Reed Creek. The most significant reduction in overall flow in the exempt user scenario is simulated to occur on the New River between Claytor Dam and Walker Creek. These results indicate that the maximum possible exempt user demands may exceed the water budget in many river segments within the basin. Preserving water supply and other beneficial uses will require managing these demands with respect to their cumulative impacts and in the context of the available resources in the basin.

A.9 Roanoke Dan

A.9.1 Watershed Overview

The Roanoke Dan Minor Basin is located in the south central portion of Virginia, with the watershed boundary extending into northern North Carolina. The basin drains from the western mountains east through the Piedmont and occupies approximately 3389.1 sq. miles including all or portions of the localities listed in Table 53. Major population centers include the cities of Danville and Martinsville, and the towns of Halifax and South Boston. Land use and cover in the basin is largely comprised of forested mountains, agricultural, with limited urban development concentrated within population centers.

The basin includes several prominent rivers including the Bannister, Smith, Dan, and the North & South Mayo rivers. The basin also includes a number of impoundments including Bannister Lake, Philpott Reservoir, Talbott Reservoir, Townes Reservoir, and the John H. Kerr Reservoir. The North Carolina portion of the watershed contains additional reservoirs including Belews Lake, Farmer Lake, Hyco Lake, and Lake Mayo.

A.9.2 Existing Water Sources

Table 53: Population Trend by Locality in Roanoke Dan Basin

Localities	20 Year % Change
Carroll	-4.16
Floyd	8.31
Franklin County	13.14
Halifax	-12.25
Henry	-17.48
Patrick	-13.62
Pittsylvania	-3.96
Danville	-24.73
Martinsville	-22.79

Major surface water sources within the basin include the Bannister, Dan, Mayo, and Smith rivers. The Beaver Creek Reservoir is also a major source of supply for the City of Martinsville. Groundwater within the basin is primarily withdrawn from bedrock aquifers to supply small self-supplied users in the basin. However, several Large Self-Supplied Users (Large SSUs) depend on groundwater for operational supply. Currently surface water sources are the primary water source.

Withdrawals within the basin are most commonly used for public water supply, manufacturing/industrial, commercial, mining, and irrigation uses. Agricultural land use is widespread throughout the basin, however reporting of the category is limited. Surface water is the primary water source for the basin with thirty-seven currently active surface water supplied facilities. Groundwater is also a significant source of supply in the basin with twenty-nine facilities reporting withdrawals from wells in the basin. The location of wells and surface water intakes known to DEQ within the basin are shown in Figure 203. This figure does not include private or domestic wells.

Surface and groundwater withdrawals are focused within areas of development and along major surface water sources. Surface water withdrawals are concentrated in the areas surrounding population centers including the City of Danville, the City of Martinsville, Halifax County, and the towns of Gretna and Stuart. Note that several surface water withdrawals are located along the Dan River in North Carolina; this data was collected in partnership with the North Carolina Department of Environmental Quality and is critical to understanding upstream withdrawals when watersheds include areas outside of Virginia.

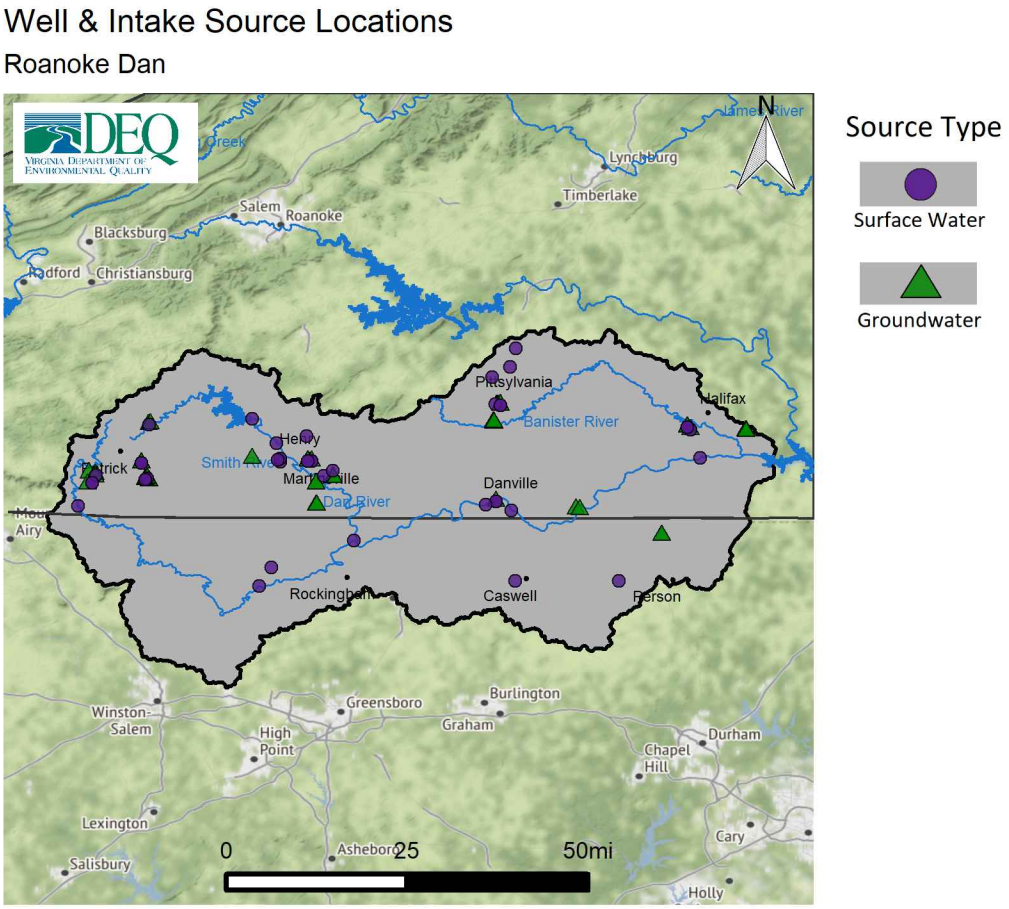

Figure 203: Location of Surface Water Intakes and Wells in the Roanoke Dan Minor Basin

A.9.3 Existing Water Use

The following section discusses current water use within the basin, which is based on existing demand estimates provided in the Water Supply Plans. Table 54 provides a summary of all water demand within the basin organized by water source type and use category. This basin does not include any active non-hydro power generation associated withdrawals.

Table 54: Summary of Roanoke Dan Minor Basin Water Demand by Source Type and System Type

System Type	Source Count	2020 Demand (MGD)	2030 Demand (MGD)	2040 Demand (MGD)	20 Year Percent Change
Surface Water					
Agriculture	11	10.75	10.82	10.89	1.28
CWS	13	23.31	24.54	25.77	10.57
Large SSU	13	3.54	3.79	4.04	14.12
Small SSU	N/A	0.00	0.00	0.00	0.00
Total SW	**37**	**37.60**	**39.15**	**40.70**	**8.24**
Groundwater					
Agriculture	3	0.15	0.15	0.15	0.11
CWS	10	0.05	0.06	0.06	4.30
Large SSU	16	0.41	0.42	0.42	1.59
Small SSU	N/A	8.40	8.34	8.27	-1.63
Total GW	**29**	**9.01**	**8.97**	**8.90**	**-1.22**
Total (SW + GW)					
Agriculture	14	10.90	10.97	11.04	1.26
CWS	23	23.36	24.60	25.83	10.55
Large SSU	29	3.96	4.21	4.46	12.81
Small SSU	N/A	8.40	8.34	8.27	-1.63
Minor Basin Total	**66**	**46.62**	**48.12**	**49.60**	**6.39**

* Small SSU demands are county-wide estimates of private well usage below 300,000 gallons a month. The number of private wells is not known.

The total existing demand from all surface and groundwater sources is approximately 46.62 MGD, with groundwater supplying approximately 9.01 MGD or 19.3% of total water demands. Surface water demand within the basin totals approximately 37.60 MGD, or 80.7% of current demands. Surface water sources primarily supply Community Water System (CWS) facilities and Agricultural Self-Supplied Users (AG) with limited withdrawals from Large SSUs in the basin. Groundwater demands in the basin are largely made up of estimated demands from private Small Self-Supplied Users (Small SSUs) which make up 93.2% of existing groundwater demands in the basin.

The five largest withdrawals for each source type are provided in Table 55. The largest surface water demands are from public water supplies in the basin. The Danville WTP is currently the largest single user 5.26 MGD based on current demands. The second largest demand is located in Eden, North Carolina, with approximately 5.22 MGD in demand. The remaining largest users in the watershed include public water systems in Henry County, the City of Martinsville, and Halifax County. The largest individual groundwater demand in the basin is located in Patrick County and supports the United Elastic Stuart Plant, with approximately 0.24 MGD in demand. Groundwater demands from facilities in the basin are minimal with residential home owners the most significant source of groundwater demand in the basin.

Table 55: Top 5 Users in 2040 by Source Type in the Roanoke Dan Minor Basin

Facility Name	System Type	Locality	2020 Demand (MGD)	2030 Demand (MGD)	2040 Demand (MGD)	20 Year Percent Change	% of Total Surface Water
Surface Water							
Eden	CWS	Rockingham	5.22	5.32	5.43	4.02	13.34
Danville Main WTP	CWS	Danville	5.26	5.26	5.26	0.00	12.92
Upper Smith River WTP	CWS	Henry	3.3	3.3	3.3	0.00	8.11
City Of Martinsville WTP	CWS	Martinsville	1.96	2.55	3.13	59.69	7.69
Leigh Street Filter Plant - WTP	CWS	Halifax	1.85	2.28	2.71	46.49	6.66
Total SW			17.59	18.71	19.83	12.73	48.72
Groundwater							**% of Total Groundwater**
Stuart Plant	Large SSU	Patrick	0.24	0.24	0.24	0.00	2.7
Woolwine Plant	Large SSU	Patrick	0.13	0.13	0.13	0.00	1.46
Virginia International Raceway	Large SSU	Halifax	0.01	0.02	0.02	100	0.22
Stuart WTP	CWS	Patrick	0.02	0.02	0.02	0.00	0.22
Eastwood Service Area	CWS	Henry	0.01	0.01	0.01	0.00	0.11
Total GW			0.41	0.42	0.42	2.44	4.72

Table 54 also provides the proportion of each use category that is supplied by either surface water or groundwater. Use categories include Community Water System (CWS), Large Self-Supplied User (Large SSU), Small-Self Supplied User (Small SSU), and Agricultural User (AG). Surface water demand is primarily comprised of AG and CWS facilities. Only limited demands from Large SSUs are present in the basin.

The CWS category includes any public and private waterworks that serve at least 15 service connections used by year-round residents or regularly serve at least 25 year-round residents, and are regulated under the Virginia Department of Health's Waterworks Regulation (12VAC5-590). In the Roanoke Dan Basin, approximately 0.05 MGD of groundwater demand and 23.31 MGD of surface water demand is from CWS facilities. Surface water is the primary water source and supplies all major population centers in the watershed including Henry County, the towns of Halifax and Gretna, and the cities of Danville and Martinsville. Surface water is currently the most viable water source for CWS demands in the basin. Several smaller CWS facilities do rely on groundwater either wholly or as a supplement to surface water.

Large Self-Supplied Users (Large SSUs) include any non-CWS or AG who withdraw more than 300,000 gallons per month from a well or surface water intake. In the Roanoke Dan basin, approximately 0.41 MGD of groundwater demand and 3.54 MGD of surface water demand is from large self-supplied users. Significant groundwater users within this category include: United Elastic's manufacturing plant, Virginia International Raceway, Hanes Woolwine Plant, and the Virginia Glass Products Corp. Surface water is the primary water source for the category. Currently four facilities represent the primary users of surface water in the category including the Danville Industrial WTP, Eastman Performance Films, the Blue Ridge Fish Hatchery, and the Hanes Woolwine Plant.

Small Self-Supplied Users (Small SSUs) include any users who withdraw less than 300,000 gallons per month from wells. Small SSUs generally consist of residential or domestic use for those who live outside service

areas and provide their own water. Small SSU demand is generally met with groundwater. Estimated Small SSU demands in the basin are 8.40 MGD, or 93.2% of current demands. With the majority of the basin in a rural setting, homeowners commonly rely on private wells for household supply. Pittsylvania and Halifax counties have the largest estimated demands for Small SSUs in the basin.

The AG category includes crop farms, livestock operations, aquaculture and other agricultural facilities. In the Roanoke Dan Basin, approximately 0.15 MGD of groundwater demand and 10.75 MGD of surface water demand is from AG withdrawals. Significant surface water users from this category include numerous farms scattered throughout the basin. There are no significant individual AG facilities with groundwater demands currently identified in the basin. Patrick, Pittsylvania, and Henry counties have the highest estimated AG demands in the basin - which do include estimates for groundwater use.

A.9.4 Projected Population and Water Use

Trends in water use are generally driven by trends in population change or economic development. Increasing population within an area generally means increased connections for community water systems or additional demands from homeowners that construct wells. Increasing population in an area also tends to incentivize both new and expanded industrial and commercial water use. Alternatively, the addition of new economic opportunities such as a large employer may include additional water withdrawals for operational needs. Reviewing projections in short and long term population trends can inform water supply planning efforts.

Table 53 shows the projected change in population for each locality fully or partially within the watershed. Growth in population is limited within the Roanoke Dan Basin. Projections for increasing population are primarily focused within Floyd and Franklin counties. With much of the basin primarily rural with limited economic opportunity, decreases in population of more than 20% are projected in the cities of Danville and Martinsville by 2040.

The following section discusses projected water use through 2040 within the Roanoke Dan basin, which is based on projections provided in the Water Supply Plans for each locality. Once again Table 54 is the basis for information in this section. Total demand within the basin is projected to increase from 46.62 MGD to 49.60 MGD, or approximately 6.39% by 2040. Groundwater demand is projected to decrease slightly from 9.01 MGD to 8.90 MGD, primarily driven by projected decreases in Small SSU demands as a result of population decline in the basin. Surface water demands are projected to increase from 37.60 MGD to 40.70 MGD or 8.24% by 2040. Projected increases in surface water demands are driven by projected growth in community water systems serving increased populations within urban areas. Additionally, large self-supplied users are expected to increase demand in surface water from 3.54 MGD to 4.04 MGD or 14% by 2040, largely driven by projected demand increases for the Danville Industrial WTP.

Demands from CWS users is projected to increase by 10.55% by 2040. Within this category, surface water use is the primary source of supply and is projected to increase by 10.57%, while groundwater use is projected to increase by 4.3%. The cities of Martinsville and Danville are the greatest drivers in expected demand increases throughout the planning period. Both users currently rely on surface water as their primary water supply source.

Demands from large Self-Supplied Users is projected to increase by 12.81% by 2040. Within this category, surface water use is projected to increase by 14.12%, while groundwater use is projected to increase by 1.59%. Increases in demands are primarily driven by projected increases in withdrawal from the Danville Industrial WTP. The facility is projecting a 31.1%, or 0.48 MGD increase by 2040. Groundwater demand increases in this category are minimal.

Demands from small Self-Supplied Users is projected to decrease by 1.63% by 2040. As noted above, water demand from Small SSU in the basin is driven by withdrawals from residential homeowner wells. With widespread decreases in population expected in the basin, and growth focused within population centers which rely primarily on surface water, groundwater demands from individual homeowners is projected to

decline. Small SSUs will continue to be the largest use category of groundwater through the planning period.

Demands from Agriculture Users represent the second largest demand within the basin and are projected to increase in demand 1.26% by 2040. Surface water demand is the largest driver for the expected increases and is projected to increase by 1.28% by 2040. While groundwater demands are expected to largely remain constant through 2040.

A.9.5 Cumulative Impact Analysis

The following section provides a brief summary of the Cumulative Impact Analysis (CIA) modeling results in the Roanoke Dan Minor Basin. Discussion of these results will primarily be found in the Trends and Goals section of this appendix. However a brief overview of the VAHydro model and the scenarios and metrics is provided below.

The VAHydro surface water model simulates streamflow using inputs such as precipitation, climate, land use, and topography, combined with data on all known withdrawals and discharges, and operational rules of major hydrologic features such as reservoirs. Each minor basin is broken into smaller hydrologic subsections, or river segments. The model simulates the water balance on a daily basis for each individual river segment, with each downstream segment being affected by the cumulative impact of streamflow changes occurring in upstream segments. The following figures help analyze this cumulative impact within the Roanoke Dan Minor Basin (model results summarized by river segment). Note that this section is not intended to document in detail the methods and assumptions for the VAHydro model or for the scenarios and metrics discussed. More documentation of the model and assumptions can be found in Chapter 4.

The VAHydro surface water model was used to simulate streamflow under a variety of scenarios. Demand scenarios examine how streamflow is impacted under 2030 or 2040 demands as compared to current (2020) demands. Demands were calculated based on current and future demand information submitted through local and regional water supply plans. Climate change scenarios examine how streamflow is impacted when 2040 demands are simulated in conjunction with a range of precipitation and temperature conditions that may occur in the future due to changing climate (Dry, Median, Wet scenarios). Finally, the exempt user scenario examines impacts from users excluded, or exempt, from VWP permit requirements per Va. Code § 62.1-44.15:22 B. Exempt users were simulated at the maximum possible demand identified through a review of demand justification values commonly asserted by exempt users, including but not limited to VDH pump capacity, maximum pre-1989 withdrawal, and maximum intake capacity. In order to effectively manage surface water resources and address the uncertainty related to these demands, DEQ determined the most conservative, or maximum possible, demand should be evaluated in this scenario. However, DEQ does not agree that the maximum values used in this scenario represent an allocation for, or the expectation of, a future withdrawal of that volume; nor does DEQ concede that any particular exempt user is necessarily entitled to withdraw any particular maximum value used in this scenario. The methods and assumptions for each of these modeling scenarios are discussed in more detail in Chapter 4.

For each scenario described above, different metrics can be used to evaluate the simulated streamflow. A metric is a method for measuring or evaluating a given set of data; different metrics can be evaluated to answer different questions. Within this section the following metrics will be discussed: the lowest 30 day flow (L30), the lowest 90 day flow (L90), 7Q10, and overall change in flow. The L30 describes the lowest consecutive 30 day average daily streamflow over the simulation period. This metric is a representation of a short-term, or acute drought, and is a good metric for evaluating impacts to direct withdrawals without storage. Similarly the lowest 90 day flow represents the lowest consecutive 90 day average daily streamflow over the simulation period. This would represent a prolonged drought and is often used to evaluate impacts to reservoirs. The 7Q10 is the lowest 7-day average flow that occurs (on average) once every 10 years. 7Q10 is generally used in the evaluations of in-stream beneficial uses such as waste assimilative capacity. Overall change in flow describes the net loss of water from the riverine system as a result of off-stream use not otherwise returned through point source discharges, or losses due to evapotranspiration. This metric is useful for evaluating impacts to aquatic life and is discussed in more detail in Chapter 4.

Demand Scenarios: 2020 demand or current demand, 2030 demand, and 2040 demand scenarios were simulated. The following series of figures compares the 2030 and 2040 demand scenarios to the current demand scenario. The change in flow depicted on each map is the change expected when comparing two scenarios - in this case future demands compared to current demands. Each page includes two figures comparing either the 2030 or 2040 demand scenario to current demand using the L30, L90, and 7Q10 metrics. This allows for comparisons of simulated impacts between the 2030 and 2040 demand scenarios. The scenarios and metrics are identified in the paragraph below and in the figure captions.

Demand Scenarios: Demand scenarios that were simulated include a current demand (2020), 2030 demand, and 2040 demand. The following series of figures compares either the 2030 demand or 2040 demand scenario to the 2020, or current demand scenarios. In other words, the change in flow depicted on each map is the change expected when comparing across scenarios. Each page includes two figures comparing either the 2030 or 2040 demand scenario to current demand using either the l30, l90, or 7Q10 as the metric. This allows for comparisons of simulated impacts between the 2030 and 2040 demand scenarios.

Figures 204 and 205 compare the lowest 30 day low flow simulated with the current demand scenario (2020) with the lowest 30 day flow simulated in the 2030 and 2040 demand scenarios respectively. Figures 206 and 207 compare the lowest 90 day low flow simulated with the current demand scenario (2020) with the lowest 90 day flow simulated in the 2030 and 2040 demand scenarios respectively. Figures 208 and 209 compare the 7Q10 simulated with the current demand scenario (2020) with the 7Q10 simulated in the 2030 and 2040 demand scenarios respectively.

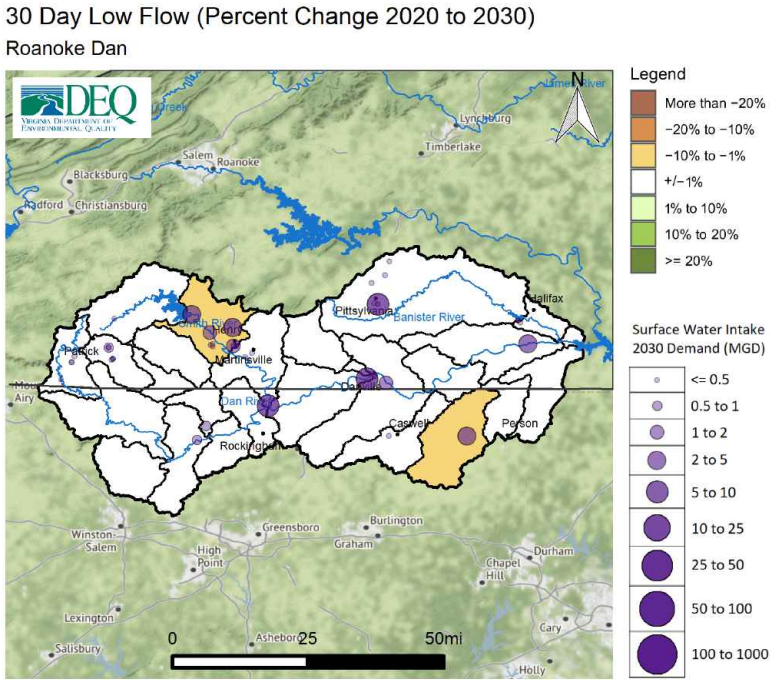

Figure 204: Change in 30 Day Low Flow between 2020 and 2030 Demand Scenarios within the Roanoke Dan Basin

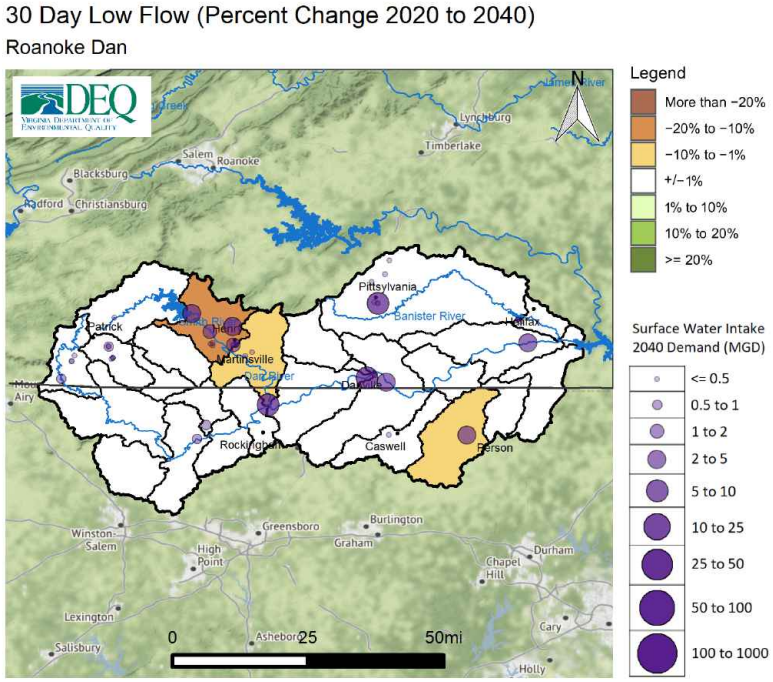

Figure 205: Change in 30 Day Low Flow between 2020 and 2040 Demand Scenarios within the Roanoke Dan Basin

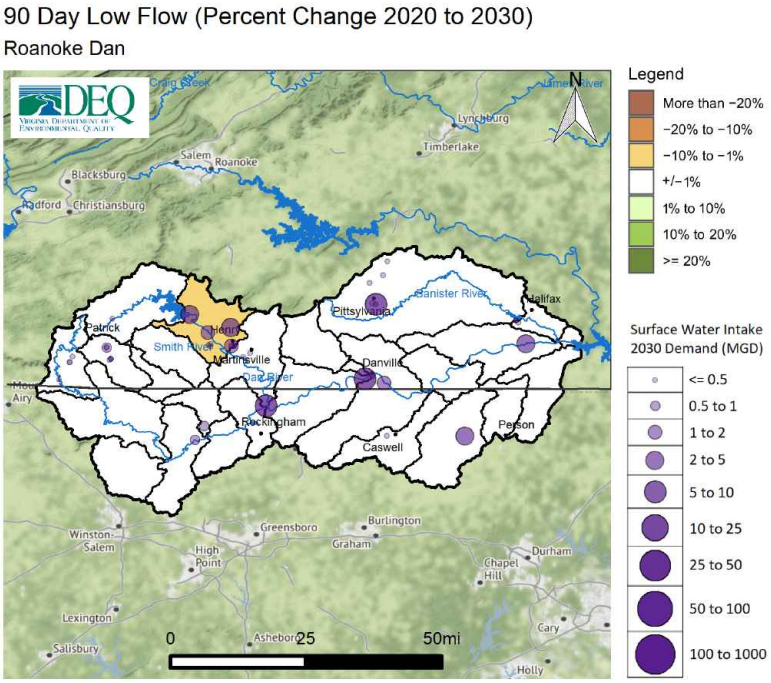

Figure 206: Change in 90 Day Low Flow between 2020 and 2030 Demand Scenarios within the Roanoke Dan Basin

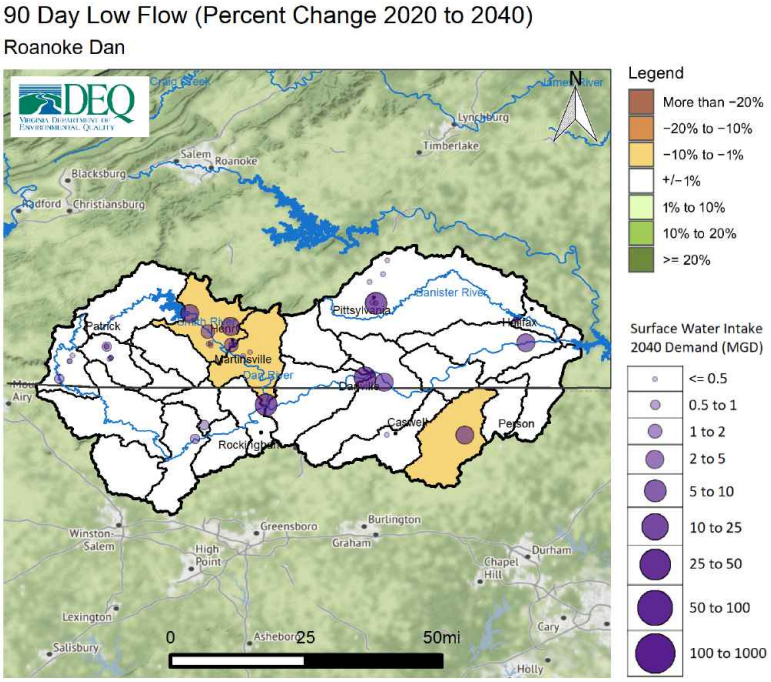

Figure 207: Change in 90 Day Low Flow between 2020 and 2040 Demand Scenarios within the Roanoke Dan Basin

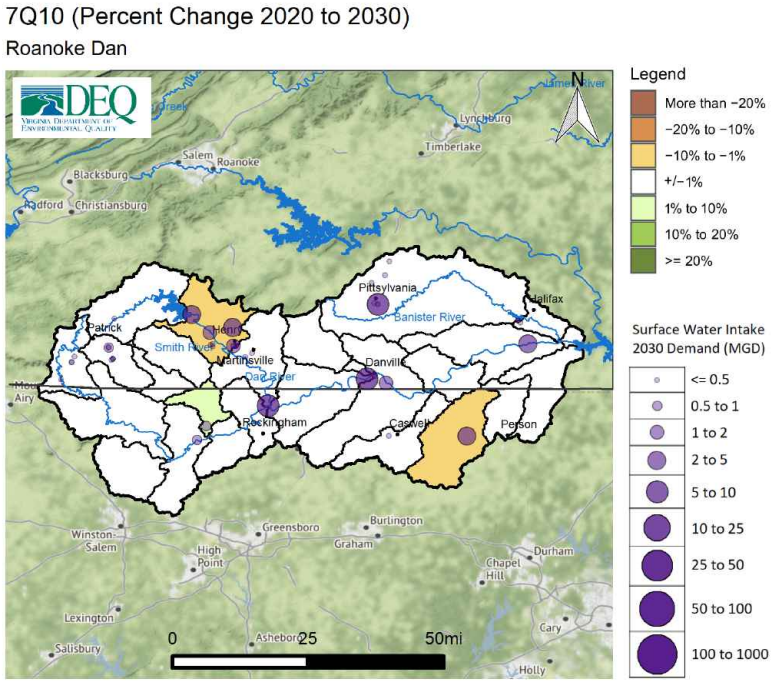

Figure 208: Change in 7Q10 between 2020 and 2030 Demand Scenarios within the Roanoke Dan Basin

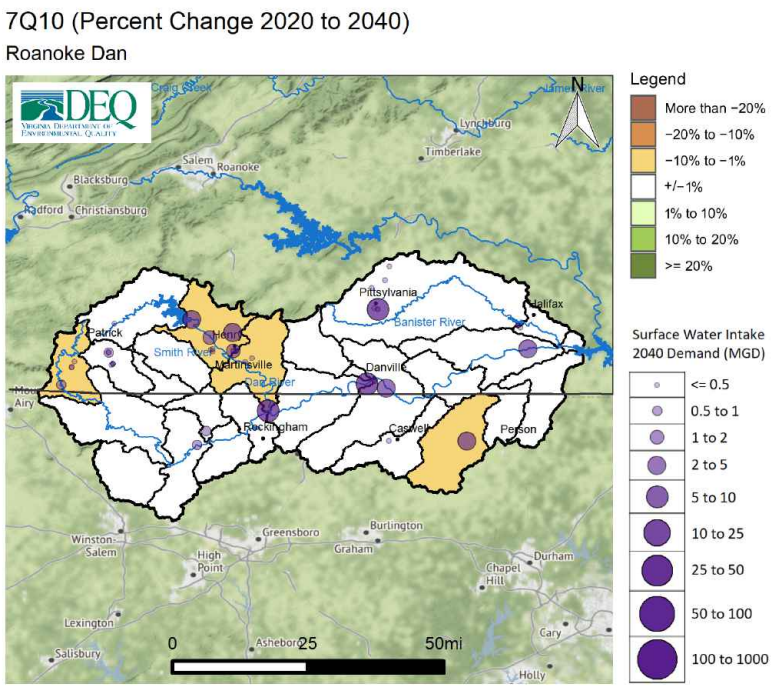

Figure 209: Change in 7Q10 between 2020 and 2040 Demand Scenarios within the Roanoke Dan Basin

The figures above show a comparison between two scenarios. An additional way to evaluate impacts to

streamflow is to examine the total reduction in streamflow resulting from all withdrawals within a river segment, as well as losses due to evapotranspiration, while taking into consideration any discharges back to the source. To use a common industry term, the overall change in flow metric evaluates "consumptive use", or the amount of water removed from the river that is not returned through discharges. This can help describe potential impacts to downstream withdrawals, while also providing a basis for evaluating impacts to aquatic life. In general, total reductions in streamflow can result in a reduction in aquatic biodiversity [93]. The relationship between streamflow and aquatic biodiversity is discussed in more detail in Chapter 4. Figure 236 shows the overall change in streamflow for the 2030 Demand Scenario, while figure 237 shows the overall change in streamflow for the 2040 Demand Scenario.

[93] Rapp, J.L., R. Burgholzer, J. Kleiner, D. Scott, and E. Passero. 2020. "Application of a New Species-Richness Based Flow EcologyFramework for Assessing Flow Reduction Effects on Aquatic Communities." Journal of the American Water Resources Association 1–14.https://doi.org/10.1111/1752-1688.12877.

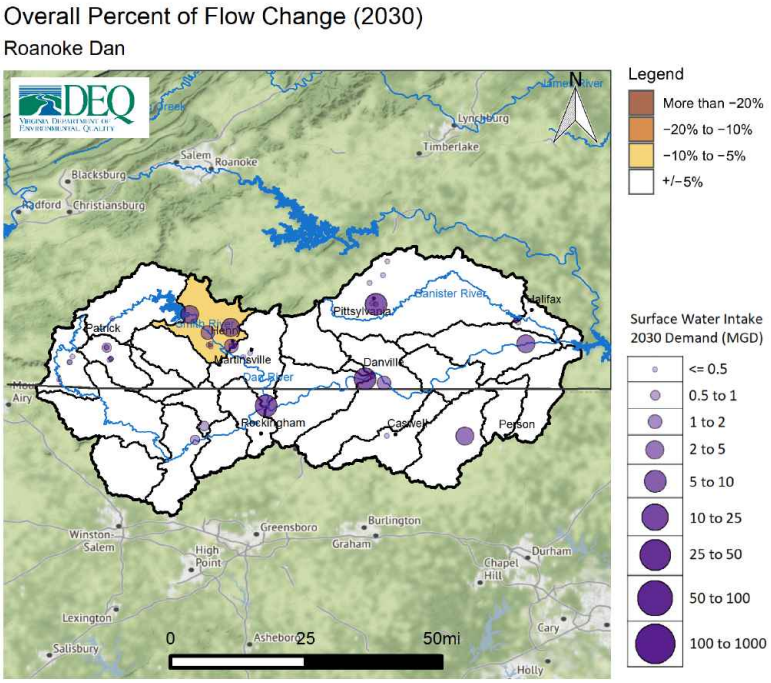

Figure 210: Overall Change in Flow for 2030 Demand Scenario within the Roanoke Dan Basin

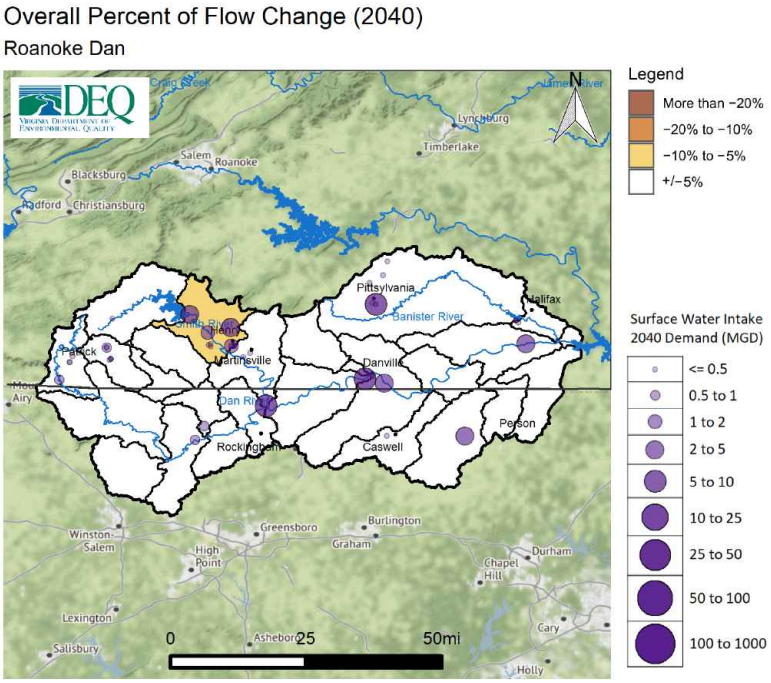

Figure 211: Overall Change in Flow for 2040 Demand Scenario within the Roanoke Dan Basin

Climate Scenarios: Three scenarios that simulate impacts to streamflow in response to changes in temperature and climate were completed for areas in the state where climate data was available, which includes the portions of the Commonwealth located in the Chesapeake Bay watershed. Details on the methods and assumptions employed for these scenarios can be found in Chapter 4. In short, the three scenarios can be described as dry, median, and wet scenarios. Virginia is expected to experience a range of precipitation and temperature changes that may vary spatially and from year to year. The potential for both more severe and prolonged droughts as well as for higher intensity and more frequent rain events must be considered. These three scenarios are not intended as predictions of future climate conditions, but as representations of several possibilities that climate change models indicate could occur. Should they occur, these results provide an evaluation of how streamflows may be impacted. Their purpose is to build upon existing climate modeling to provide a foundation for state and local government, as well as other stakeholders, to better evaluate what practical water resource challenges may be associated with the range of climate conditions Virginia could experience. Note that this Basin is located outside of the Chesapeake Bay watershed and therefore climate scenarios were not completed at this time. DEQ is working to expand these climate scenarios to cover the entire state for future planning efforts.

Exempt User Scenario: The exempt user scenario simulates the maximum possible exempt demand for users excluded from Virginia Water Protection permitting requirements per Va. Code § 62.1-44.15:22 B., in combination with the permitted withdrawal limits for those users that are permitted. A more detailed discussion of the data and assumptions used in this scenario can be found in Appendix B. Note that this scenario uses current climate conditions. Figure 212 depicts the percent change in the Lowest 30 Day Flow between the exempt user scenario and current (2020) demand. Figure 213 depicts the percent change in the Lowest 90 Day Flow between the exempt user scenario and current (2020) demand. Figure 214 depicts the percent change in the 7Q10 between the exempt user scenario and current (2020) demand.

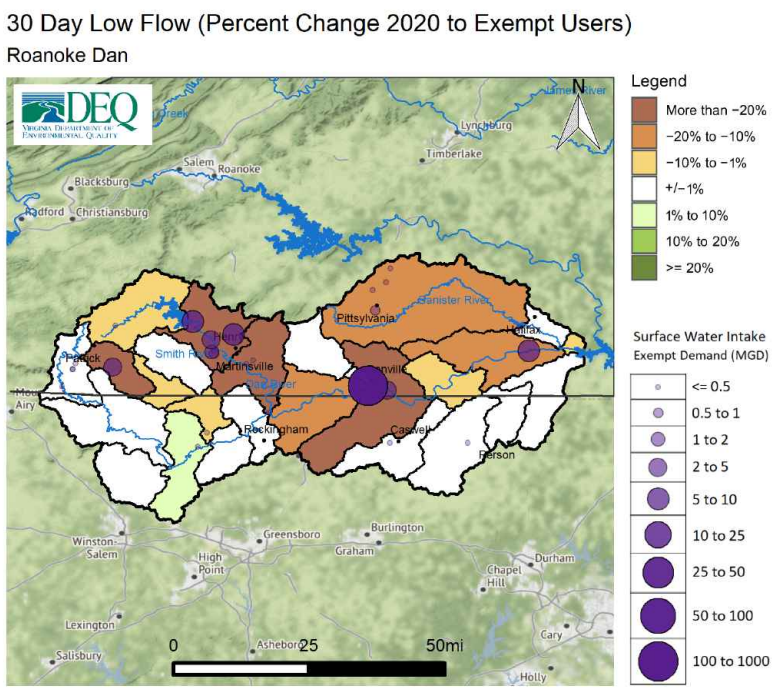

Figure 212: Change in 30 Day Low Flow between current demand scenario and exempt user scenario within the Roanoke Dan Basin

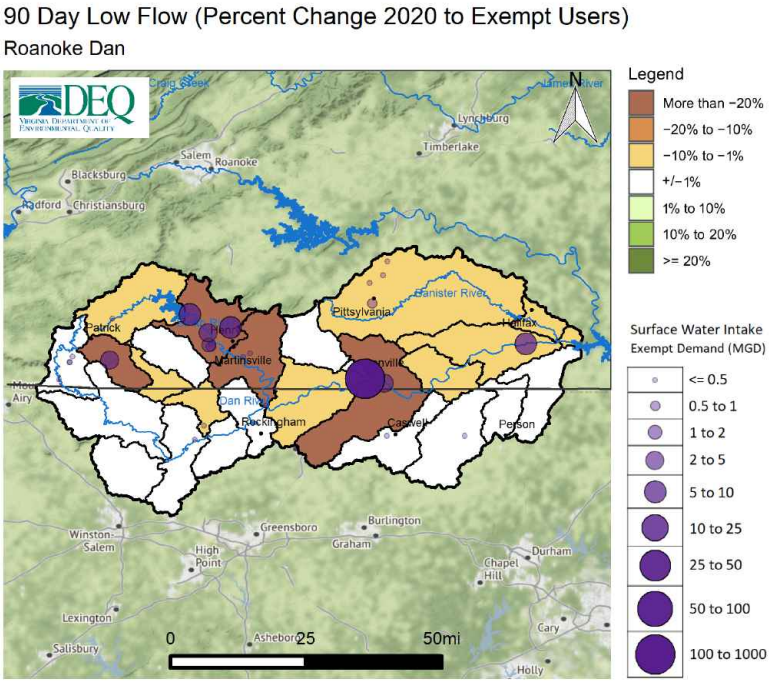

Figure 213: Change in 90 Day Low Flow between current demand scenario and exempt user scenario within the Roanoke Dan Basin

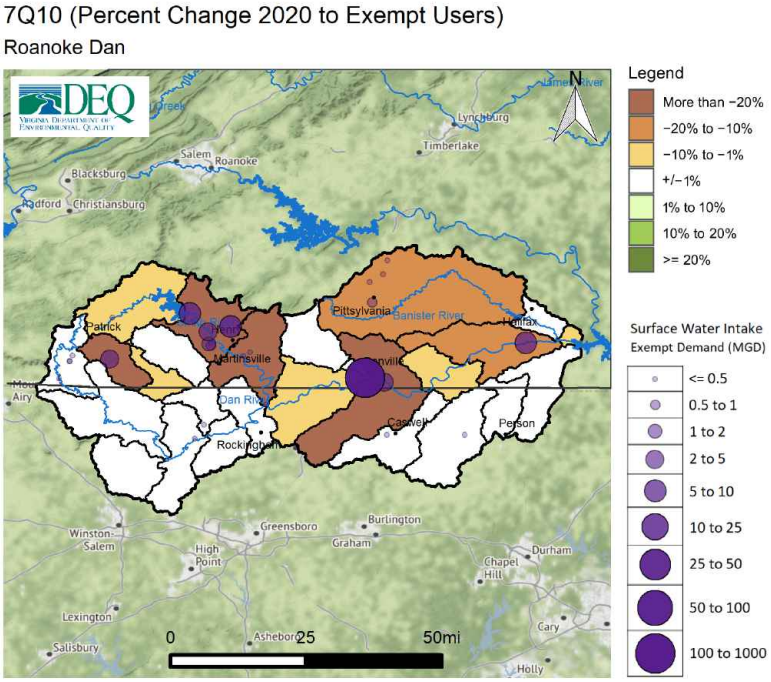

Figure 214: Change in 7Q10 between current demand scenario and exempt user scenario within the Roanoke Dan Basin

Potential Unmet Demand: Potential unmet demand was evaluated for all facilities within the basin for each scenario. Potential unmet demand is the portion of surface water demand for a specific facility that is limited by available streamflow as simulated in a given model scenario, including any known operational limits such as flow-by requirements. This unmet demand, if realized, could be managed through water conservation, through alternative sources, operational changes, or from available storage. Absent of these or other options, this portion of demand could remain unmet. As with all scenarios, demand requirements were determined using demand projections provided in the water supply plans. In the case of the exempt user scenario, the highest possible withdrawal amount was used for users exempt from VWP permitting requirements.

This metric is useful for evaluating where the results seen in the above figures may result in challenges in meeting future demands under a variety of conditions including increasing demands in the basin, changing climate, or withdrawals from users exempt from permitting requirements. Table 56 provides for each facility the highest average daily potential unmet demand over a 30 day period over the course of the simulation for the following scenarios: 2020 demand, 2030 demand, 2040 demand, and exempt user. Only facilities showing potential unmet demand in at least one scenario appear on this table. Additional information on the potential unmet demand metric can be found in Appendix B.

Table 56: Change in Highest 30 Day Potential Unmet Demand (MGD) in Roanoke Dan Minor Basin

Facility	**2020 Demand**	**2030 Demand**	**2040 Demand**	**Dry Climate**	**Exempt User**
Danville Main WTP	0.00	0.00	0.00	-	58.09
Martinsville WTP	0.19	0.00	0.65	-	16.11
Martinsville WTP	0.00	0.00	0.00	-	3.45
Upper Smith River WTP	0.65	0.00	0.73	-	3.37
Martinsville Plant	0.02	0.00	0.02	-	1.38
Fieldale Plant	0.05	0.00	0.05	-	1.28
Stanleytown Plant	0.00	0.00	0.00	-	1.27
F.c. Dumaine Plant WTP	0.00	0.00	0.00	-	0.95
Eden	0.00	0.00	0.00	-	0.29
Stuart WTP	0.00	0.00	0.00	-	0.25
Bassett Division	0.00	0.00	0.00	-	0.24
Bassett Plant	0.00	0.00	0.00	-	0.21
Martinsville WTP	0.00	0.00	0.00	-	0.12
Gretna WTP	0.00	0.00	0.00	-	0.01
Chatham WTP	0.00	0.00	0.00	-	0.01
Halifax (Town) WTP	0.00	0.00	0.00	-	0.01
Roxboro	0.01	0.01	0.01	-	0.01
Yanceyville	0.01	0.01	0.01	-	0.01

* Climate scenarios were not completed in areas located outside of the Chesapeake Bay Basin

Note: Potential unmet demand is the portion of surface water demand for a specific facility that is limited by available streamflow as simulated in a given model scenario, including any known operational limits such as flow-by requirements. This unmet demand, if realized, could be managed through water conservation, alternative sources, operational changes, or from available storage.

A.9.6 Trends and Goals

The Code of Virginia mandates that the State Water Control Board should take into consideration the principle that "adequate and safe supplies shall be preserved and protected for human consumption, while conserving maximum supplies for other beneficial uses".[94] This principle is the key driver of the challenges in water resource management, which is that all beneficial uses must be adequately considered when evaluating impacts to surface water resources. The State Water Control Board is tasked with ensuring that water supply quantity needs are met at all times while also protecting Virginia's natural resources, and furthermore, ensuring equitable allocation during a time of shortage.[95] While evaluating and planning for the long-term sustainability of water supply for Virginia is the primary goal for the State Plan, evaluating and limiting impacts to in-stream beneficial uses such as aquatic habitat life is also part of DEQ's responsibility.

The primary purpose of this section is to identify where the most significant challenges to long-term sustainability of water supply and other beneficial uses are indicated based on the CIA and information collated from local water supply plans within this basin. Goals for future planning and areas for additional data collection or analysis are also suggested where appropriate.

The CIAs were completed using the best available data and methods known to DEQ. This discussion focuses on the evaluation of trends - in other words the prevailing tendency or inclination. This means evaluating whether streamflow is simulated to increase or decrease in a given scenario, and by how much. A relative trend indicating reductions of greater than or equal to 10% in streamflow, whether driven by demand increases, changing climate conditions, or exempt user demands was considered a threshold for potential impacts to beneficial uses. The following summarize the key trends or goals for this basin:

- **Demand Scenarios:** Total demands in the Roanoke Dan Minor Basin are projected to increase by approximately 6.39%, the majority of the increase expected from surface water sources. Overall, increases in demand in the basin are limited. Under the demand scenario only one river segment was simulated with a 10% or greater reduction when comparing the 2020 and 2040 demand scenarios across all metrics. A 10% reduction in L30 (short-term drought) was simulated in the Smith River below Philpott when comparing the 2020 and 2040 demand scenarios. Potential unmet demands were simulated during the 2040 demand scenario for the the City of Martinsville and the Henry County Public Service Authority's Smith River Intake. Significant increases in demand from the City of Martinsville and withdrawals from the Smith River below Philpott Dam from the Henry County PSA drive the potential for unmet demands in the river segment. Overall reductions below Philpott Dam in the Smith River is driven by Henry County PSA withdrawals from the Smith River below Philpott Dam and significant demand increases from the City of Martinsville WTP. Unmet demands during the 2040 scenario for both facilities are less than 1 MGD. Simulated reductions of overall flow suggest potential for impacts to aquatic life and species biodiversity in these segments.

- **Climate Scenarios:** As climate change data was not available in this basin, climate change scenarios were not completed for this basin. The overall trend in climate change simulations statewide suggests the potential for higher average temperatures and higher average precipitation totals. However, the simulations also suggest the potential for more significant droughts than have been historically experienced in Virginia. Simulations completed elsewhere in the Commonwealth show short-term and long-term droughts with 20-50% reductions in streamflow compared to previous droughts. The potential for more severe droughts must be considered by localities and users when evaluating existing sources and alternatives, as well as for broader planning and resource management efforts by all stakeholders whether state or local.

- **Exempt User Scenario:** The exempt user scenario, which models the cumulative maximum possible exempt demands from all users exempt from VWP permitting requirements, shows reductions

[94] § 62.1-44.36 of the Code of Virginia
[95] 9VAC25-390-20.1

in streamflow of more than 10% during short term (L30) and long term droughts (L90) as well as in the 7q10, for numerous river segments in the basin compared to current demands. Reductions in L30 from the maximum possible exempt demands are as high as 73%, with the highest reductions in L30 occurring in the Smith River below Philpott Dam, Leatherwood Creek, and the Dan River near Danville. Reductions in these segments are largely driven by the maximum possible exempt demands from Martinsville's Beaver Creek Reservoir, and Danville's Dan River intake. Reductions in L90 or long term drought from exempt demands are as high as 68% compared to the 2020 demand scenario with the most significant reductions occurring within the same river segments noted above, with addition of the South Mayo River due to the maximum possible exempt demand from the Stuart WTP South Fork Intake. Potential unmet demands were simulated during the exempt user demand scenario for major public water suppliers and industrial users in the basin including the City of Danville, City of Martinsville, Henry County PSA, the Town of Stuart, and others. These results indicate that the cumulative maximum possible exempt demands in the basin exceed the water budget in many river segments. Preserving water supply and other beneficial uses may require managing these demands with respect to their cumulative impacts and in the context of the available resources in the basin.

A.10 Roanoke River Minor Basin

A.10.1 Watershed Overview

The Roanoke Minor Basin is located in the south central portion of Virginia. The basin drains the eastern side of the Blue Ridge Mountains, flowing southeast until eventually reaching the North Carolina border and the Albemarle Sound. Land use and cover in the basin is largely comprised of forested mountains in the headwaters, and increasing agricultural use moving into the Piedmont. Development and impervious land cover are primarily concentrated within several urban areas.

The total spatial area of the basin is approximately 8269 sq. miles. Localities that are either wholly or partially within this basin are listed in Table 57. The major population centers are primarily located in the headwaters of the basin, with the Cities of Salem and Roanoke being the most significant.

A.10.2 Existing Water Sources

Major surface water sources within the basin include the Roanoke River, Carvins Cove, Smith Mountain Lake, Keysville Reservoir, Kerr Reservoir, Lake Gaston, Crystal Spring, and the Big Otter River. Groundwater within the basin is primarily withdrawn from bedrock or fractured rock aquifers. The basin relies heavily on surface water sources for water supply, with surface water making up several times the groundwater demand.

Withdrawals within the basin are used for public water supply, agriculture, irrigation, commercial, and industrial/manufacturing, power generation, commercial, and mining operations.

The location of wells and surface water intakes identified to DEQ within the basin are shown in Figure 215. This figure does not include private or domestic wells. The map also shows locations of any Instream Flow Incremental Method (IFIM) studies completed in the basin. The greatest density of surface and groundwater withdrawal locations are concentrated within the population centers of the City of Salem and Roanoke City. Surface and groundwater withdrawals are also clustered around the cities of Bedford and Lynchburg, the towns Keysville and Rocky Mount, and smaller towns throughout the basin. Surface and groundwater demands associated with agricultural users are scattered throughout the basin.

Table 57: Population Trend by Locality in Roanoke Basin

Localities	20 Year % Change
Appomattox	9.61
Bedford County	12.05
Botetourt	5.22
Brunswick	-16.56
Campbell	4.62
Charlotte	-7.85
Craig	-3.72
Floyd	8.31
Franklin County	13.14
Halifax	-12.25
Henry	-17.48
Mecklenburg	-8.67
Montgomery	13.10
Pittsylvania	-3.96
Prince Edward	12.54
Roanoke County	5.24
Bedford City	NA
Roanoke City	1.68
Salem	0.19

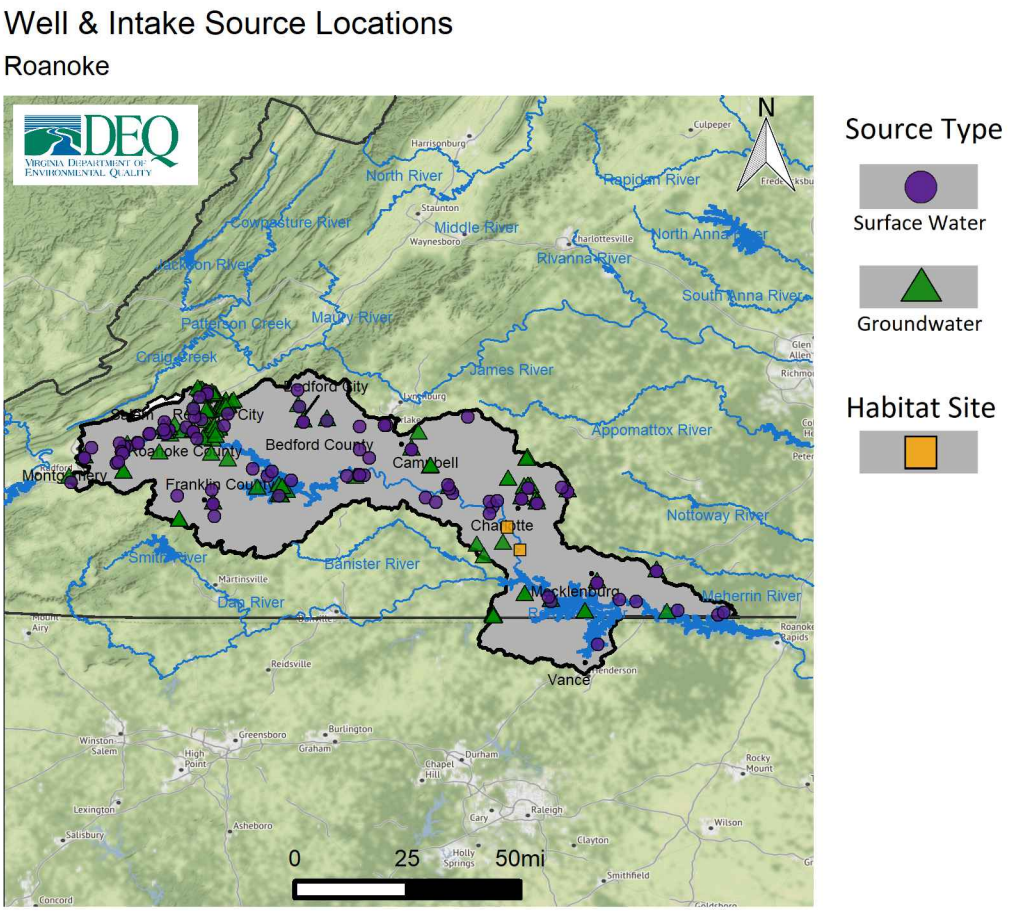

Figure 215: Spatial distribution of groundwater wells and intakes in the Roanoke Minor Basin

A.10.3 Existing Water Use

The following section discusses existing (current) water use within the basin, which is based on existing demand information submitted to DEQ in the water supply plans. Table 58 provides a summary of all demands within the basin including demand associated with power generation. Note that withdrawals related to power generally dwarf other demand categories and can therefore make evaluating trends for other categories more challenging. Most power generation withdrawals are also largely non-consumptive; water is withdrawn for cooling purposes and then discharged back into the source stream with minimal loss. The Roanoke Basin currently has four active power generation facilities including the Altavista Power Station, Clover Power Plant, Mecklenburg Power Station, and the Pittsylvania Power Station. The table also includes the number of sources, groundwater or surface water sources within each category.

Table 58: Summary of Roanoke Minor Basin Water Demand by Source Type and System Type (including Power Generation)

System Type	Source Count	2020 Demand (MGD)	2030 Demand (MGD)	2040 Demand (MGD)	20 Year Percent Change
Surface Water					
Agriculture	30	6.44	6.64	6.83	6.20
CWS	21	76.29	90.38	104.47	36.95
Large SSU	32	16.44	16.12	15.81	-3.88
Small SSU	N/A	0.00	0.00	0.00	0.00
Total SW	**83**	**99.17**	**113.14**	**127.11**	**28.17**
Groundwater					
Agriculture	7	1.67	1.82	1.98	18.20
CWS	108	4.99	6.04	7.09	41.88
Large SSU	22	0.26	0.32	0.38	47.19
Small SSU	N/A	12.14	13.49	14.84	22.26
Total GW	**137**	**19.06**	**21.67**	**24.29**	**27.44**
Total (SW + GW)					
Agriculture	37	8.11	8.46	8.81	8.67
CWS	129	81.28	96.42	111.56	37.25
Large SSU	54	16.70	16.45	16.19	-3.08
Small SSU	N/A	12.14	13.49	14.84	22.26
Minor Basin Total	**220**	**118.23**	**134.82**	**151.40**	**28.06**

* Small SSU demands are county-wide estimates of private well usage below 300,000 gallons a month. The number of private wells is not known.

The total existing demand from all surface and groundwater sources including power generation is approximately 118.23 MGD, with groundwater supplying approximately 19.06 MGD or 16.1% of total water demands. Surface water demand within the basin totals approximately 99.17 MGD, or 83.9% of current demands. As with most watersheds in Virginia, surface water sources account for the majority of current and future water demands, in the Roanoke Minor Basin, withdrawals for Community Water System (CWS) facilities are the primary driver of water demands in the basin.

The five largest withdrawals for each source type including power generation are provided in table 59. The largest groundwater demands include public water supply within the cities of Salem and Roanoke, with over 19% of current groundwater demand coming from those localities. The largest surface water demands support both public water supply and power generation facilities within and outside of the basin. Lake Gaston is currently a major water supply source that provides water to the City of Virginia Beach via the longest water transfer in Virginia. The second largest surface water demand supports the City of Roanoke and the surrounding service area. The Clover Power Plant is also a significant source of surface water demand in the basin as the third largest user in the watershed; however the water is primarily used for cooling and is returned to the Roanoke River.

Table 59: Top 5 Users in 2040 by Source Type in the Roanoke Minor Basin (including Power Generation)

Facility Name	System Type	Locality	2020 Demand (MGD)	2030 Demand (MGD)	2040 Demand (MGD)	20 Year Percent Change	% of Total Surface Water
Surface Water							
Virginia Beach Service Area	CWS	Virginia Beach	28.84	34.29	39.75	37.83	31.27
Roanoke (City) Service Area	CWS	Roanoke City	18.42	22.39	26.37	43.16	20.75
Clover Power Plant	Large SSU	Halifax	11.53	11.53	11.53	0.00	9.07
Spring Hollow WTP	CWS	Roanoke County	6.08	7.4	8.71	43.26	6.85
Kerr Lake Regional Water	CWS	Vance	6.42	7.14	7.86	22.43	6.18
Total SW			71.29	82.75	94.22	32.16	74.12
Groundwater							**% of Total Groundwater**
Salem WTP	CWS	Salem	1.13	1.46	1.79	58.41	7.37
Roanoke (City) Service Area	CWS	Roanoke City	1.25	1.52	1.78	42.4	7.33
Vinton Service Area	CWS	Roanoke County	1.26	1.44	1.62	28.57	6.67
Charlotte Ct Hse Service Area	CWS	Charlotte	0.07	0.14	0.21	200	0.86
Troutville Service Area	CWS	Botetourt	0.15	0.17	0.19	26.67	0.78
Total GW			3.86	4.73	5.59	44.82	23.01

Table 58 also provides the proportion of each use category that is supplied by either surface water or groundwater. Use categories include Community Water System (CWS), Large Self-Supplied User (Large SSU), Small Self-Supplied User (Small SSU), and Agricultural Self-Supplied User (AG). These categories are defined below. Surface water demand is primarily comprised of CWS (76.29 MGD) and Large SSUs (16.44 MGD) (including power generation). Groundwater demand is primarily comprised of Small SSUs (12.14 MGD) and CWS (4.99 MGD) demands. Consistent with much of the state, surface water is the primary source for CWS, or major municipal systems, while groundwater supplies the majority of domestic or residential use.

The CWS category includes any public and private waterworks that serve at least 15 service connections used by year-round residents or regularly serve at least 25 year-round residents, and are regulated under the Virginia Department of Health's Waterworks Regulation (12VAC5-590). In the Roanoke Minor Basin, approximately 4.99 MGD of groundwater demand and 76.29 MGD of surface water demand is currently associated with CWS facilities. Significant groundwater users within this category include the cities of Salem and Roanoke, the towns of Vinton and Troutville. Significant surface water users from this category include the Lake Gaston water transfer to the City of Virginia Beach, Western Virginia Water Authority's withdrawals from Carvins Cove, Crystal Spring, and the Spring Hollow Reservoir, and the Campbell County Big Otter River intake and several other intakes supporting the towns of Altavista, Brookneal, Clarksville, and Keysville. Nearly every CWS in the basin withdraws or purchases surface water in some capacity to meet public water supply demands.

Large SSUs include any non-CWS or AG that withdraw more than 300,000 gallons per month from a well or surface water intake. In the Roanoke Minor Basin, approximately 0.26 MGD of groundwater demand and 16.44 MGD of surface water demand is from Large SSUs. Significant groundwater users within this category

include the Rustburg Correctional Facility, Hidden Valley Country Club, Blue Hills Golf Course, and the Boxely Blue Ridge Mine. Significant surface water users from the category include the Clover, Mecklenburg, Altavista, and Pittsylvania power stations. Significant surface water withdrawals excluding power generation include the Boxely Mining facilities, and numerous golf courses including the West Lake and Water Front Country Clubs.

Small SSUs include any users who withdraw less than 300,000 gallons per month from wells. Small SSUs generally consist of residential or domestic use for those who live outside service areas and provide their own water via a private well. In the Roanoke Minor Basin, approximately 12.14 MGD of groundwater demand is from Small SSUs. Localities within the basin with the greatest estimated contribution from Small SSUs include the counties of Bedford, Franklin, and Campbell.

The AG category includes crop farms, livestock operations, aquaculture and other agricultural facilities. In the Roanoke Minor Basin, approximately 1.67 MGD of groundwater demand and 6.44 MGD of surface water demand is from AG. Significant groundwater users within this category includes the New Leaf Farm and Yagle Nursery. Primarily groundwater demands in the category are reported as countywide estimates of groundwater use for all AG. Charlotte, Franklin, and Bedford counties have the largest countywide groundwater demands in the basin. Significant surface water uses in the category include New Leaf Farm, Lavery's Sod Farm, and Bass Farm. Surface water demands in the basin are primarily reported as countywide estimates of use with Franklin, Bedford, and Charlotte counties providing the largest estimated demands for surface water AG.

A.10.4 Projected Population and Water Use

Projected Population: Trends in water use are generally driven by trends in population change or economic development. Increasing population within an area generally means increased connections for community water systems or additional demands from homeowners that construct wells. Increasing population in an area also tends to incentivize both new and expanded industrial and commercial water use. Alternatively, the addition of new economic opportunities such as a large employer may include additional water withdrawals for operational needs. Reviewing short and long term population projections can inform water supply planning efforts.

For reference, Table 57 shows the projected change in population for each locality in the Commonwealth. The Roanoke Basin is expecting moderate population growth over the course of the planning period, with the localities projected to increase the most through 2040 include Franklin (13.14%), Bedford (12.05%), Montgomery (13.10%), and Prince Edward Counties (12.54%). Increases in domestic water use (Small SSUs) as well as increasing CWS demands generally align with the expected population growth in the basin.

Projected Water Use: The following section discusses projected water use through 2040 within the Roanoke basin, based on projections provided in local and regional water supply plans. Table 58, included in the existing demand section above, is the basis for information discussed in this section.

Total demand within the basin is projected to increase from 118.23 MGD in 2020 to 151.40 MGD in 2040. Surface water demand is projected to increase by 27.94 MGD, or 28.17%, by 2040. Groundwater demand is projected to increase by 5.23 MGD, or 27.44%, by 2040. Projected increases in demand are primarily driven by expected increases in surface and groundwater withdrawals to meet CWS and Small SSU demands over the planning period.

The largest contributors to this trend in total projected demand is a 10.9 MGD increase in water demands transferred to the City of Virginia Beach. Additional contributions include increases in withdrawals from the Western Virginia Water Authority and Salem WTP to supply the greater Roanoke and City of Salem service areas, and projected increases within the greater Smith Mountain area. Increases in water demand are generally concentrated within the largest public water suppliers.

Demands from CWS users within the basin is projected to increase in demand by 37.25% by 2040. Within this category, surface water use is projected to increase by 36.95%, while groundwater use is projected to increase by 41.88%. Projected surface water demand increases are driven primarily from projected demand increases from the City of Virginia Beach, Roanoke's Western Virginia Water Authority, and the Salem WTP, and Bedford Smith Mountain Lake intakes. Expected increases in groundwater demand are also expected to primarily occur within the Salem and Roanoke service areas.

Demands from Large SSUs within the basin is projected to decrease in demand by approximately 3.08% by 2040. Within this category, surface water use is projected to decrease by 3.88%, while groundwater use is projected to increase by 47.19%. Surface water is the primary source for the category, when compared to surface water demands groundwater demands are minimal. The 47.19% projected increase for groundwater represents only a 0.12 MGD increase by volume. Declines in surface water demand for the Large SSU category are the result of the Boxely Lawyer Road mine ending withdrawals from Flat Creek.

Demands from Small SSUs within the basin is projected to increase in demand by 22.26% by 2040. Within this category, groundwater is the only known source of supply in the basin. As populations expand in the watershed increases in private well construction will continue to increase demand from groundwater. The greatest demand increases are expected to occur within Bedford, Franklin, and Campbell Counties.

Demands from Agriculture Users within the basin is projected to increase in demand by 8.67% by 2040. Within this category, surface water use is projected to increase by 6.20%, while groundwater use is projected to increase by 18.20%. Projected increases within the category are driven by increases in countywide agricultural demands from Charlotte, Bedford, and Franklin counties.

A.10.5 Cumulative Impact Analysis

The following section provides a brief summary of the Cumulative Impact Analysis (CIA) modeling results in the Roanoke River Minor Basin. Discussion of these results will primarily be found in the "Trends and Goals" section of this appendix. However a brief overview of the VAHydro model and the scenarios and metrics is provided below.

The VAHydro surface water model simulates streamflow using inputs such as precipitation, climate, land use, and topography, combined with data on all known withdrawals and discharges, and operational rules of major hydrologic features such as reservoirs. Each minor basin is broken into smaller hydrologic subsections, or river segments. The model simulates the water balance on a daily basis for each individual river segment, with each downstream segment being affected by the "cumulative impact" of streamflow changes occurring in upstream segments. The following figures help analyze this cumulative impact within the Roanoke Minor Basin (model results summarized by river segment). Note that this section is not intended to document in detail the methods and assumptions for the VAHydro model or for the scenarios and metrics discussed. Detailed documentation of the model and assumptions can be found in Chapter 4.

The VAHydro surface water model was used to simulate streamflow under a variety of scenarios. Demand scenarios examine how streamflow is impacted under 2030 or 2040 demands as compared to current (2020) demands. Demands were calculated based on current and future demand information submitted through local and regional water supply plans. Climate change scenarios examine how streamflow is impacted when 2040 demands are simulated in conjunction with a range of precipitation and temperature conditions that may occur in the future due to changing climate (Dry, Median, Wet scenarios). Finally, the exempt user scenario examines impacts from users excluded, or exempt, from VWP permit requirements per Va. Code § 62.1-44.15:22 B. Exempt users were simulated at the maximum possible demand identified through a review of demand justification values commonly asserted by exempt users, including but not limited to VDH pump capacity, maximum pre-1989 withdrawal, and maximum intake capacity. In order to effectively manage surface water resources and address the uncertainty related to these demands, DEQ determined the most conservative, or maximum possible, demand should be evaluated in this scenario. However, DEQ does not agree that the maximum values used in this scenario represent an allocation for, or the expectation of, a future withdrawal of that volume; nor does DEQ concede that any particular exempt user is necessarily

entitled to withdraw any particular maximum value used in this scenario. The methods and assumptions for each of these modeling scenarios are discussed in more detail in Chapter 4.

For each scenario described above, different metrics can be used to evaluate the simulated streamflow. A metric is a method for measuring or evaluating a given set of data; different metrics can be evaluated to answer different questions. Within this section the following metrics will be discussed: the lowest 30 day flow (L30), the lowest 90 day flow (L90), 7Q10, and overall change in flow. The L30 describes the lowest consecutive 30 day average daily streamflow over the simulation period. This metric is a representation of a short-term, or acute drought, and is a good metric for evaluating impacts to direct withdrawals without storage. Similarly the lowest 90 day flow represents the lowest consecutive 90 day average daily streamflow over the simulation period. This would represent a prolonged drought and is often used to evaluate impacts to reservoirs. The 7Q10 is the lowest 7-day average flow that occurs (on average) once every 10 years. 7Q10 is generally used in the evaluations of in-stream beneficial uses such as waste assimilative capacity. Overall change in flow describes the net loss of water from the riverine system as a result of off-stream use not otherwise returned through point source discharges, or losses due to evapotranspiration. This metric is useful for evaluating impacts to aquatic life and is discussed in more detail in Chapter 4.

Demand Scenarios: 2020 demand or current demand, 2030 demand, and 2040 demand scenarios were simulated. The following series of figures compares the 2030 and 2040 demand scenarios to the current demand scenario. The change in flow depicted on each map is the change expected when comparing two scenarios - in this case future demands compared to current demands. Each page includes two figures comparing either the 2030 or 2040 demand scenario to current demand using the L30, L90, and 7Q10 metrics. This allows for comparisons of simulated impacts between the 2030 and 2040 demand scenarios. The scenarios and metrics are identified in the paragraph below and in the figure captions.

Figures 216 and 217 compare the lowest 30 day flow simulated with the current demand scenario with the lowest 30 day flow simulated in the 2030 and 2040 demand scenarios respectively. Figures 218 and 219 compare the lowest 90 day low flow simulated with the current demand scenario with the lowest 90 day flow simulated in the 2030 and 2040 demand scenarios respectively. Figures 220 and 221 compare the 7Q10 simulated with the current demand scenario with the 7Q10 simulated in the 2030 and 2040 demand scenarios respectively.

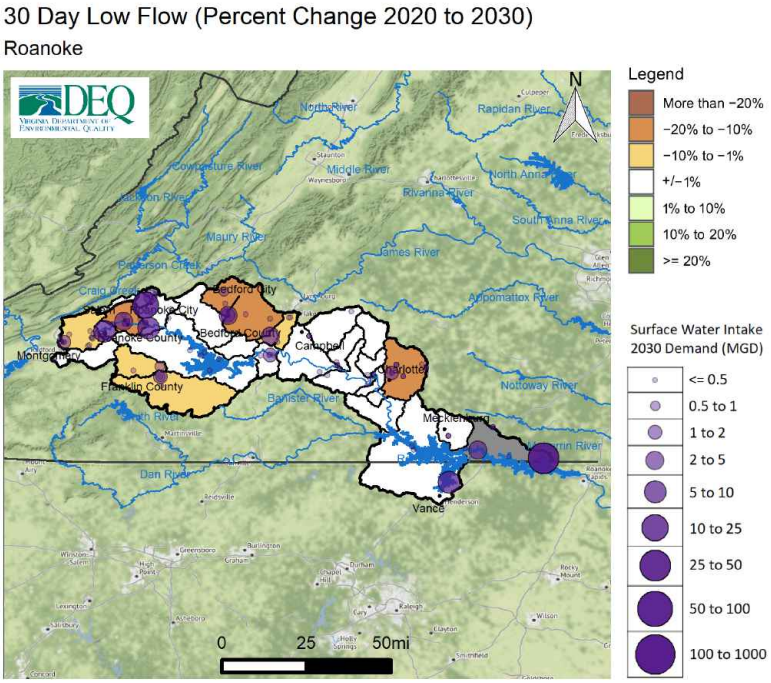

Figure 216: Change in 30 day low flow between 2020 and 2030 demand scenarios within the Roanoke Basin

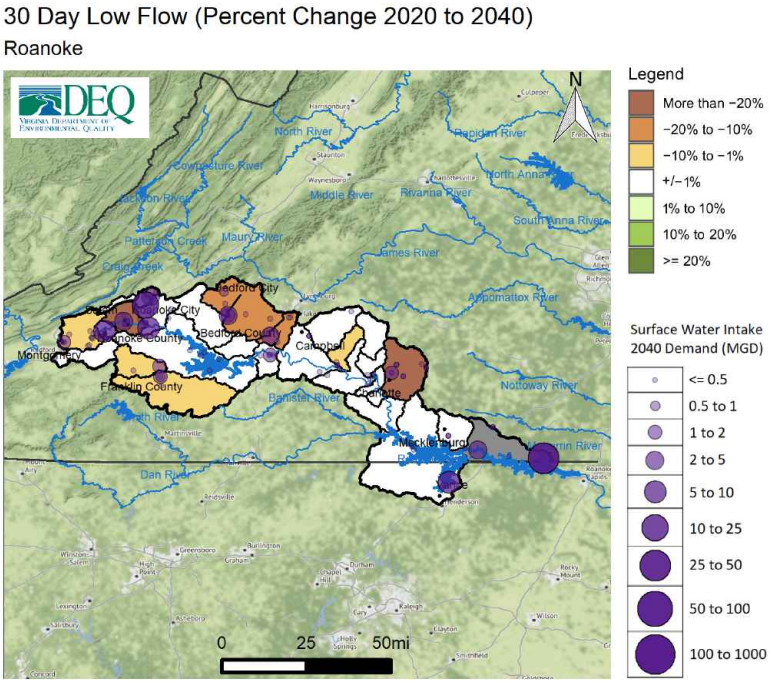

Figure 217: Change in 30 day low flow between 2020 and 2040 demand scenarios within the

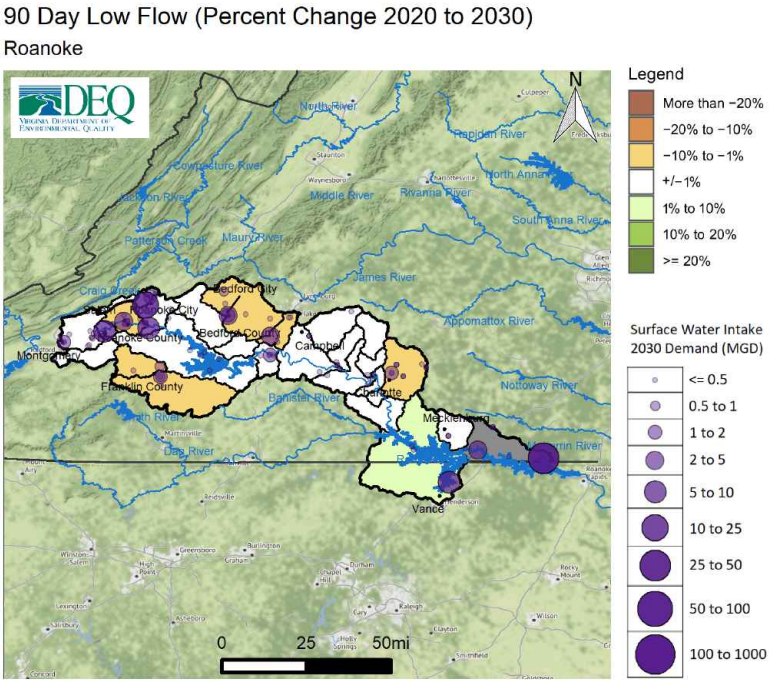

Figure 218: Change in 90 day low flow between 2020 and 2030 demand scenarios within the Roanoke Basin

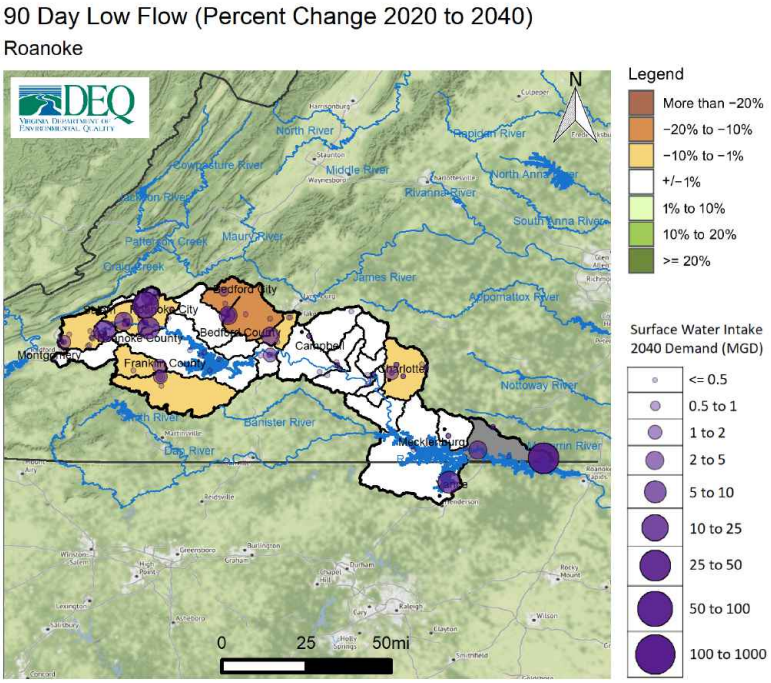

Figure 219: Change in 90 day low flow between 2020 and 2040 demand scenarios within the Roanoke Basin

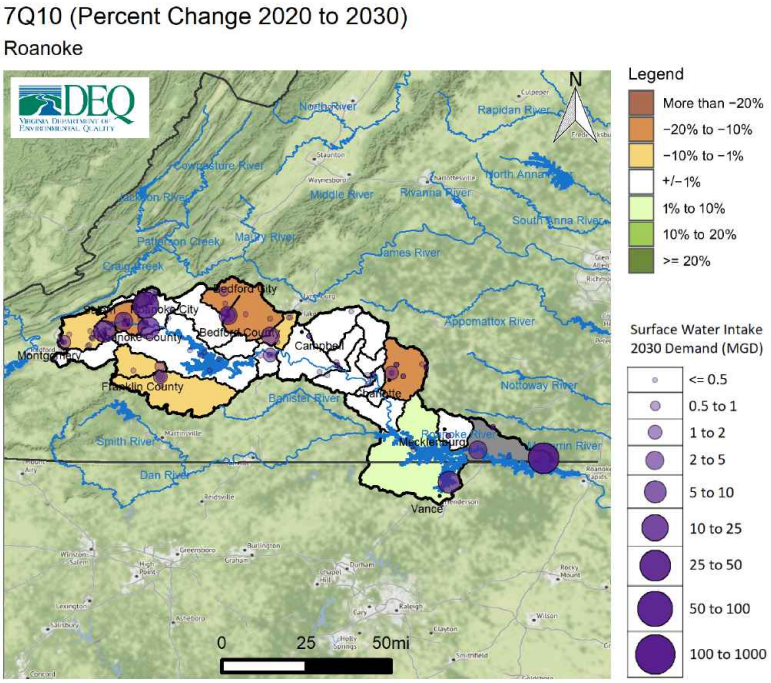

Figure 220: Change in 7Q10 between 2020 and 2030 demand scenarios within the Roanoke Basin

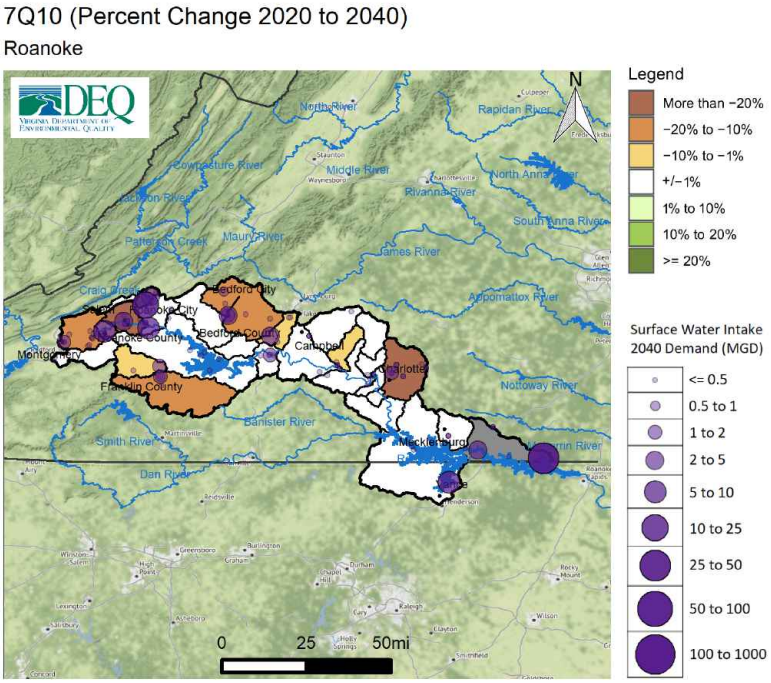

Figure 221: Change in 7Q10 between 2020 and 2040 demand scenarios within the Roanoke Basin

The figures above show a comparison between two scenarios. An additional way to evaluate impacts to streamflow is to examine the total reduction in streamflow resulting from all withdrawals within a river segment, as well as losses due to evapotranspiration, while taking into consideration any discharges back to the source. To use a common industry term, the overall change in flow metric evaluates "consumptive use", or the amount of water removed from the river that is not returned through discharges. This can help describe potential impacts to downstream withdrawals, while also providing a basis for evaluating impacts to aquatic life. In general, total reductions in streamflow can result in a reduction in aquatic biodiversity [96]. The relationship between streamflow and aquatic biodiversity is discussed in more detail in the "Analysis of Ecological Impacts" section below and in Chapter 4. Figure 222 shows the overall change in streamflow for the 2030 Demand Scenario, while figure 223 shows the overall change in streamflow for the 2040 Demand Scenario.

[96] Rapp, J.L., R. Burgholzer, J. Kleiner, D. Scott, and E. Passero. 2020. "Application of a New Species-Richness Based Flow Ecology Framework for Assessing Flow Reduction Effects on Aquatic Communities." Journal of the American Water Resources Association 1–14.https://doi.org/10.1111/1752-1688.12877.

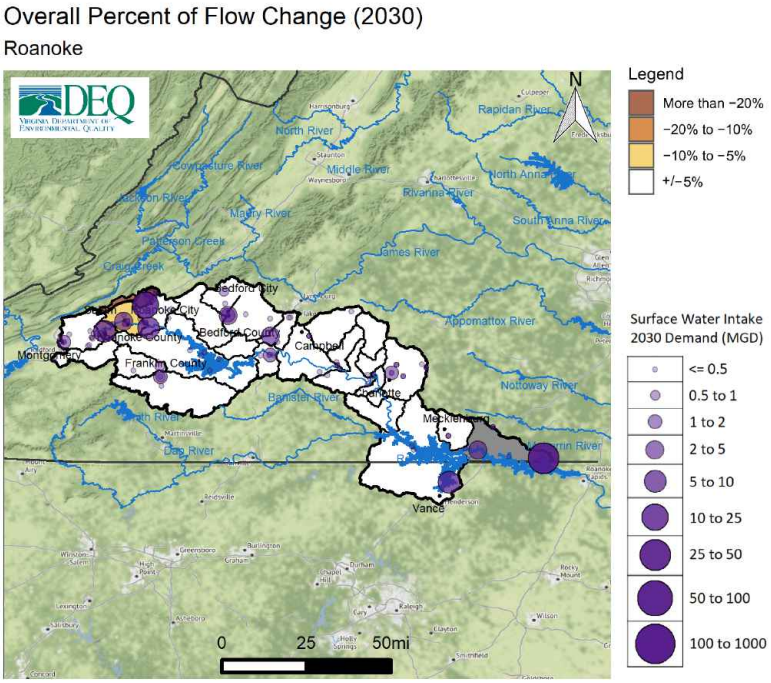

Figure 222: Overall change in flow in percent for 2030 demand scenario within the Roanoke Basin

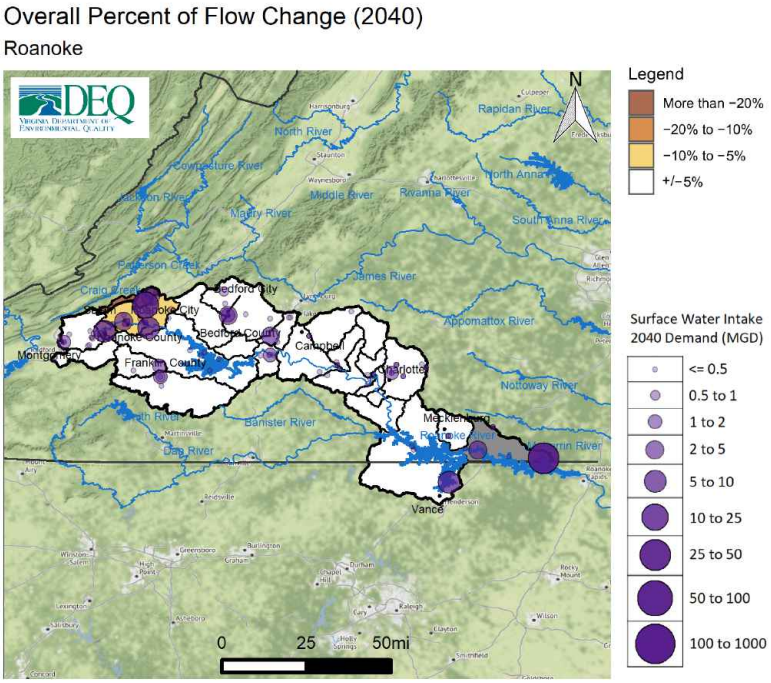

Figure 223: Overall change in flow in percent for 2040 demand scenario within the Roanoke Basin

Climate Scenarios:Three scenarios that simulate impacts to streamflow in response to changes in temperature and climate were completed for areas in the state where climate data was available, which includes the portions of the Commonwealth located in the Chesapeake Bay watershed. Details on the methods and assumptions employed for these scenarios can be found in Appendix B. In short, the three scenarios can be described as dry, median, and wet scenarios. Virginia is expected to experience a range of precipitation and temperature changes that may vary spatially and from year to year. The potential for both more severe and prolonged droughts as well as for higher intensity and more frequent rain events must be considered. These three scenarios are not intended as predictions of future climate conditions, but as representations of several possibilities that climate change models indicate could occur. Should they occur, these results provide an evaluation of how streamflows may be impacted. Their purpose is to build upon existing climate modeling to provide a foundation for state and local government, as well as other stakeholders, to better evaluate what practical water resource challenges may be associated with the range of climate conditions Virginia could experience. Note that this Basin is located outside of the Chesapeake Bay watershed and therefore climate scenarios were not completed at this time. DEQ is working to expand these climate scenarios to cover the entire state for future planning efforts.

Exempt User Scenario: The exempt user scenario simulates the maximum possible exempt demand for users excluded from Virginia Water Protection permitting requirements per Va. Code § 62.1-44.15:22 B, in combination with the permitted withdrawal limits for those users that are permitted. A more detailed discussion of the data and assumptions used in this scenario can be found in Appendix B. Note that this scenario uses current climate conditions. Figure 224 depicts the percent change in the Lowest 30 Day Flow between the exempt user scenario and current (2020) demand. Figure 225 depicts the percent change in the Lowest 90 Day Flow between the exempt user scenario and current (2020) demand. Figure 226 depicts the percent change in the 7Q10 between the exempt user scenario and current (2020) demand. Finally, figure 227 depicts the overall change in flow in percent (consumptive use) for the exempt user scenario.

Notes on Exempt user scenario. The Tinker Creek intake is used to refill the Carvins Cove reservoir, and therefore its demands are determined by refill needs in Carvins Cove. Because the Carvins Cove refill considers the flowby requirement in Tinker Creek, demand never exceeds available flow in the normal operation (non-exempt) scenarios. It does, however, have a separate intake and accompanying estimated maximum exempt demand amount, though this is only used to limit the maximum pumping rate from Tinker Creek in the exempt demand scenario.

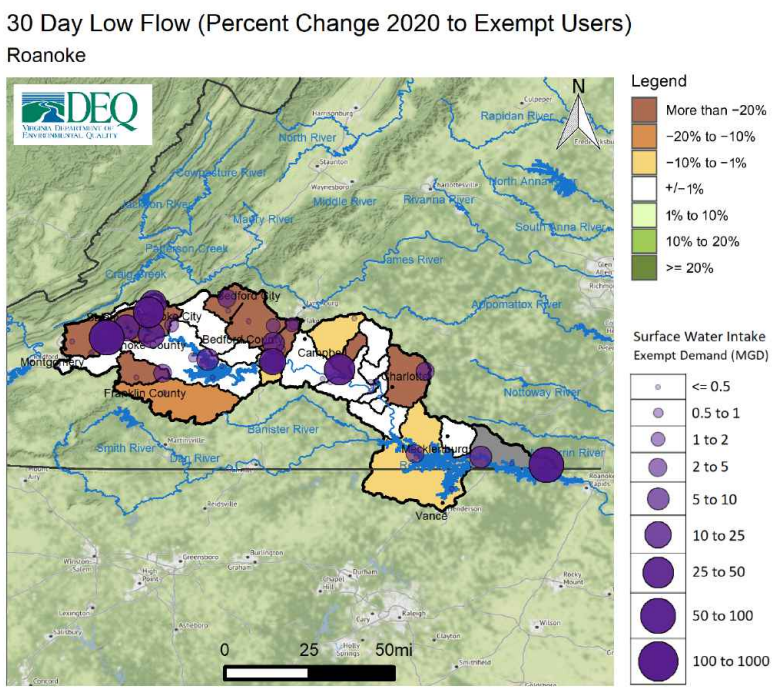

Figure 224: Change in 30 day low flow between current demand scenario and exempt user scenario within the Roanoke Basin

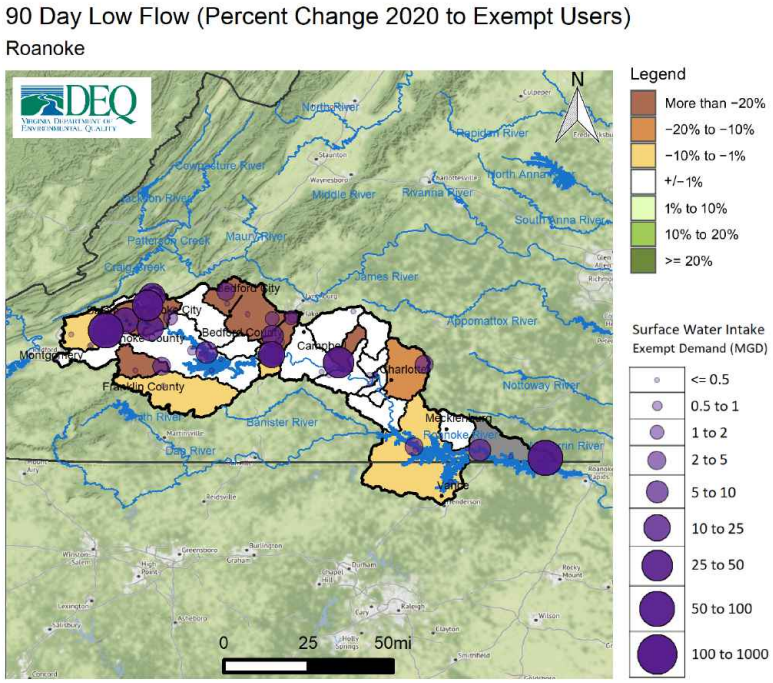

Figure 225: Change in 90 day low flow between current demand scenario and exempt user scenario within the Roanoke Basin

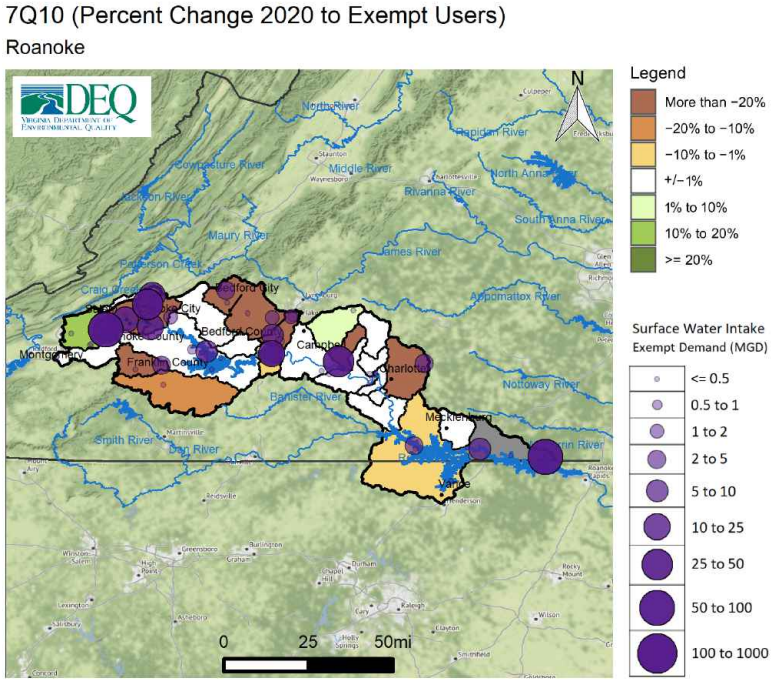

Figure 226: Change in 7Q10 between current demand scenario and exempt user scenario within the Roanoke Basin

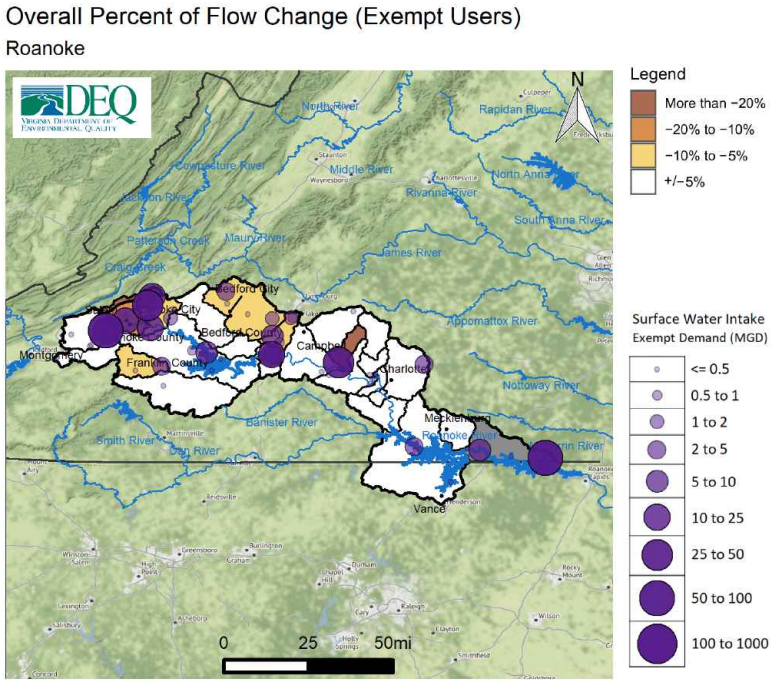

Figure 227: Overall change in flow in percent for exempt user scenario within the Roanoke Basin

Potential Unmet Demand: Potential unmet demand was evaluated for all facilities within the basin for each scenario. Potential unmet demand is the portion of surface water demand for a specific facility that is limited by available streamflow as simulated in a given model scenario, including any known operational limits such as flow-by requirements. This unmet demand, if realized, could be managed through water conservation, through alternative sources, operational changes, or from available storage. Absent of these or other options, this portion of demand could remain unmet. As with all scenarios, demand requirements were determined using demand projections provided in the water supply plans. In the case of the exempt user scenario, the highest possible withdrawal amount was used for users exempt from VWP permitting requirements.

This metric is useful for evaluating where the results seen in the above figures may result in challenges in meeting future demands under a variety of conditions including increasing demands in the basin, changing climate, or withdrawals from users exempt from permitting requirements. Table 60 provides for each facility the highest average daily potential unmet demand over a 30 day period over the course of the simulation for the following scenarios: 2020 demand, 2030 demand, 2040 demand, and exempt User. Only facilities showing potential unmet demand in at least one scenario appear on this table. Additional information on the potential unmet demand metric can be found in B.

Table 60: Change in Highest 30 Day Potential Unmet Demand (MGD) in Roanoke Minor Basin

Facility	2020 Demand	2030 Demand	2040 Demand	Dry Climate	Exempt User
Brookneal WTP	0.00	0.00	0.00	-	38.16
Roanoke (City) Service Area	0.00	0.00	0.00	-	27.12
Salem WTP	0.00	0.04	0.26	-	13.61
Central System Service Area	0.93	1.06	1.19	-	5.19
Bedford Central WTP	0.00	0.02	0.04	-	3.67
Brookneal WTP	0.00	0.00	0.00	-	2.85
Roanoke Facilities	0.00	0.00	0.00	-	2.75
Blackwater River WTP	0.00	0.00	0.02	-	2.49
Salem Glenvar WTP 2	0.00	0.00	0.00	-	1.77
Lawyers Road Plant	0.16	0.16	0.16	-	1.58
Keysville WTP	0.00	0.00	0.01	-	1.07
Roanoke City Service Area	0.00	0.00	0.00	-	0.90
London Downs Golf Course	0.00	0.00	0.00	-	0.41
Catawba WTP	0.00	0.00	0.00	-	0.19
Altavista Service Area	0.00	0.00	0.00	-	0.18
Laverys Sod Farm	0.00	0.00	0.00	-	0.12
Glenvar Plant	0.00	0.00	0.00	-	0.12
Blacksburg Country Club	0.00	0.00	0.00	-	0.11
New Leaf Farms, Inc.	0.00	0.00	0.00	-	0.01
Drakes Branch Plant	0.00	0.00	0.00	-	0.01

* Climate scenarios were not completed in areas located outside of the Chesapeake Bay Basin

Note: Potential unmet demand is the portion of surface water demand for a specific facility that is limited by available streamflow as simulated in a given model scenario, including any known operational limits such as flow-by requirements. This unmet demand, if realized, could be managed through water conservation, alternative sources, operational changes, or from available storage.

A.10.6 Spatial Overview of Groundwater Demands

The cumulative impact analysis figures above provide an overview of surface water demands in the basin but did not include groundwater demands. Figure 228 identifies the location and size of projected groundwater demands in the basin for 2040 based on information provided by localities in water supply plans.

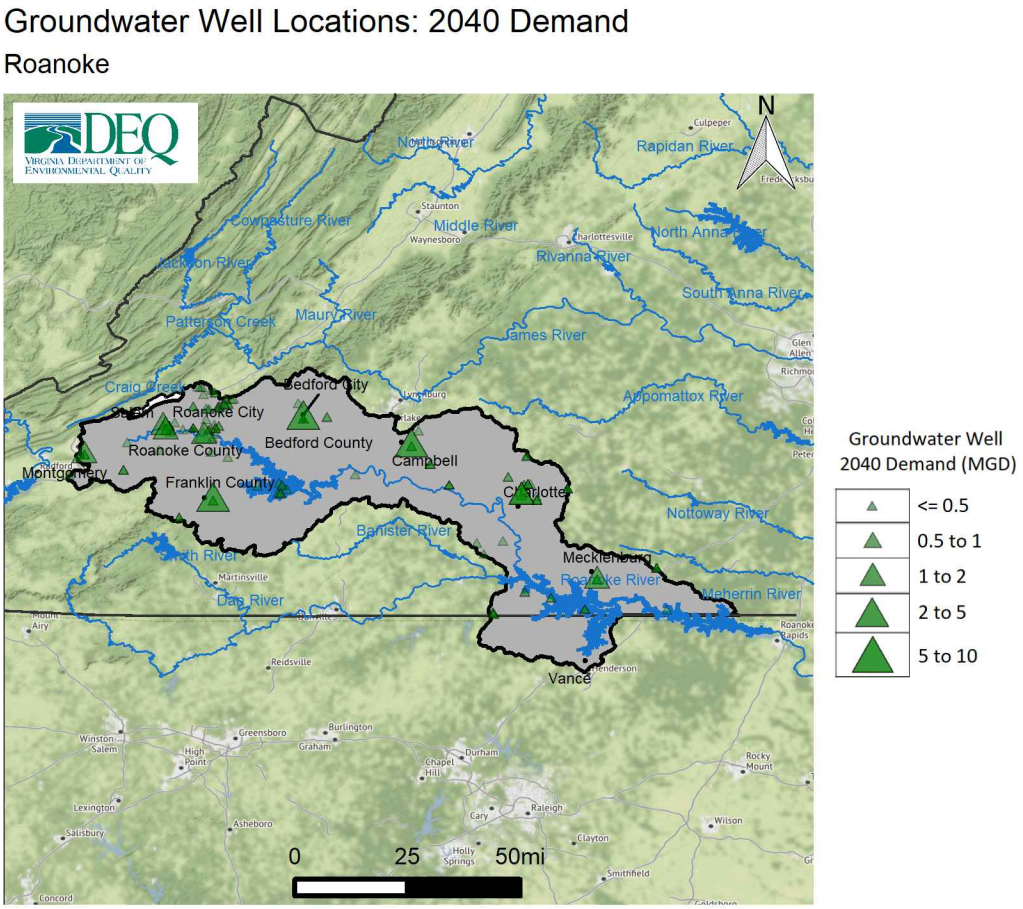

Figure 228: Projected 2040 Groundwater Demands in the Roanoke Minor Basin

A.10.7 Trends and Goals

The Code of Virginia mandates that the State Water Control Board should take into consideration the principle that "adequate and safe supplies shall be preserved and protected for human consumption, while conserving maximum supplies for other beneficial uses".[97] This principle is the key driver of the challenges in water resource management, which is that all beneficial uses must be adequately considered when evaluating impacts to surface water resources. The State Water Control Board is tasked with ensuring that water supply quantity needs are met at all times while also protecting Virginia's natural resources, and furthermore, ensuring equitable allocation during a time of shortage.[98] While evaluating and planning for the long-term sustainability of water supply for Virginia is the primary goal for the State Plan, evaluating and limiting impacts to in-stream beneficial uses such as aquatic habitat life is also part of DEQ's responsibility.

The primary purpose of this section is to identify where the most significant challenges to long-term sustainability of water supply and other beneficial uses are indicated based on the CIA and information collated from local water supply plans within this basin. Goals for future planning and areas for additional data collection or analysis are also suggested where appropriate.

The CIAs were completed using the best available data and methods known to DEQ. This discussion focuses on the evaluation of trends - in other words the prevailing tendency or inclination. This means evaluating whether streamflow is simulated to increase or decrease in a given scenario, and by how much. A relative trend indicating reductions of greater than or equal to 10% in streamflow, whether driven by demand increases, changing climate conditions, or exempt user demands was considered a threshold for potential impacts to beneficial uses. The following summarize the key trends or goals for this basin:

- **Demand Scenarios:** Surface water demands in the Roanoke Minor Basin are projected to increase approximately 28% through 2040, and the demand scenarios showed impacts from increasing demands may result in significant water resource management challenges in parts of the basin. Simulated reductions of 10% or more were seen within the basin for the short-term drought (L30), long-term drought (L90), and 7Q10 metrics when comparing the 2040 demand scenario to the 2020 demand scenario. A greater than 10% reduction in short term drought flows (L30) was simulated in four river segments during the 2040 scenario compared to 2020 demands. The greatest reductions were simulated in the Roanoke River near Salem, the Roanoke River near Saxe, Upper Big Otter River near Evington, and the Lower Big Otter River. Reductions are largely driven by increasing demands in the cities of Salem and Roanoke, Bedford County, Campbell County, and by effects of widespread agricultural users in the basin. For long term drought (L90), only one river segment showed a 10% or greater reduction when comparing the 2040 demand scenario to the 2020 demand scenario. These reductions in the Upper Big Otter River near Evington are driven by projected increases for Campbell County's Big Otter River intake. Significant reductions in short and long term drought flows were also simulated in Roanoke Creek near Saxe, driven by withdrawals from agricultural irrigation, livestock, and withdrawals from the Keysville Reservoir. Increasing agricultural and irrigation demands in the North and South Fork of Roanoke River in Montgomery County also drove streamflow reductions of greater than 10% reduction in the headwaters of the basin. Eight facilities show potential unmet demand in the 2040 demand scenario including large public water suppliers in Salem, Altavista, Bedford, and Campbell Counties. Overall Percent of Flow Change (consumptive use) is simulated to exceed 75% below Carvins Cove under 2040 demands due to limited releases. Increased demands from the Roanoke area drive demands on Carvins Cove which leads to reduced releases. The Roanoke River near Roanoke is also simulated to experience a 10% reduction in overall flow (consumptive use) in the 2040 demand scenario. This segment is adjacent and downstream of Carvins Cove. Driven by demands from the urban and suburban Roanoke/Salem area, an overall percent of flow reduction of near 10% is also simulated in the Roanoke River down to the Smith Mountain Lake impoundment. The City of Salem has several wells that may provide an alternative when surface water flows are not sufficient to meet demands. Significant reductions in overall streamflow from consumptive withdrawals in the Roanoke River headwaters may

[97] § 62.1-44.36 of the Code of Virginia
[98] 9VAC25-390-20.1

impact aquatic life, as well as other beneficial uses. Projected demands indicate the potential for impacts to future water supply availability and in-stream beneficial uses within the basin.

- **Climate Scenarios:** As climate change data was not available in this basin, climate change scenarios were not completed for this basin. The overall trend in climate change simulations statewide suggests the potential for higher average temperatures and higher average precipitation totals. However, the simulations also suggest the potential for more significant droughts than have been historically experienced in Virginia. Simulations completed elsewhere in the Commonwealth show short-term and long-term droughts with 20-50% reductions in streamflow compared to previous droughts. The potential for more severe droughts must be considered by localities and users when evaluating existing sources and alternatives, as well as for broader planning and resource management efforts by all stakeholders whether state or local.

- **Exempt User Scenario:** The exempt user scenario models the cumulative maximum possible exempt demands from all users exempt from VWP permitting requirements in the basin. Widespread reductions in streamflow of more than 10% during short term (L30) and long term droughts (L90), 7Q10, and overall change in flow were simulated when compared to current demands. Ten river segments were simulated with a 10% or greater reduction in L30 in the basin, with the most significant reductions (70%) in the Roanoke River near the City of Salem. Simulated reductions in the Roanoke River near the City of Salem are driven primarily from permitted withdrawals from the Roanoke River by the City of Salem and the the maximum possible exempt demand from Koppers Industries Inc. Glenvar Plant. Short term drought flows (L30) are simulated to be reduced by 10% in the exempt scenario elsewhere in the basin due to the maximum possible exempt demands from Spring Hollow Reservoir, Phelps Creek Reservoir, Crystal Spring Reservoir, the Town of Rocky Mount Blackwater River intake, and the Burlington Industries Roanoke River intake. A more than 10% or greater reduction in long term drought flow (L90) was simulated in seven river segments when comparing the exempt scenario to 2020 demands. The greatest reductions were simulated within the Lower Falling River, Roanoke River near the City of Salem, and Blackwater River. Additionally, with simulated reductions in overall flow (consumptive use) of more than 20% in four river segments, the exempt user scenario also suggests the possibility of impacts to aquatic life when simulating the highest possible exempt user demands. Finally, potential unmet demand in the exempt scenario is simulated for more than 15 facilities including several major public water suppliers. In summary, the cumulative highest possible exempt user demands in the basin exceed the water budget in many river segments. Preserving water supply and other beneficial uses will require managing these demands with respect to their cumulative impacts and in the context of the available resources in the basin.

A.11 Potomac Shenandoah

A.11.1 Watershed Overview

The Potomac River is one of the primary contributors to the Chesapeake Bay and its drainage spans across four states including Virginia, Maryland, Pennsylvania, and West Virginia. The Potomac River runs 405 miles beginning in West Virginia and drains into the Chesapeake Bay. The Potomac is fed by several smaller rivers, including the Shenandoah River which meets the Potomac River at Harpers Ferry, West Virginia. The basin as a whole is characterized by a mix of mountainous terrain in the western headwaters which gradually give way to rolling hills, and finally into an increasingly urbanized region as the river meets the fall-line and flows into the D.C. metropolitan area and suburban portions of Virginia and Maryland.

The Potomac Shenandoah Minor Basin is located in the northwestern portion of Virginia and makes up a large portion of the West Virginia and Virginia borders. The basin flows north east with the confluence of the Shenandoah and Potomac rivers joining at the Town of Harpers Ferry. All or portions of the localities listed in Table 61 are within the basin, with major population centers including the cities of Harrisonburg, Staunton, and Winchester. Land use and cover in the basin is largely comprised of agricultural, urban, or prominent forested mountains. Urban and impervious surfaces are concentrated within the major cities and heavily populated counties within northern Virginia.

The basin captures and transports water through three sections of the Shenandoah River, the North Fork, the South Fork, and the Shenandoah main stem at the confluence of the North Fork and South Fork. The North Fork of the Shenandoah River flows from Rockingham County to the Town of Front Royal where it joins the South Fork. The South Fork of the Shenandoah River begins at the confluence of the North and South rivers near Port Republic, flowing north until it meets the North Fork of the Shenandoah River to form the Shenandoah River. The South Fork is fed from the western slope of the Blue Ridge, Allegheny, and Massanutten mountains. Groundwater from the karst geology is also a significant source of base flow. Three run of river low head dams are located on the South Fork at the Town of Shenandoah, Newport County, and the Town of Luray.

Table 61: Population Trend by Locality in Potomac Shenandoah Basin

Localities	20 Year % Change
Albemarle	24.72
Augusta	9.92
Clarke	9.19
Fauquier	18.85
Frederick	30.34
Greene	21.16
Highland	-16.69
Loudoun	55.39
Madison	2.35
Nelson	-0.94
Page	-0.82
Rappahannock	-0.25
Rockingham	14.04
Shenandoah	15.80
Warren	17.78
Harrisonburg	23.38
Staunton	0.98
Waynesboro	9.38

A.11.2 Existing Water Sources

Major surface water sources within the basin include the North and South Fork of the Shenandoah River and its tributaries. Groundwater within the basin is primarily withdrawn from bedrock aquifers. The Shenandoah Basin is unique in western Virginia as groundwater demand is higher than surface water demand.

Withdrawals within the basin are primarily used for public water supply, industrial/manufacturing, irrigation, and commercial uses. Agricultural land use is widespread throughout the basin, however reporting of this category is limited. Surface water is not the primary water source for the basin with 104 intakes currently active in the basin. Groundwater wells are the most prevalent in the basin with 149 currently active in the basin, not including domestic or private wells. The location of wells and surface water intakes identified to DEQ within the watershed is shown in Figure 229. This figure also does not include private or domestic wells. This map also shows locations of any Instream Flow Incremental Method (IFIM) studies completed in the basin.

Surface and groundwater withdrawal locations are focused within the headwaters of the watershed with groundwater wells located within close proximity to surface water bodies. Groundwater wells are the most

prevalent source, and are scattered throughout the basin. Wells are primarily located within close proximity to prominent surface water sources and population centers. The greatest density of surface water withdrawals are near the confluence of the North and Middle rivers, just south of the City of Harrisonburg. Water supply demands are focused in developed areas surrounding the cities of Harrisonburg, Staunton, Waynesboro, Winchester, and surrounding communities. With the greatest density of surface and groundwater withdrawals occurring near the start of the South Fork of the Shenandoah River, moving downstream through the watershed the number of withdrawal locations generally declines, however numerous intakes and wells follow the Shenandoah River and its tributaries downstream.

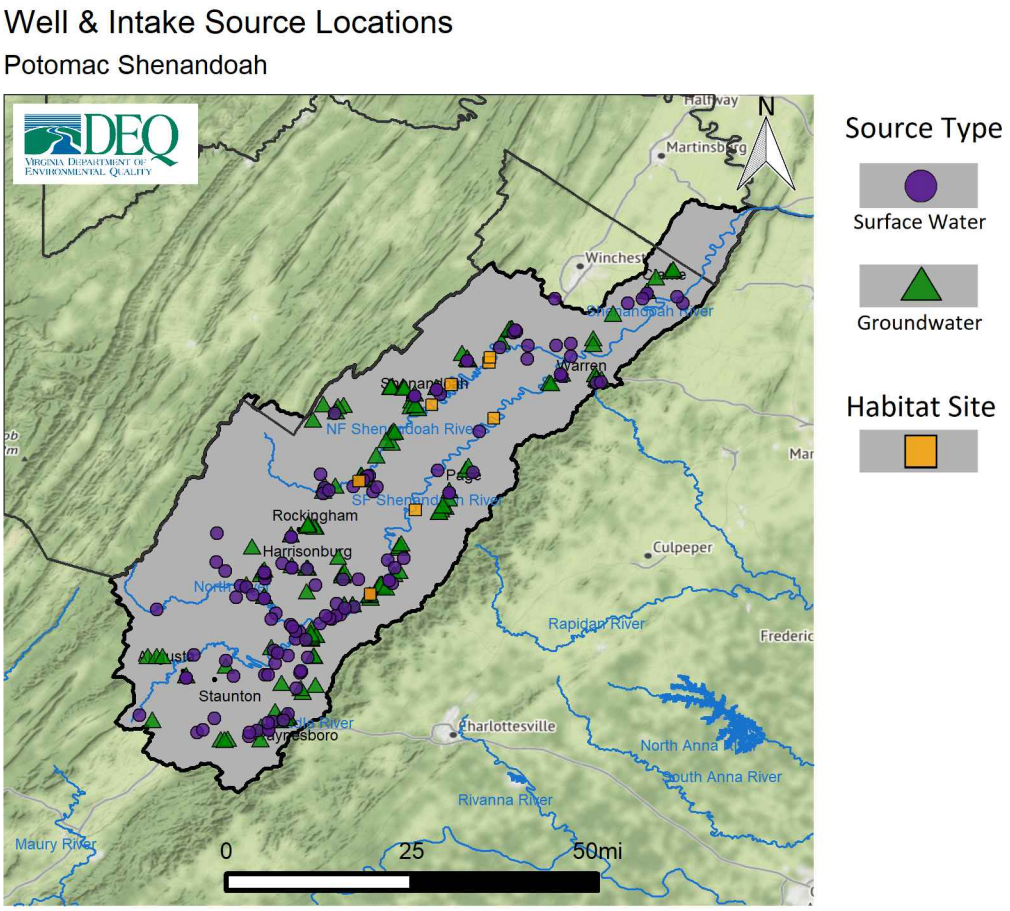

Figure 229: Location of Surface Water Intakes and Wells in the Potomac Shenandoah Minor Basin

A.11.3 Existing Water Use

The following section discusses existing (current) water use within the basin, which is based on existing demand information submitted to DEQ in the water supply plans. Table 62 provides a summary of all water demand within the basin organized by water source type and use category.

Table 62: Summary of Potomac Shenandoah Minor Basin Water Demand by Source Type and System Type

System Type	Source Count	2020 Demand (MGD)	2030 Demand (MGD)	2040 Demand (MGD)	20 Year Percent Change
Surface Water					
Agriculture	61	1.47	1.47	1.47	0.00
CWS	23	26.15	32.06	37.96	45.14
Large SSU	20	3.68	3.68	3.68	0.00
Small SSU	N/A	0.00	0.00	0.00	0.00
Total SW	**104**	**31.30**	**37.21**	**43.11**	**37.73**
Groundwater					
Agriculture	17	0.30	0.30	0.30	0.00
CWS	74	11.78	16.07	20.37	72.92
Large SSU	58	16.23	16.23	16.23	0.00
Small SSU	N/A	7.37	9.09	10.81	46.66
Total GW	**149**	**35.68**	**41.69**	**47.71**	**33.72**
Total (SW + GW)					
Agriculture	78	1.77	1.77	1.77	0.00
CWS	97	37.93	48.13	58.33	53.77
Large SSU	78	19.91	19.91	19.91	0.00
Small SSU	N/A	7.37	9.09	10.81	46.66
Minor Basin Total	**253**	**66.98**	**78.90**	**90.82**	**35.59**

* Small SSU demands are county-wide estimates of private well usage below 300,000 gallons a month. The number of private wells is not known.

The current demand from all surface and groundwater sources is approximately 66.98 MGD. Surface water supplies approximately 31.30 MGD or 46.7% of total water demands. Groundwater demand within the basin totals approximately 35.68 MGD, or 54.3% of current demand. Groundwater sources outnumber the number surface water intakes in the basin, and are the primary source of supply by volume in the watershed. Surface water sources primarily supply public water supplies such as the cities of Harrisonburg and Winchester. While groundwater withdrawals do supply a significant volume to public water suppliers, the majority is used by Large Self-Supplied Users in the watershed. Additionally, the large number of private individual well owners in the basin contributes to the primary reliance on groundwater in the basin.

The five largest withdrawals for each source type are provided in Table 63. The largest groundwater withdrawals include the Merck & Co Elkton Plant which currently withdraws approximately 6.61 MGD, and the LYCRA Company Waynesboro Plant that currently withdraws approximately 3.91 MGD. While Large Self-Supplied Users (Large SSUs) and Community Water System (CWS) facilities dominate the largest groundwater withdrawals, note that Small Self-Supplied Users (Small SSUs) are responsible for 7.37 MGD in demand currently. Groundwater demands from individual private wells are a significant source of water demand in the basin.

The largest surface water withdrawals in the basin are for CWS serving the City of Harrisonburg Water Treatment Plant and the City of Winchester's Percy Miller Water Treatment Plant. The City of Harrisonburg

is located in the headwaters of the basin and currently withdraws from three surface water sources (the Dry River, North River, and South Fork of the Shenandoah River) with a current demand of approximately 6.47 MGD. The City of Winchester currently withdrawals approximately 7.7 MGD from the North Fork of the Shenandoah River. Additionally, the City of Staunton, Frederick County, and the Town of Front Royal are reliant on surface water supplies as their primary source.

Table 63: Top 5 Users in 2040 by Source Type in the Potomac Shenandoah Minor Basin

Facility Name	**System Type**	**Locality**	**2020 Demand (MGD)**	**2030 Demand (MGD)**	**2040 Demand (MGD)**	**20 Year Percent Change**	**% of Total Surface Water**
Surface Water							
Harrisonburg WTP	CWS	Rockingham	6.47	7.88	9.29	43.59	21.55
Percy D. Miller WTP	CWS	Warren	7.7	8.41	9.12	18.44	21.16
Staunton WTP	CWS	Augusta	3.91	5.19	6.47	65.47	15.01
Frederick County Sanitation Authority	CWS	Frederick	1.1	2.12	3.14	185.45	7.28
Front Royal WTP	CWS	Warren	2.26	2.53	2.79	23.45	6.47
Total SW			21.44	26.13	30.81	43.7	71.47
Groundwater							**% of Total Groundwater**
Elkton Plant	Large SSU	Rockingham	6.61	6.61	6.61	0.00	13.85
Three Springs Service Area	CWS	Rockingham	2.11	3.55	4.99	136.49	10.46
South River Service Area	CWS	Augusta	2.33	3.56	4.79	105.58	10.04
Waynesboro Plant	Large SSU	Waynesboro	3.91	3.91	3.91	0.00	8.2
Dayton Service Area	CWS	Rockingham	1.38	1.7	2.02	46.38	4.23
Total GW			16.34	19.33	22.32	36.6	46.78

Table 62 also provides the proportion of each use category that is supplied by either surface water or groundwater. Use categories include Community Water System (CWS), Large Self-Supplied User (Large SSU), Small Self-Supplied User (Small SSU), and Agricultural Self-Supplied User (AG). CWS facilities are currently responsible for 26.15 MGD or 83.5% of all surface water demands in the basin. As shown in 63, the cities of Harrisonburg and Winchester are responsible for approximately 20.6% and 24.6% of all surface water withdrawals respectively. Groundwater demand is primarily comprised of Large SSUs totaling 16.23 MGD or 45.5% of all groundwater demands in the watershed. The Merck & Co. Elkton Plant is the largest user of groundwater with in the watershed, with 6.61 MGD or 18.5% of all groundwater demand in the basin.

The CWS category includes any public and private waterworks that serve at least 15 service connections used by year-round residents or regularly serve at least 25 year-round residents, and are regulated under the Virginia Department of Health's Waterworks Regulation (12VAC5-590). In the Potomac Shenandoah Minor Basin, approximately 33% of annual groundwater demand and 83.5% of surface water demand supports CWS facilities. Significant groundwater users within this category include: Rockingham County Service Area, the City of Waynesboro, and smaller towns within the basin including Dayton and Bridgewater. Surface water withdrawals in the category primarily support large urban service areas including the cities of Harrisonburg, Staunton, and Winchester, as well as the towns of Front Royal and Strasburg.

Large SSUs include any non-CWS or AG users who withdraw more than 300,000 gallons per month from a well or surface water intake. In the Potomac Shenandoah Minor Basin, approximately 45.5% of annual groundwater and 11.7% of surface water demand is from the 97 Large SSUs identified to DEQ. Significant groundwater users within this category include: LYCRA Company, Merck & Co, Grottoes Plastics, and the Coors Shenandoah Brewery. Significant surface water users from this category include: O-N Mineral Company, Food Processor Cooperative, and the Bryce and Massanutten Resorts.

Small SSUs include any users who withdraw less than 300,000 gallons per month from wells. Small SSUs generally consist of residential or domestic use for those who live outside service areas and provide their own water. Small SSU demand is generally met with groundwater. Localities within the basin with the greatest estimated demands from Small SSUs include Rockingham and Warren counties.

The AG category includes livestock operations, aquaculture and other agricultural facilities. Approximately 0.8% of annual groundwater and 4.7% of surface water demand is from AG withdrawals. Significant surface water users from this category include the Front Royal Fish Culture Station and the Laurel Hill Trout Farms.

A.11.4 Projected Population and Water Use

Projected Population: Trends in water use are generally driven by trends in population change or economic development. Increasing population within an area generally means increased connections for community water systems or additional groundwater demand from homeowners that construct wells. Increasing population in an area also tends to incentivize both new and expanded industrial and commercial water use.

Table 61 shows the projected change in population by percent between 2020 and 2040 for each locality located partly or wholly within this minor basin. Population trends within the watershed show significant increases through the planning period for most of the localities partially or fully within the basin. The largest increases in population are expected to occur within Frederick County (30.34%), the City of Harrisonburg (23.38%), and the City of Winchester (13.77%). Frederick County continues to see influence from the greater northern Virginia metro area and is one of the fastest growing localities in the Commonwealth with more than 25,000 additional residents expected by 2040. A similar trend is observed within the cities of Harrisonburg and Winchester. While growth is focused in these areas, it is important to note that increases in population are expected throughout the basin with Augusta, Rockingham, and Shenandoah counties expected to observe significant increases throughout the planning period. Minimal decreases in overall population are expected to occur within Highland and Bath counties as migration out of more rural areas is seen statewide.

Projected Water Use: The following section discusses projected water use through 2040 within the Potomac Shenandoah basin, based on projections provided in local and regional water supply plans. Table 62, included in the existing demand section above, is the basis for information discussed in this section.

Total demand within the basin is projected to increase from 66.98 MGD in 2020 to 90.82 MGD in 2040, an approximately 35.5% increase. Surface water demand is projected to increase by 11.81 MGD, or 37.73% by 2040. Groundwater demand is projected to increase by 12.03 MGD, or 33.72%, by 2040. The 35.5% increase in demands projected over the planning period is concentrated within Community Water Systems and groundwater withdrawals from Small Self-Supplied Users. Increased population growth and residential development drives demands in these categories.

The largest contributors to increases in projected demands include: the cities of Harrisonburg, Winchester, Staunton, Waynesboro, and the Frederick County Water Authority. Small Self-Supplied Users are also a primary driver of projected increases of groundwater withdrawals in the watershed. Small SSU demand is projected to increase by 46.66% over the planning period.

Demand from CWS users within the basin is projected to increase by 53.77% by 2040. Within this category, surface water use is projected to increase by 43.14%, while groundwater use is projected to increase by 72.92%. Increases in surface water demand are focused within the City of Harrisonburg, the City of Winchester, and Frederick County with the largest systems projecting the largest increases in demand. Groundwater demands for CWS users is projected to increase by 72.92% over the planning period, more than any other category in the watershed. Increased withdrawals from groundwater sources will occur throughout the basin as many cities, towns, and community water supplies rely solely or partially on groundwater supplies.

Demand from Large SSUs within the basin is projected to remain stable through 2040. Within this category, groundwater is the primary water source with 16.23 MGD of demand expected through 2040. No increase in surface water demand is projected in this category.

Demand from Small SSUs within the basin is projected to increase by 46.66% by 2040, which is comprised entirely of residential well demands. Increased development from residential homeowners as population continues to increase across the basin is driving the projected increases in groundwater demands for Small Self-Supplied Users.

Demand from Agriculture Users within the basin is projected to remain stable throughout 2040 for both surface and groundwater withdrawals.

A.11.5 Cumulative Impact Analysis

The following section provides a brief summary of the Cumulative Impact Analysis (CIA) modeling results in the Potomac Shenandoah Minor Basin. Discussion of these results will primarily be found in the Trends and Goals section of this appendix. However a brief overview of the VAHydro model and the scenarios and metrics is provided below.

The VAHydro surface water model simulates streamflow using inputs such as precipitation, climate, land use, and topography, combined with data on all known withdrawals and discharges, and operational rules of major hydrologic features such as reservoirs. Each minor basin is broken into smaller hydrologic subsections, or river segments. The model simulates the water balance on a daily basis for each individual river segment, with each downstream segment being affected by the cumulative impact of streamflow changes occurring in upstream segments. The following figures help analyze this cumulative impact within the Potomac Shenandoah Minor Basin (model results summarized by river segment). Note that this section is not intended to document in detail the methods and assumptions for the VAHydro model or for the scenarios and metrics discussed. More documentation of the model and assumptions can be found in Chapter 4.

The VAHydro surface water model was used to simulate streamflow under a variety of scenarios. Demand scenarios examine how streamflow is impacted under 2030 or 2040 demands as compared to current (2020) demands. Demands were calculated based on current and future demand information submitted through local and regional water supply plans. Climate change scenarios examine how streamflow is impacted when 2040 demands are simulated in conjunction with a range of precipitation and temperature conditions that may occur in the future due to changing climate (Dry, Median, Wet scenarios). Finally, the exempt user scenario examines impacts from users excluded, or exempt, from VWP permit requirements per Va. Code § 62.1-44.15:22 B. Exempt users were simulated at the maximum possible demand identified through a review of demand justification values commonly asserted by exempt users, including but not limited to VDH pump capacity, maximum pre-1989 withdrawal, and maximum intake capacity. In order to effectively manage surface water resources and address the uncertainty related to these demands, DEQ determined the most conservative, or maximum possible, demand should be evaluated in this scenario. However, DEQ does not agree that the maximum values used in this scenario represent an allocation for, or the expectation of, a future withdrawal of that volume; nor does DEQ concede that any particular exempt user is necessarily entitled to withdraw any particular maximum value used in this scenario. The methods and assumptions for each of these modeling scenarios are discussed in more detail in Chapter 4.

For each scenario described above, different metrics can be used to evaluate the simulated streamflow. A metric is a method for measuring or evaluating a given set of data; different metrics can be evaluated to answer different questions. Within this section the following metrics will be discussed: the lowest 30 day flow (L30), the lowest 90 day flow (L90), 7Q10, and overall change in flow. The L30 describes the lowest consecutive 30 day average daily streamflow over the simulation period. This metric is a representation of a short-term, or acute drought, and is a good metric for evaluating impacts to direct withdrawals without storage. Similarly, the lowest 90 day flow represents the lowest consecutive 90 day average daily streamflow over the simulation period. This would represent a prolonged drought and is often used to evaluate impacts to reservoirs. The 7Q10 is the lowest 7-day average flow that occurs (on average) once every 10 years. 7Q10 is generally used in the evaluations of in-stream beneficial uses such as waste assimilative capacity. Overall change in flow describes the net loss of water from the riverine system as a result of off-stream use not otherwise returned through point source discharges, or losses due to evapotranspiration. This metric is useful for evaluating impacts to aquatic life and is discussed in more detail in Chapter 4.

Demand Scenarios: 2020 demand or current demand, 2030 demand, and 2040 demand scenarios were simulated. The following series of figures compares the 2030 and 2040 demand scenarios to the current demand scenario. The change in flow depicted on each map is the change expected when comparing two scenarios - in this case future demands compared to current demands. Each page includes two figures comparing either the 2030 or 2040 demand scenario to current demand using the L30, L90, and 7Q10 metrics. This allows for comparisons of simulated impacts between the 2030 and 2040 demand scenarios. The scenarios and metrics are identified in the paragraph below and in the figure captions.

Figures 230 and 231 compare the lowest 30 day flow simulated with the current demand scenario with the lowest 30 day flow simulated in the 2030 and 2040 demand scenarios respectively. Figures 232 and 233 compare the lowest 90 day low flow simulated with the current demand scenario with the lowest 90 day flow simulated in the 2030 and 2040 demand scenarios respectively. Figures 234 and 235 compare the 7Q10 simulated with the current demand scenario with the 7Q10 simulated in the 2030 and 2040 demand scenarios respectively.

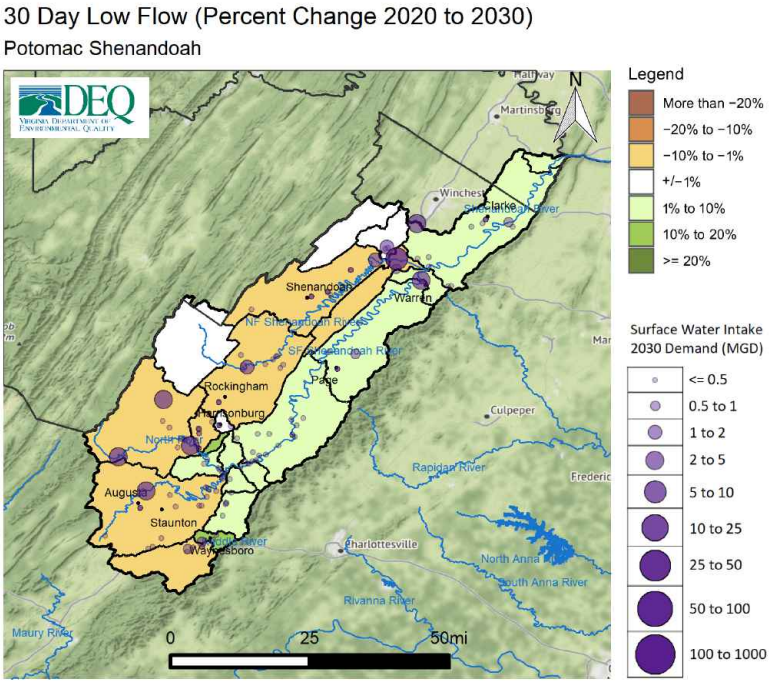

Figure 230: Change in 30 day low flow between 2020 and 2030 demand scenarios within the Potomac Shenandoah Basin

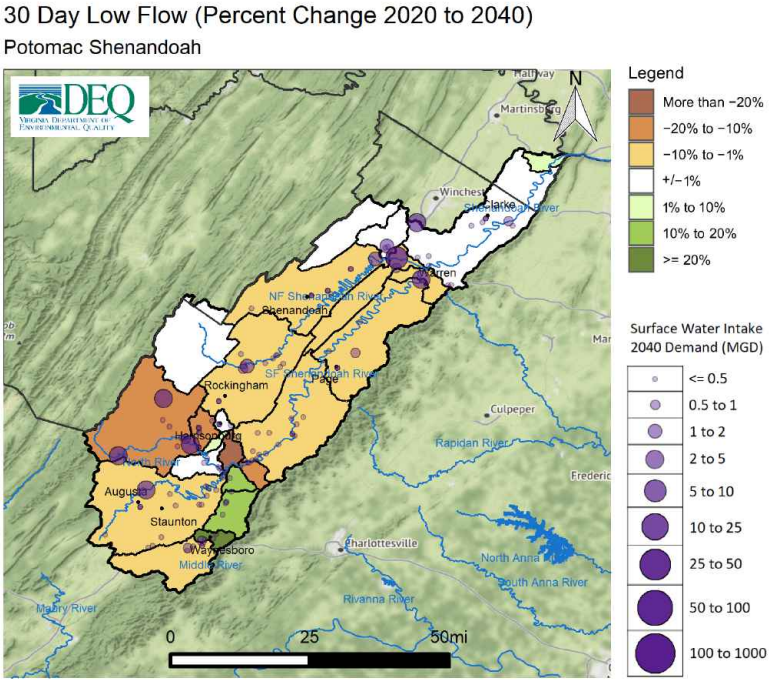

Figure 231: Change in 30 day low flow between 2020 and 2040 demand scenarios within the Potomac Shenandoah Basin

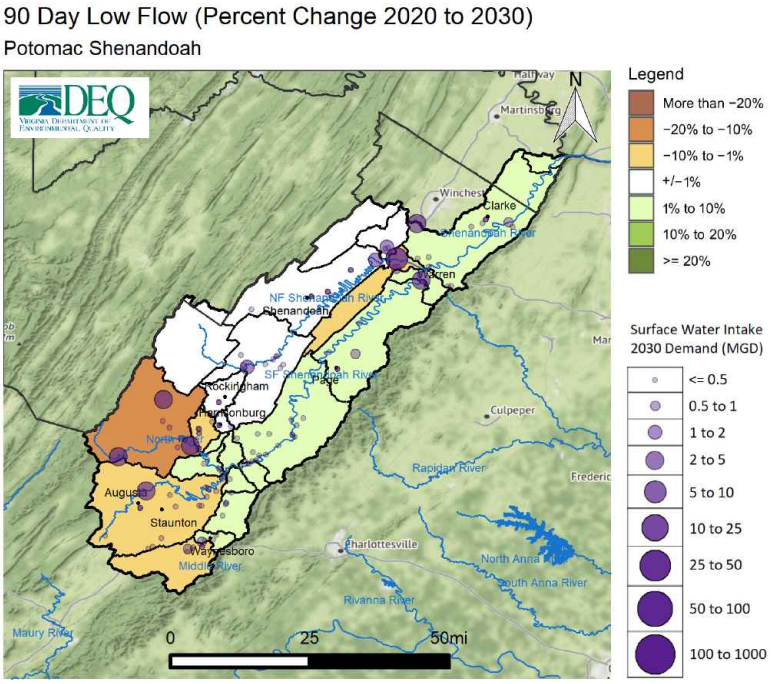

Figure 232: Change in 90 day low flow between 2020 and 2030 demand scenarios within the Potomac Shenandoah Basin

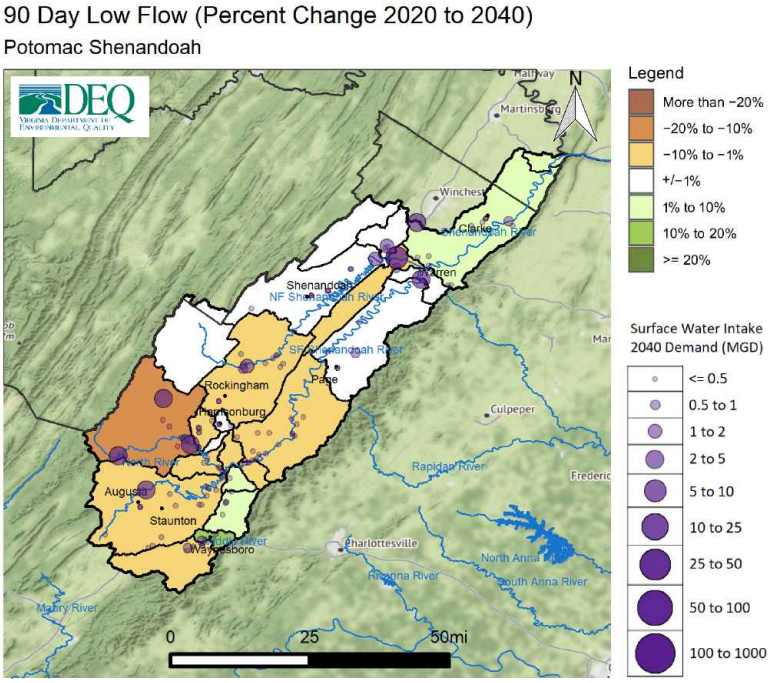

Figure 233: Change in 90 day low flow between 2020 and 2040 demand scenarios within the Potomac Shenandoah Basin

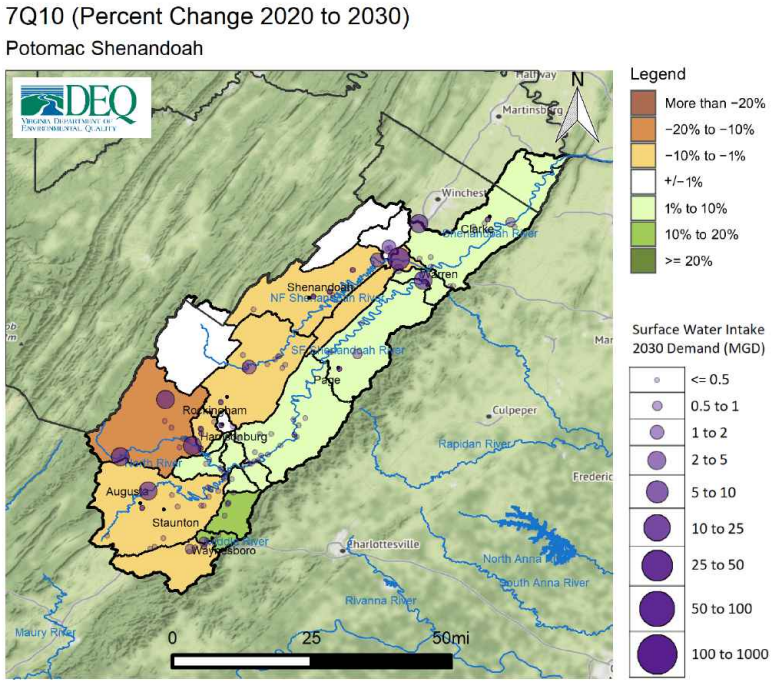

Figure 234: Change in 7Q10 between 2020 and 2030 demand scenarios within the Potomac Shenandoah Basin

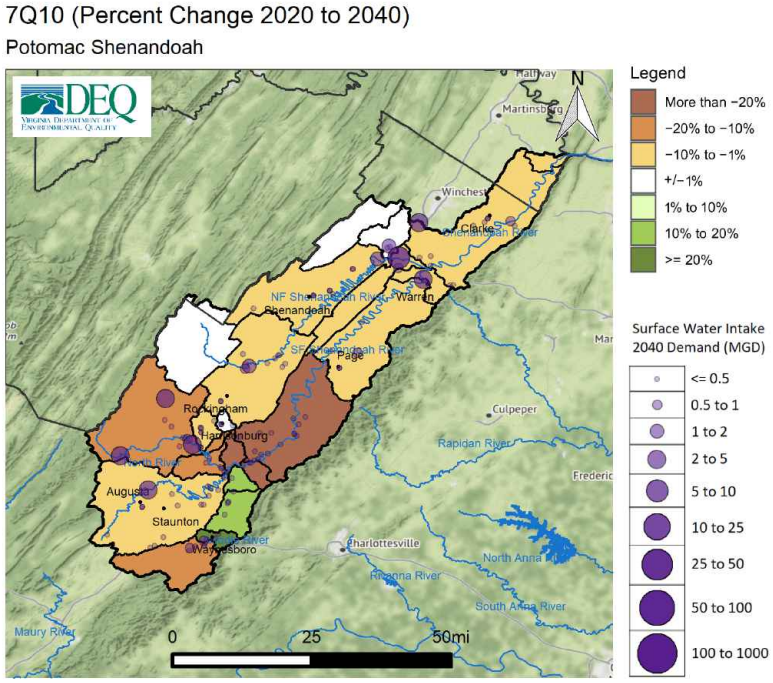

Figure 235: Change in 7Q10 between 2020 and 2040 demand scenarios within the Potomac Shenandoah Basin

The figures above show a comparison between two scenarios. An additional way to evaluate impacts to streamflow is to examine the total reduction in streamflow resulting from all withdrawals within a river segment, as well as losses due to evapotranspiration, while taking into consideration any discharges back to the source. To use a common industry term, the overall change in flow metric evaluates "consumptive use", or the amount of water removed from the river that is not returned through discharges. This can help describe potential impacts to downstream withdrawals, while also providing a basis for evaluating impacts to aquatic life. In general, total reductions in streamflow can result in a reduction in aquatic biodiversity [99]. The relationship between streamflow and aquatic biodiversity is discussed in more detail in Chapter 4. Figure 236 shows the overall change in streamflow for the 2030 Demand Scenario, while figure 237 shows the overall change in streamflow for the 2040 Demand Scenario.

[99] Rapp, J.L., R. Burgholzer, J. Kleiner, D. Scott, and E. Passero. 2020. "Application of a New Species-Richness Based Flow Ecology Framework for Assessing Flow Reduction Effects on Aquatic Communities." Journal of the American Water Resources Association 1–14.https://doi.org/10.1111/1752-1688.12877.

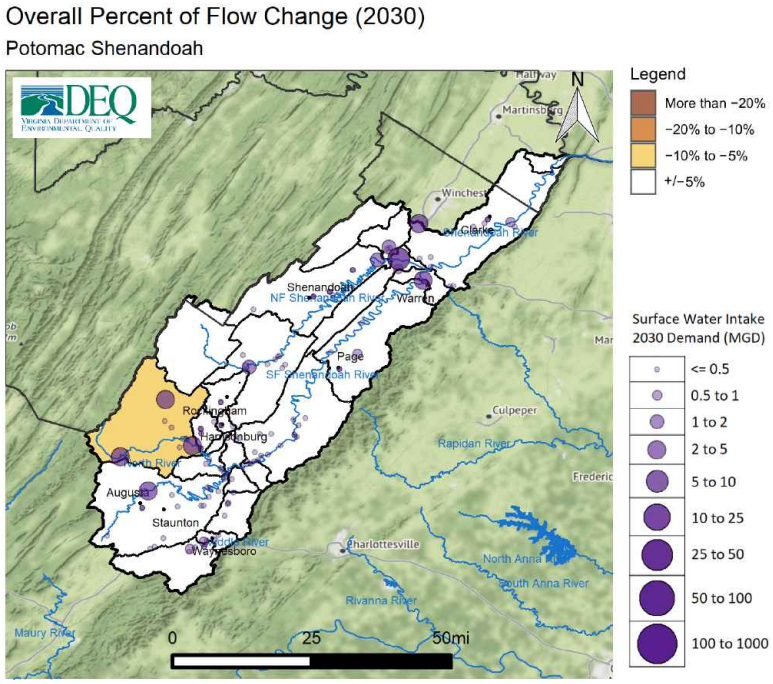

Figure 236: Overall change in flow in percent for 2030 demand scenario within the Potomac Shenandoah Basin

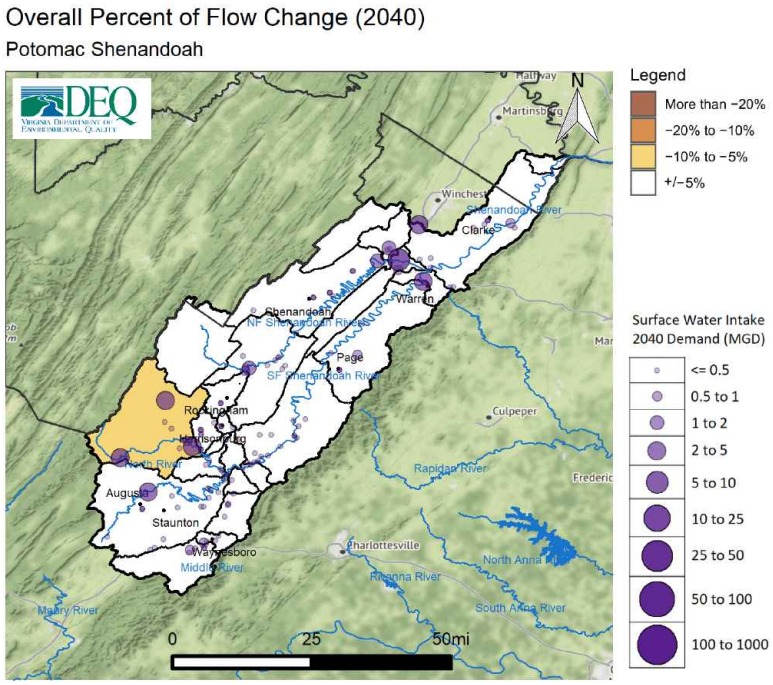

Figure 237: Overall change in flow in percent for 2040 demand scenario within the Potomac Shenandoah Basin

Climate Scenarios: Three scenarios that simulate impacts to streamflow in response to changes in temperature and climate were completed for areas in the state where climate data was available, which includes the portions of the Commonwealth located in the Chesapeake Bay watershed. Details on the methods and assumptions employed for these scenarios can be found in Chapter 4. The three scenarios can be described as dry, median, and wet scenarios. Virginia is expected to experience a range of precipitation and temperature changes that may vary spatially and from year to year. The potential for both more severe and prolonged droughts as well as for higher intensity and more frequent rain events must be considered. These three scenarios are not intended as predictions of future climate conditions, but as representations of several possibilities that climate change models indicate could occur. Should they occur, these results provide an evaluation of how streamflows may be impacted. Their purpose is to build upon existing climate modeling to provide a foundation for state and local government, as well as other stakeholders, to better evaluate what practical water resource challenges may be associated with the range of climate conditions Virginia could experience.

Figure 238 depicts the percent change in the L30 for the dry climate scenario in conjunction with 2040 demands, as compared to the current climate and demand scenario. Reductions in streamflow in this scenario may be caused by reduced precipitation, increased demand, or as is generally the case, a combination of both. Figures 239 and 240 depict the L30 for the median and wet climate scenarios (in conjunction with 2040 demands) as compared to the current climate and demand scenario.

Figure 241 depicts the percent change in the L90 for the dry climate scenario in conjunction with 2040 demands, as compared to the current climate and demand scenario. Figures 242 and 243 depict the L30 for the median and wet climate scenarios (in conjunction with 2040 demands) as compared to the current climate and demand scenario.

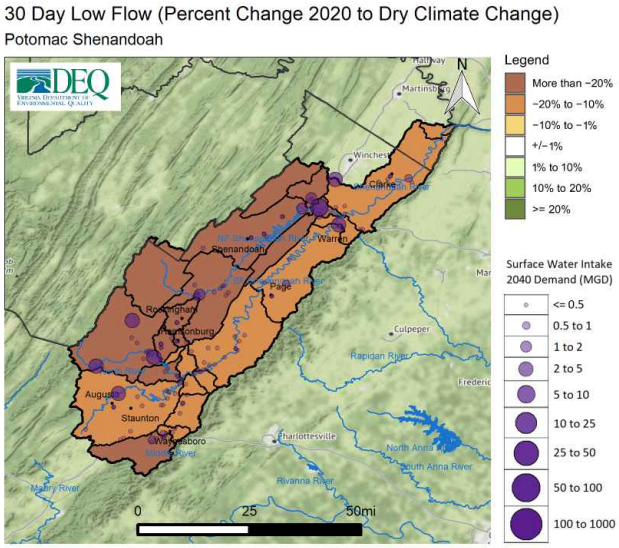

Figure 238: Change in 30 day low flow between current climate/demand scenario and the dry climate/2040 demand scenario within the Potomac Shenandoah Basin

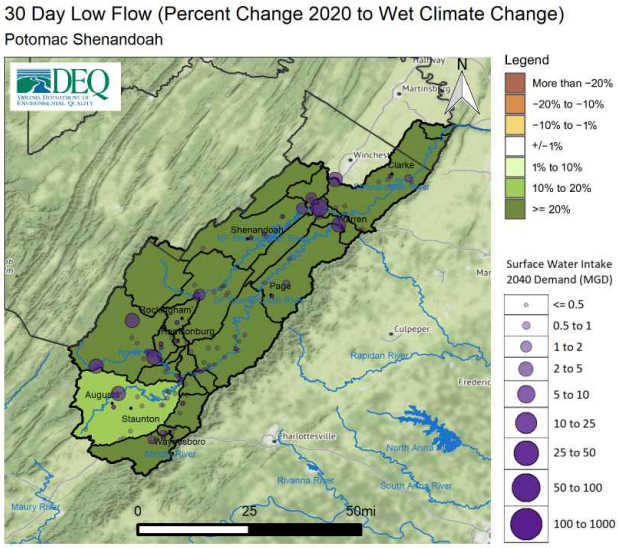

Figure 240: Change in 30 day low flow between current climate/demand scenario and the wet climate/2040 demand scenario within the Potomac Shenandoah Basin

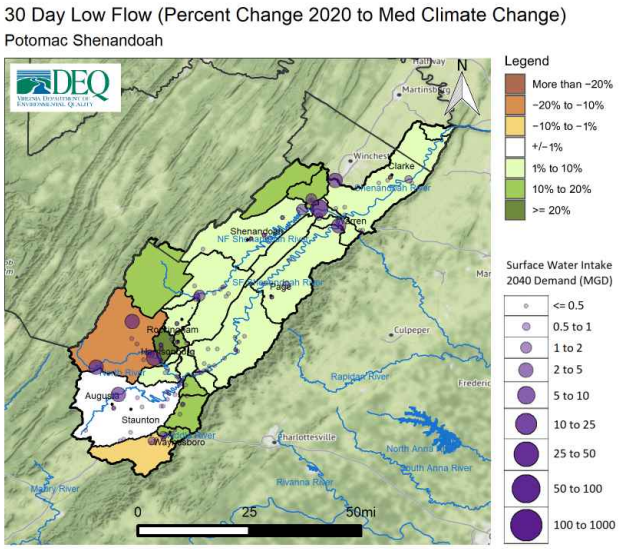

Figure 239: Change in 30 day low flow between current climate/demand scenario and the median climate/2040 demand scenario within the Potomac Shenandoah Basin

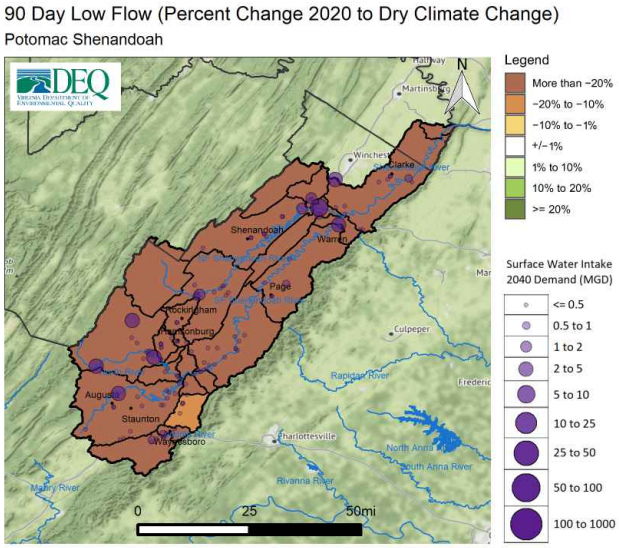

Figure 241: Change in 90 day low flow between current climate/demand scenario and the dry climate/2040 demand scenario within the Potomac Shenandoah Basin

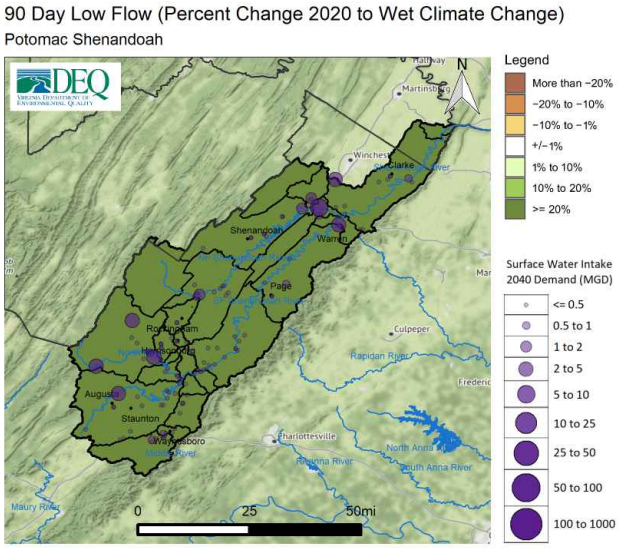

Figure 243: Change in 90 day low flow between current climate/demand scenario and wet climate/2040 demand scenario within the Potomac Shenandoah Basin

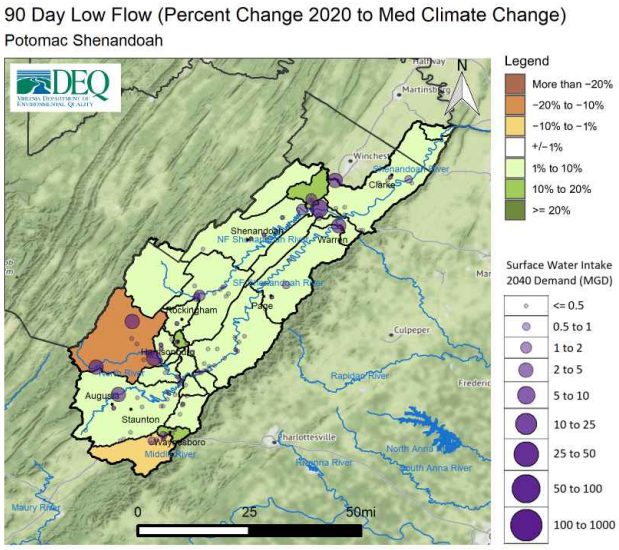

Figure 242: Change in 90 day low flow between current climate/demand scenario and median climate/2040 demand scenario within the Potomac Shenandoah Basin

Exempt User Scenario: The exempt user scenario simulates the maximum possible exempt demand for users excluded from Virginia Water Protection permitting requirements per Va. Code § 62.1-44.15:22 B, in combination with the permitted withdrawal limits for those users that are permitted. A more detailed discussion of the data and assumptions used in this scenario can be found in Appendix B. Note that this scenario uses current climate conditions. Figure 244 depicts the percent change in 30 day low flow between the exempt user scenario and current (2020) demand. Figure 245 depicts the percent change in 90 day low flow between the exempt user scenario and current (2020) demand. Figure 246 depicts the percent change in the 7Q10 between the exempt user scenario and current (2020) demand. Finally, figure 247 depicts the overall change in flow in percent (consumptive use) for the exempt user scenario.

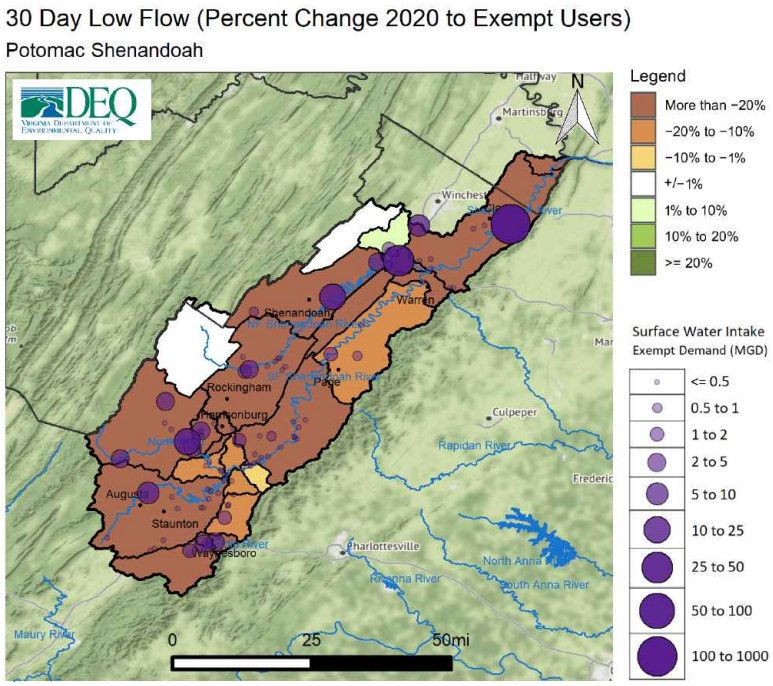

Figure 244: Change in 30 day low flow between current demand scenario and exempt user scenario within the Potomac Shenandoah Basin

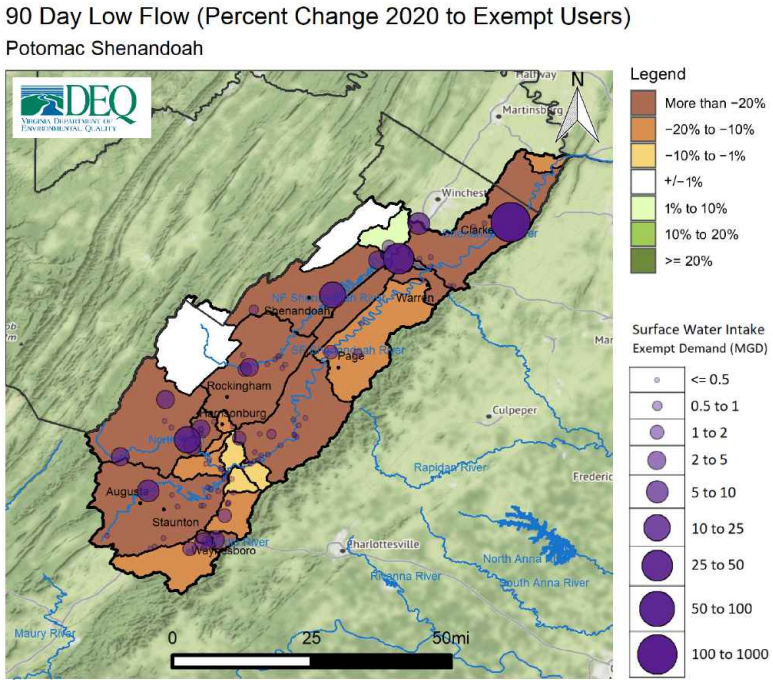

Figure 245: Change in 90 day low flow between current demand scenario and exempt user scenario within the Potomac Shenandoah Basin

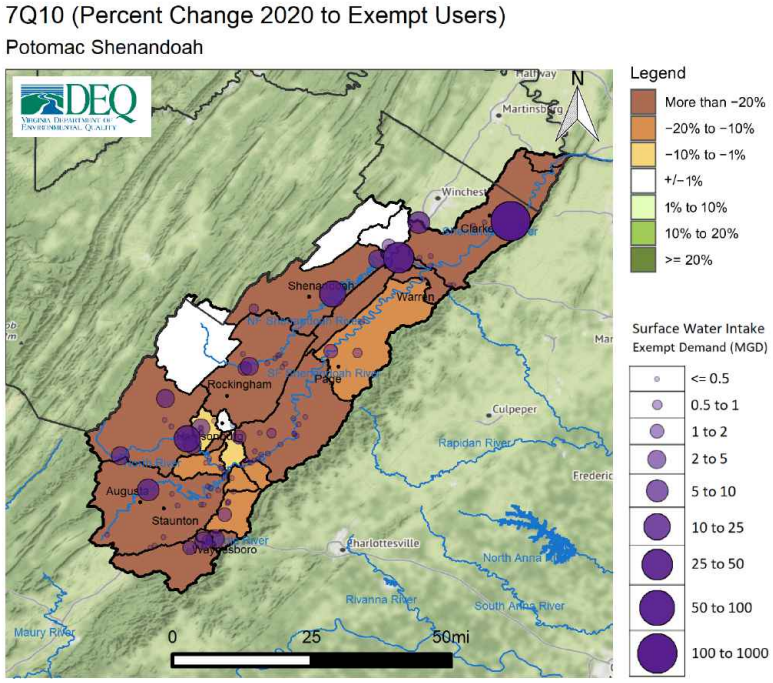

Figure 246: Change in 7Q10 between current demand scenario and exempt user scenario within the Potomac Shenandoah Basin

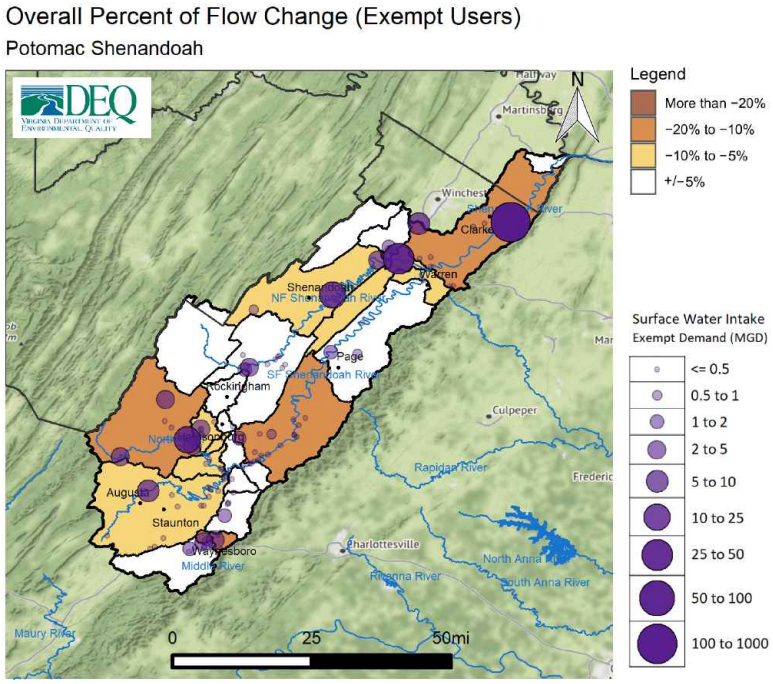

Figure 247: Overall change in flow in percent for exempt user scenario within the Potomac Shenandoah Basin

Potential Unmet Demand: Potential unmet demand was evaluated for all facilities within the basin for each scenario. Potential unmet demand is the portion of surface water demand for a specific facility that is limited by available streamflow as simulated in a given model scenario, including any known operational limits such as flow-by requirements. This unmet demand, if realized, could be managed through water conservation, through alternative sources, operational changes, or from available storage. Absent of these or other options, this portion of demand could remain unmet. As with all scenarios, demand requirements were determined using demand projections provided in the water supply plans. In the case of the exempt user scenario, the highest possible withdrawal amount was used for users exempt from VWP permitting requirements.

This metric is useful for evaluating where the results seen in the above figures may result in challenges in meeting future demands under a variety of conditions including increasing demands in the basin, changing climate, or withdrawals from users exempt from permitting requirements. Table 64 provides for each facility the highest average daily potential unmet demand over a 30 day period over the course of the simulation for the following scenarios: 2020 demand, 2030 demand, 2040 demand, dry climate, and exempt user. Only facilities showing potential unmet demand in at least one scenario appear on this table. The dry climate scenario is selected among the climate scenarios as the dry scenario represents the potential for increased drought intensity and frequency, and therefore poses the greatest challenge for water supply. Additional information on the potential unmet demand metric can be found in Chapter 4.

Table 64: Change in Highest 30 Day Potential Unmet Demand (MGD) in Potomac Shenandoah Minor Basin

Facility	2020 Demand	2030 Demand	2040 Demand	Dry Climate	Exempt User
Berryville WTP	0.00	0.00	0.00	0.00	70.73
Shenandoah (Town) WTP	0.00	0.00	0.00	0.00	59.18
Percy D. Miller WTP	0.02	0.12	0.27	1.64	23.56
Bridgewater Service Area	0.00	0.00	0.01	0.03	12.21
Staunton WTP	0.00	0.00	0.00	0.00	12.02
Waynesboro Plant	0.00	0.00	0.00	0.00	11.19
Harrisonburg WTP	3.36	5.06	6.6	5.84	10.31
North Fork Shenandoah WTP	0.00	0.00	0.00	0.00	7.76
Dayton Service Area	0.2	0.22	0.31	0.26	2.18
Food Processors North Fork Shenandoah WTP	0.00	0.00	0.00	0.00	0.99
South River Service Area	0.00	0.06	0.16	0.08	0.99
New Market WTP	0.00	0.00	0.00	0.00	0.93
Staunton WTP	0.00	0.06	0.54	0.5	0.69
Strasburg Plant	1.11	1.11	1.11	1.1	0.60
Waynesboro Service Area	0.00	0.00	0.00	0.00	0.51
Bridgewater WTP	0.00	0.00	0.00	0.00	0.35
Spotswood Country Club	0.02	0.02	0.02	0.02	0.23
SDWC Service Area	0.00	0.00	0.00	0.00	0.13
Meadow Stream Farm	0.00	0.00	0.00	0.00	0.04
Lakeview Dairy	0.14	0.14	0.14	0.13	0.03
Verona Service Area	0.00	0.00	0.00	0.00	0.03
Waynesboro Country Club	0.00	0.00	0.00	0.00	0.02
Galen L Wenger	0.00	0.00	0.00	0.00	0.02
Golden View Farm	0.00	0.00	0.00	0.00	0.02
Ottobine Dairy	0.00	0.00	0.00	0.00	0.01
The Club At Ironwood	0.00	0.00	0.00	0.00	0.01
River Bend Farm	0.00	0.00	0.00	0.00	0.01
Oakland Farms, Inc.	0.00	0.00	0.00	0.00	0.01
Shenmont Farms	0.00	0.00	0.00	0.00	0.01
Broadway WTP	0.00	0.00	0.00	0.00	0.01
Broadway Plant Complex	0.00	0.00	0.00	0.00	0.01
Roselawn	0.00	0.00	0.00	0.00	0.01
Hillview Farm Inc	0.00	0.00	0.00	0.00	0.01
Kentmere Farm	0.00	0.00	0.00	0.00	0.01
Christians Creek Holsteins, Inc	0.00	0.00	0.00	0.00	0.01
Shenvalee Lodge Inc	0.00	0.00	0.00	0.00	0.01

* Climate scenarios were not completed in areas located outside of the Chesapeake Bay watershed

Note: Potential unmet demand is the portion of surface water demand for a specific facility that is limited by available streamflow as simulated in a given model scenario, including any known operational limits such as flow-by requirements. This unmet demand, if realized, could be managed through water conservation, alternative sources, operational changes, or from available storage.

A.11.6 Spatial Overview of Groundwater Demands

The cumulative impact analysis figures above provide an overview of surface water demands in the basin but did not include groundwater demands. A substantial portion of the demands in this basin are supplied by groundwater. Figure 248 identifies the location and size of projected groundwater demands in the basin for 2040 based on information provided by localities in water supply plans.

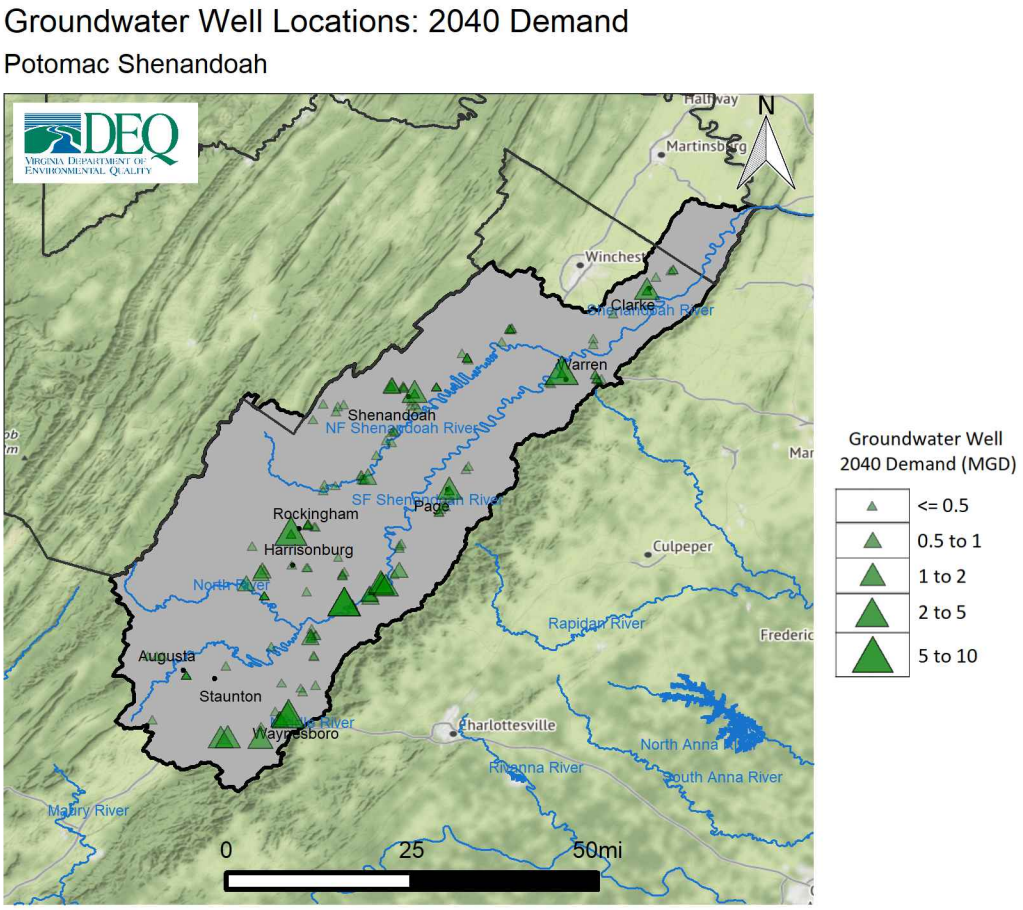

Figure 248: Projected 2040 Groundwater Demands in the Potomac Shenandoah Minor Basin

A.11.7 Trends and Goals

The Code of Virginia mandates that the State Water Control Board should take into consideration the principle that "adequate and safe supplies shall be preserved and protected for human consumption, while conserving maximum supplies for other beneficial uses".[100] This principle is the key driver of the challenges in water resource management, which is that all beneficial uses must be adequately considered when evaluating impacts to surface water resources. The State Water Control Board is tasked with ensuring that water supply quantity needs are met at all times while also protecting Virginia's natural resources, and furthermore, ensuring equitable allocation during a time of shortage.[101] While evaluating and planning for the long-term sustainability of water supply for Virginia is the primary goal for the State Plan, evaluating and limiting impacts to in-stream beneficial uses such as aquatic habitat life is also part of DEQ's responsibility.

The primary purpose of this section is to identify where the most significant challenges to long-term sustainability of water supply and other beneficial uses are indicated based on the CIA and information collated from local water supply plans within this basin. Goals for future planning and areas for additional data collection or analysis are also suggested where appropriate.

The CIAs were completed using the best available data and methods known to DEQ. This discussion focuses on the evaluation of trends - in other words the prevailing tendency or inclination. This means evaluating whether streamflow is simulated to increase or decrease in a given scenario, and by how much. A relative trend indicating reductions of greater than or equal to 10% in streamflow, whether driven by demand increases, changing climate conditions, or exempt user demands was considered a threshold for potential impacts to beneficial uses. The following summarize the key trends or goals for this basin are as follows:

- **Demand Scenarios:** Surface water demand in the Potomac Shenandoah is projected to increase by approximately 37% through 2040, with Community Water Systems being the primary category of growth. A greater than 10% reduction in streamflow in the short term drought (L30) and long term drought (L90) metrics is simulated within the watershed driven by increasing 2040 demands. Four river segments have a 10% or more reduction in streamflow in short term (L30) drought flows when comparing the 2020 and 2040 demand scenarios. These reductions are focused within the head water portion of the watershed and are primarily driven by increased demands from the cities of Harrisonburg, Staunton, and Waynesboro. The greatest reductions are simulated in the North River at Port Republic. Reductions are a result of combined reductions in streamflow observed at the confluence of the North, Middle, and South rivers at Port Republic. One river segment shows a more than 10% reduction in long-term drought flows (L90). Demands within the North and Dry rivers from the Town of Bridgewater and the City of Harrisonburg contribute to these simulated reductions. The 2040 demand scenario also results in an overall percent of flow change, or consumptive use of approximately 6% within the North and Dry river segment. Demands within the North and Dry rivers from the Town of Bridgewater and the City of Harrisonburg contribute to these simulated reductions as population and water demands are focused within this area. Potential unmet demand is simulated to occur for several facilities in the 2040 demand scenario, including CWS facilities for the cities of Harrisonburg, Winchester, Staunton, as well as the Augusta County Service Authority, and the Town of Dayton. The City of Harrisonburg's operational changes associated with their VWP withdrawal permit for withdrawals from the South Fork of the Shenandoah River could allow for greater system balancing, which would mitigate some of the impacts seen in the 2040 demand scenario. Current operational withdrawals are only from the North and Dry rivers and limit withdrawal balancing, especially during low flows. Furthermore, system interconnection is needed to maximize flexibility so withdrawals can be shifted in response to stream flow conditions. Overall, the basin has significant demands located in the headwaters that project further growth, but there is also limited storage. This means demand increases have an increased impact on streamflows during critical periods such as droughts. Regional coordination and planning, as well as investment in additional alternatives to include storage may be required to meet the projected increases in demands.

[100] § 62.1-44.36 of the Code of Virginia
[101] 9VAC25-390-20.1

- **Climate Scenarios:** Current climate modeling suggests Virginia will generally receive more precipitation on average in the future. However, the data also suggests the possibility of more severe droughts despite this overall trend of increasing precipitation. The dry climate scenario simulates significant reductions in streamflow of more than 20% for at least half of the basin for both the short-term (L30) and long-term drought (L90) metrics. The dry climate scenario also results in potential unmet demand in the largest public water suppliers including the cities of Winchester, Harrisonburg, and Staunton, as well as the Augusta County Service Authority, and the towns of Dayton and Bridgewater. The City of Harrisonburg shows the greatest unmet demand of 5.84 MGD in the basin under the dry scenario, as the city does not have surface water storage available to mitigate supply demands during extreme drought conditions. The South Fork River intake is not currently operating under the current VWP permit 16-0730. Large Self-Supplied Users including the O-N Minerals Strasburg Plant, Lakeview Dairy, and Spotswood Country Club show the greatest potential unmet water demands for Large SSUs during the dry scenario. Where future climate conditions resemble this dry scenario, the simulations indicate that drought conditions are more severe than the current drought of record for most of the basin. Simulations show short-term and long-term droughts with streamflows up to 20% lower than those experienced during the drought of record, which would result in broad impacts to public water supply as well as aquatic life and other beneficial uses during these periods. These scenarios should be evaluated and considered by localities and users when evaluating existing sources and alternatives, as well as for broader planning and resource management efforts by all stakeholders whether state or local.

- **Exempt User Scenario** The exempt user scenario, which models the cumulative maximum possible exempt demand from all users exempt from VWP permitting requirements, results in reductions in streamflow of more than 10% in both the short term (L30) and long term drought (L90) metrics for more than 80% of the basin when compared to current demands. For the short-term drought (L30) metric, simulating the maximum possible exempt user demands results in streamflow reductions of 9-95%, which occur across approximately 83% of the watershed. Similar results are simulated with the long term drought (L90) metric, with 6-56% reductions in streamflows occurring throughout approximately 83% of the basin compared to the current demand scenario. The greatest simulated reduction of streamflow in this scenario occurs in the North Fork near the City of Harrisonburg, the South Fork near the Town of Luray, and the Shenandoah River near the City of Winchester. Streamflow reductions of greater than 30% occur within the North Fork of the Shenandoah River near Harrisonburg, driven by the maximum possible exempt demands from the Dry River and North Fork of the Shenandoah River by the cities of Harrisonburg and Staunton. Reductions within the South Fork of the Shenandoah River near Luray are driven by upstream exempt demands from the City of Staunton's Gardner Spring intake. A more than 20% reduction compared to current demands is simulated near the confluence of the North and South Fork, driven by the maximum possible exempt demands for the Town of Berryville, City of Winchester, and FEMA intakes on the Shenandoah River. These results indicate that the cumulative maximum possible exempt demands in the basin exceed the water budget in many river segments, and could further impact water availability downstream in the Potomac River. Preserving water supply and other beneficial uses will require managing these demands with respect to their cumulative impacts and in the context of the available resources in the basin.

A.12 Upper Potomac Minor Basin

A.12.1 Watershed Overview

The Potomac River is one of the primary contributors to the Chesapeake Bay and its drainage spans across four states including Virginia, Maryland, Pennsylvania, and West Virginia. The Potomac River runs 405 miles beginning in West Virginia and draining into the Chesapeake Bay. The Potomac is fed by several smaller rivers, including the Shenandoah River which meets the Potomac at Harper's Ferry, West Virginia. The basin as a whole is characterized by a mix of mountainous terrain in the western headwaters which gradually give way to rolling hills, and finally into an increasingly urbanized region as the river meets the fall-line and flows into the D.C. metropolitan area and suburban portions of Virginia and Maryland.

The Upper Potomac Minor Basin is primarily located within northeast West Virginia, western Maryland, and southern Pennsylvania. A small segment of the watershed is located within Virginia. This section will focus on water resource information for the portions of the watershed located in Virginia - which is made up primarily of parts of Frederick and Clarke Counties. Streamflow in the Upper Potomac contributes directly to the streamflows in the Middle Potomac, which does include many Virginia water users. In this way, the demands in the upper portion of the basin have a very real impact on flows downstream. For modeling purposes, Virginia relies on data provided by the Interstate Commission on the Potomac River Basin for an estimate of these out-of-state demands from the Upper Potomac as they are passed through to the Middle Potomac, but they are not captured in the tables provided below.

The Potomac River as a whole spans across four of Virginia's Physiographic Provinces. The topography varies widely as it stretches east from the Valley & Ridge to the Coastal Plain where it enters the Chesapeake Bay. Fertile valleys in the Shenandoah Valley progress into steep slopes along the Blue Ridge, gradually wearing into rolling hills of the Piedmont and flat descending landscapes of the Coastal Plain.

A.12.2 Existing Water Sources

Major surface water sources within the basin include Vandevender Spring, Clearbrook quarry, and Abrams Creek. Groundwater within the basin is primarily withdrawn from bedrock aquifers and is the primary water source in the watershed.

Withdrawals within the basin are used for public water supply as well as for agriculture, irrigation, commercial, and industrial/manufacturing, and mining operations.

The location of wells and surface water intakes identified to DEQ within the basin are shown in figure 249. This figure does not include private or domestic wells. This map also shows locations of any Instream Flow Incremental Method (IFIM) studies completed in the basin.

Table 65: Population Trend by Locality in the Upper Potomac Basin

Localities	20 Year % Change
Clarke	9.19
Frederick	30.34
Highland	-16.69
Winchester	13.77

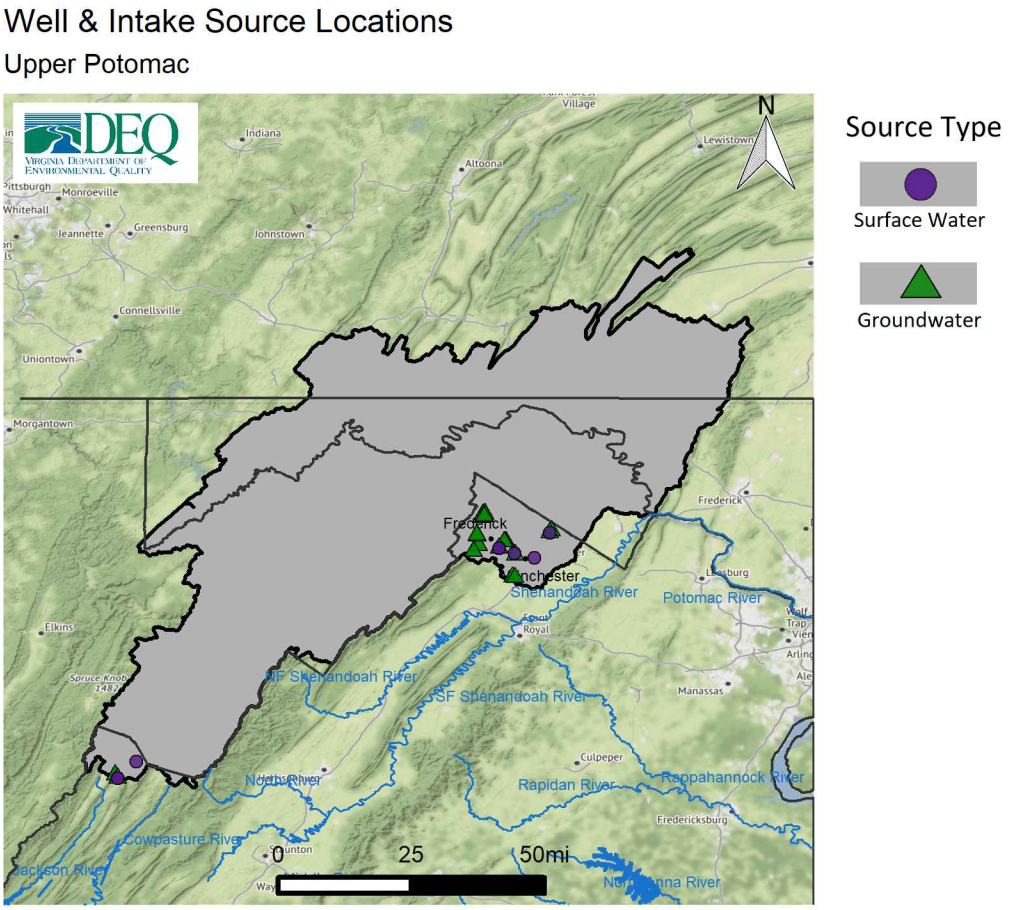

Figure 249: Spatial distribution of groundwater wells and intakes in the Upper Potomac Minor Basin

A.12.3 Existing Water Use

The following section discusses existing (current) water use within the basin, which is based on existing demand information submitted to DEQ in the water supply plans. Note once again that the majority of the Upper Potomac Basin is outside of Virginia and the following tables cover only the portions within Virginia. Table 66 provides a summary of all demands within the basin by system and source type. It also provides a count of surface and groundwater sources associated with each system type.

Table 66: Summary of Upper Potomac Minor Basin Water Demand by Source Type and System Type

System Type	Source Count	2020 Demand (MGD)	2030 Demand (MGD)	2040 Demand (MGD)	20 Year Percent Change
Surface Water					
Agriculture	1	2.09	2.09	2.09	0.00
CWS	1	1.14	1.77	2.41	110.71
Large SSU	2	0.26	0.26	0.26	0.00
Small SSU	N/A	0.00	0.00	0.00	0.00
Total SW	**4**	**3.49**	**4.12**	**4.76**	**36.39**
Groundwater					
Agriculture	0	0.01	0.01	0.01	0.00
CWS	19	1.30	1.94	2.59	100.05
Large SSU	9	0.07	0.07	0.07	0.01
Small SSU	N/A	2.49	3.45	4.40	76.91
Total GW	**28**	**3.87**	**5.47**	**7.07**	**82.69**
Total (SW + GW)					
Agriculture	1	2.10	2.10	2.10	0.00
CWS	20	2.44	3.72	5.00	105.05
Large SSU	11	0.33	0.33	0.33	0.00
Small SSU	N/A	2.49	3.45	4.40	76.91
Minor Basin Total	**32**	**7.36**	**9.60**	**11.83**	**60.73**

* Small SSU demands are county-wide estimates of private well usage below 300,000 gallons a month. The number of private wells is not known.

The total existing demand from all surface and groundwater sources is approximately 7.36 MGD, with groundwater supplying approximately 3.87 MGD or 53% of total water demands. Surface water demand within the basin totals approximately 3.49 MGD, or 47% of current demands. Groundwater demands are primarily driven by Small Self-Supplied Users (Small SSUs) reliant on private wells for water supply. Community Water System (CWS) facilities are the second largest demand of groundwater in the basin. Surface water demands are primarily demanded from Agricultural Self-Supplied Users (AG), with CWS the second largest demand in the basin.

The five largest facility demands for each source type are provided in Table 67. The largest groundwater demands include withdrawals for public water supply by the Frederick County Sanitation Authority and the Lake Holiday Estate.

Table 67: Top 5 Users in 2040 by Source Type in the Upper Potomac Minor Basin

Facility Name	System Type	Locality	2020 Demand (MGD)	2030 Demand (MGD)	2040 Demand (MGD)	20 Year Percent Change	% of Total Surface Water
Surface Water							
Laurel Hill Trout Farm- North Monterey	AG	Highland	2.06	2.06	2.06	0.00	43.28
Frederick County Sanitation Authority	CWS	Frederick	0.68	1.32	1.95	186.76	40.97
Rock Harbor Golf Course	Large SSU	Frederick	0.17	0.17	0.17	0.00	3.57
Winchester Golf Club	Large SSU	Frederick	0.09	0.09	0.09	0.00	1.89
Total SW			3	3.64	4.27	42.33	89.71
Groundwater							**% of Total Groundwater**
Frederick County Sanitation Authority	CWS	Frederick	0.7	1.35	2	185.71	28.29
Lk Holiday Estate (The Summit)	CWS	Frederick	0.37	0.37	0.37	0.00	5.23
Monterey Service Area	CWS	Highland	0.07	0.07	0.07	0.00	0.99
Winchester Plant	Large SSU	Frederick	0.04	0.04	0.04	0.00	0.57
Shawnee Land Utilities Co	CWS	Frederick	0.03	0.03	0.03	0.00	0.42
Total GW			1.21	1.86	2.51	107.44	35.5

Table 66 also provides the proportion of each use category that is supplied by either surface water or groundwater. Use categories include Community Water System , Large Self-Supplied User), Small Self-Supplied User , and Agricultural Self-Supplied User. These categories are defined below. Surface water demand is primarily comprised of AG and CWS demands. Groundwater demand is primarily comprised of domestic well use from Small SSUs and CWS facilities reliant on groundwater for supply.

The CWS category includes any public and private waterworks that serve at least 15 service connections used by year-round residents or regularly serve at least 25 year-round residents, and are regulated under the Virginia Department of Health's Waterworks Regulation (12VAC5-590). In the Upper Potomac Minor Basin, approximately 1.3 MGD of groundwater demand and 1.14 MGD of surface water demand is from CWS facilities. Significant groundwater users within this category include Frederick County Sanitation Authority, the Town of Monterey, and the Lake Holiday Estate. Significant surface water users in the category also include the Frederick County Sanitation Authority. CWS demands represent approximately 28% of current water demands in the basin.

Large SSUs include any non-CWS or AG who withdraw more than 300,000 gallons per month from a well or surface water intake. In the Upper Potomac Minor Basin, approximately 0.07 MGD of groundwater demand and 0.26 MGD of surface water demand is from Large SSUs. Significant groundwater users within this category include the Valley Protein Winchester Plant, Roch Harbor Golf Course, and the Covia Holding Corporation Gore Mining Plant. Significant surface water users include the Rock Harbor Golf Course and Winchester Golf Club. Large SSU demands are limited in the basin and it is the smallest use category.

Small SSUs include any users who withdraw less than 300,000 gallons per month from wells. Small SSUs generally consist of residential or domestic use for those who live outside service areas and provide their own water. Small SSU demand is met with groundwater. In the Upper Potomac Minor Basin, approximately 2.49 MGD of groundwater demand is from Small SSUs. Localities within the basin with the greatest estimated contribution from Small SSUs include Frederick County and the Town of Monterey.

The AG category includes crop farms, livestock operations, aquaculture and other agricultural facilities. In the Upper Potomac Minor Basin, approximately 0.01 MGD of groundwater demand and 2.09 MGD of surface water demand is from AG. No significant groundwater users are present within this category. Estimates of AG demands were supplied by the Town of Monterey and Frederick County. The Laurel Hill Trout Farm is the only surface water user in the basin for this category.

A.12.4 Projected Population and Water Use

Projected Population: Trends in water use are generally driven by trends in population change or economic development. Increasing population within an area generally means increased connections for community water systems or additional demands from homeowners that construct wells. Increasing population in an area also tends to incentivize both new and expanded industrial and commercial water use.

Table 65 shows the projected change in population by percent between 2020 and 2040 for each locality located partly or wholly within this minor basin. The watersheds proximity to Northern Virginia, Washington D.C. metro area, and Shenandoah Valley is the primary driver of projected increases in population over the planning period. This is most prominent in Frederick County with a more than 30% increase in population projected by 2040. As noted previously, much of this basin falls outside of Virginia.

Projected Water Use: The following section discusses projected water use through 2040 within the Upper Potomac basin, based on projections provided in local and regional water supply plans. Table 66, included in the existing demand section above, is the basis for information discussed in this section. This Table, as noted earlier, covers only facilities within Virginia.

Total demand within the basin is projected to increase from 7.36 MGD in 2020 to 11.83 MGD in 2040. Growth is driven primarily by increases in surface water withdrawals to support CWS facilities. No other use categories are projecting increased surface water demands in the basin. Groundwater is projected to increase in demand by approximately 82% by 2040, more than twice as much as surface water demands. Projected increases in groundwater demands are driven by projected increases in domestic well users (Small SSU) and increased reliance on groundwater by CWS facilities in the basin. The total projected increase in water demand is approximately 60% by 2040. The largest contributors to this trend in total projected demand include Small SSU increases in Frederick County, and increased demands from the Frederick County Sanitation Authority.

CWS users within the basin are projected to increase in demand by 105% by 2040. Within this category, surface water use is projected to increase by 110%, while groundwater use is projected to increase by 100%. The Frederick County Sanitation Authority is the only CWS projecting increases in water demand in the basin. Projected increases in surface and groundwater demands are fully represented by the Frederick County Sanitation Authority.

Large SSUs within the basin are projected to remain constant in demand by 2040. Within this category, surface water use is primarily driven by by several golf courses in the basin, while groundwater use is more diverse supplying golf course, mining operations, and manufacturing users.

Small SSU demands within the basin are projected to increase in demand by 2040. As noted previously, small SSU demand is entirely met with groundwater and represents domestic water use from private wells. Estimated Small SSU demands in total are the largest portion of groundwater demand currently, and are projected to remain the largest use category throughout the planning period. Significant increases in domestic

well use are projected to occur within Frederick County. Projected increases in population align with increased groundwater demands.

Agriculture Users within the basin are projected to remain constant in demand by 2040. Within this category notable surface water users include the Laurel Hill Trout Farm and other small agricultural users in Frederick County. No known groundwater users are present in the basin; groundwater demand for the basin was estimated and is not projected to increase.

A.12.5 Cumulative Impact Analysis

The following section provides a brief summary of the Cumulative Impact Analysis (CIA) modeling results in the Upper Potomac Minor Basin. Note that much of this basin lies outside of the Virginia. While the results do include areas outside of Virginia, only those river segments within Virginia will be evaluated here. Areas outside of Virginia have cannot be verified due to limited information available in these areas. Discussion of these results will primarily be found in the Trends and Goals section of this appendix. However a brief overview of the VAHydro model and the scenarios and metrics is provided below.

The VAHydro surface water model simulates streamflow using inputs such as precipitation, climate, land use, and topography, combined with data on all known withdrawals and discharges, and operational rules of major hydrologic features such as reservoirs. Each minor basin is broken into smaller hydrologic subsections, or river segments. The model simulates the water balance on a daily basis for each individual river segment, with each downstream segment being affected by the cumulative impact of streamflow changes occurring in upstream segments. The following figures help analyze this cumulative impact within the Upper Potomac Minor Basin (model results summarized by river segment). Note that this section is not intended to document in detail the methods and assumptions for the VAHydro model or for the scenarios and metrics discussed. More documentation of the model and assumptions can be found in Chapter 4.

The VAHydro surface water model was used to simulate streamflow under a variety of scenarios. Demand scenarios examine how streamflow is impacted under 2030 or 2040 demands as compared to current (2020) demands. Demands were calculated based on current and future demand information submitted through local and regional water supply plans. Climate change scenarios examine how streamflow is impacted when 2040 demands are simulated in conjunction with a range of precipitation and temperature conditions that may occur in the future due to changing climate (Dry, Median, Wet scenarios). Finally, the exempt user scenario examines impacts from users excluded, or exempt, from VWP permit requirements per Va. Code § 62.1-44.15:22 B. Exempt users were simulated at the maximum possible demand identified through a review of demand justification values commonly asserted by exempt users, including but not limited to VDH pump capacity, maximum pre-1989 withdrawal, and maximum intake capacity. In order to effectively manage surface water resources and address the uncertainty related to these demands, DEQ determined the most conservative, or maximum possible, demand should be evaluated in this scenario. However, DEQ does not agree that the maximum values used in this scenario represent an allocation for, or the expectation of, a future withdrawal of that volume; nor does DEQ concede that any particular exempt user is necessarily entitled to withdraw any particular maximum value used in this scenario. The methods and assumptions for each of these modeling scenarios are discussed in more detail in Chapter 4.

For each scenario described above, different metrics can be used to evaluate the simulated streamflow. A metric is a method for measuring or evaluating a given set of data; different metrics can be evaluated to answer different questions. Within this section the following metrics will be discussed: the lowest 30 day flow (L30), the lowest 90 day flow (L90), 7Q10, and overall change in flow. The L30 describes the lowest consecutive 30 day average daily streamflow over the simulation period. This metric is a representation of a short-term, or acute drought, and is a good metric for evaluating impacts to direct withdrawals without storage. Similarly the lowest 90 day flow represents the lowest consecutive 90 day average daily streamflow over the simulation period. This would represent a prolonged drought and is often used to evaluate impacts to reservoirs. The 7Q10 is the lowest 7-day average flow that occurs (on average) once every 10 years. 7Q10 is generally used in the evaluations of in-stream beneficial uses such as waste assimilative capacity. Overall change in flow describes the net loss of water from the riverine system as a result of off-stream use

not otherwise returned through point source discharges, or losses due to evapotranspiration. This metric is useful for evaluating impacts to aquatic life and is discussed in more detail in Chapter 4.

Demand Scenarios: 2020 demand or current demand, 2030 demand, and 2040 demand scenarios were simulated. The following series of figures compares the 2030 and 2040 demand scenarios to the current demand scenario. The change in flow depicted on each map is the change expected when comparing two scenarios - in this case future demands compared to current demands. Each page includes two figures comparing either the 2030 or 2040 demand scenario to current demand using the l30, l90, and 7Q10 metrics. This allows for comparisons of simulated impacts between the 2030 and 2040 demand scenarios. The scenarios and metrics are identified in the paragraph below and in the figure captions.

Figures 250 and 251 compare the lowest 30 day flow simulated with the current demand scenario with the lowest 30 day flow simulated in the 2030 and 2040 demand scenarios respectively. Figures 252 and 253 compare the lowest 90 day low flow simulated with the current demand scenario with the lowest 90 day flow simulated in the 2030 and 2040 demand scenarios respectively. Figures 254 and 255 compare the 7Q10 simulated with the current demand scenario with the 7Q10 simulated in the 2030 and 2040 demand scenarios respectively.

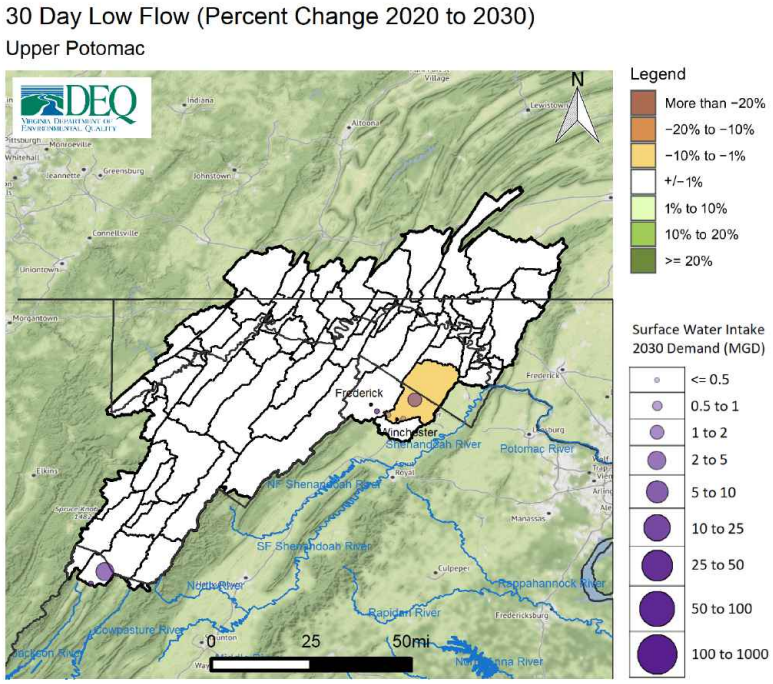

Figure 250: Change in 30 day low flow between 2020 and 2030 demand scenarios within the Upper Potomac Minor Basin

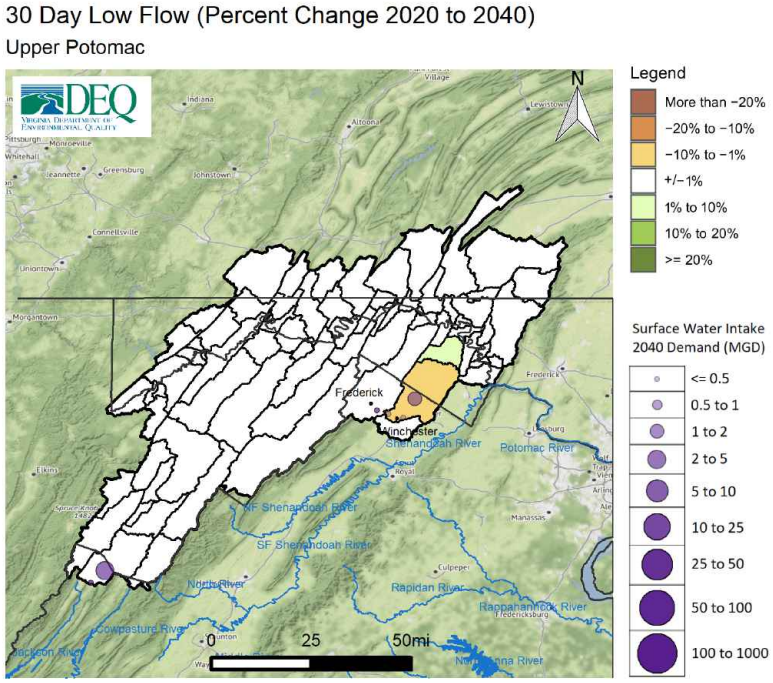

Figure 251: Change in 30 day low flow between 2020 and 2040 demand scenarios within the Upper Potomac Minor Basin

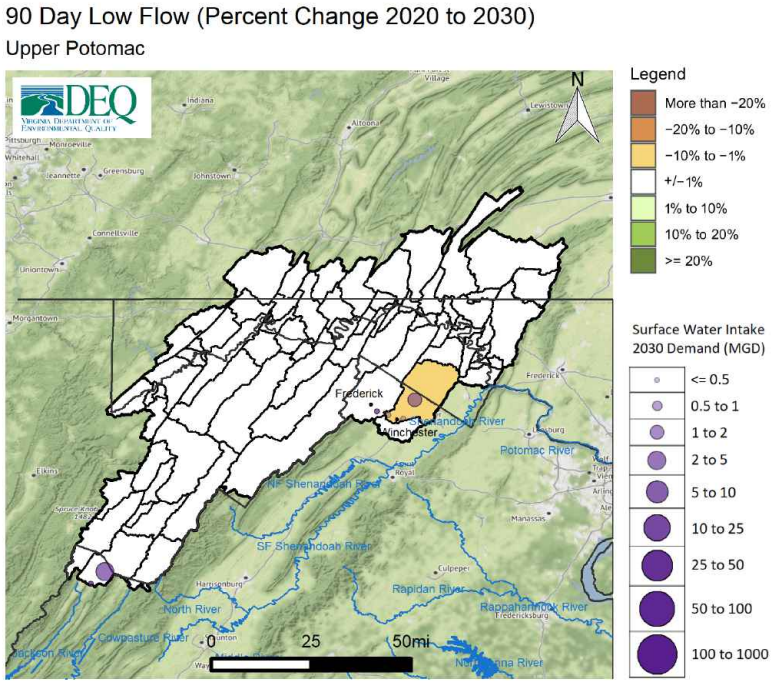

Figure 252: Change in 90 day low flow between 2020 and 2030 demand scenarios within the Upper Potomac Minor Basin

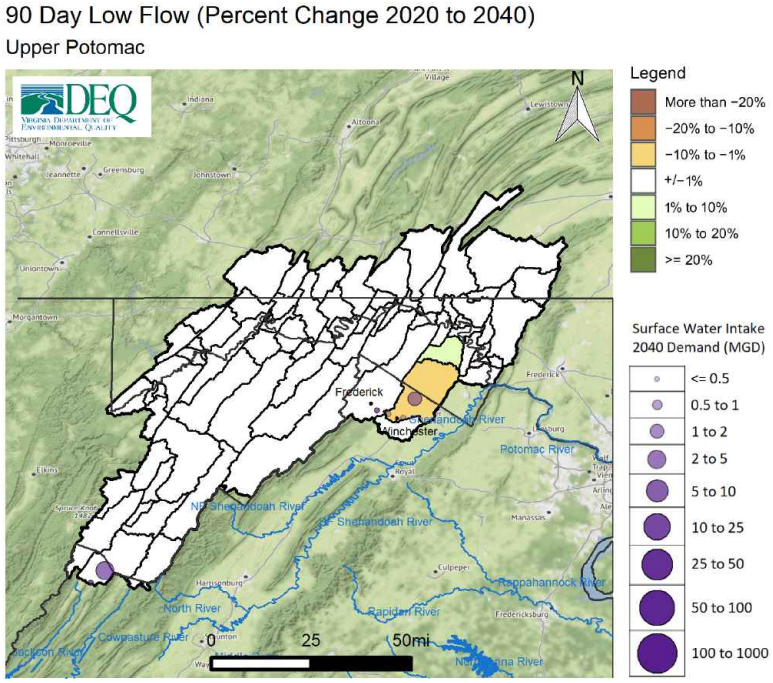

Figure 253: Change in 90 day low flow between 2020 and 2040 demand scenarios within the Upper Potomac Minor Basin

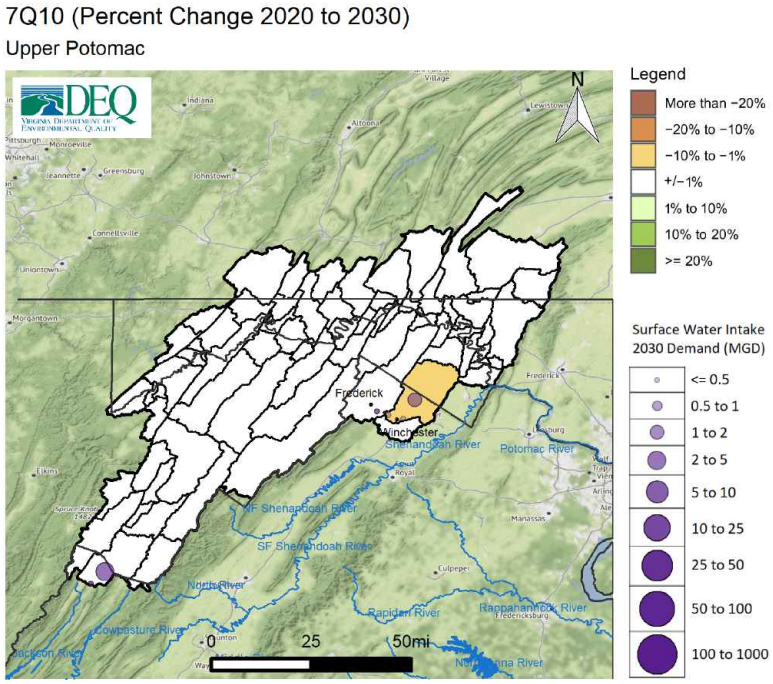

Figure 254: Change in 7Q10 between 2020 and 2030 demand scenarios within the Upper Potomac Minor Basin

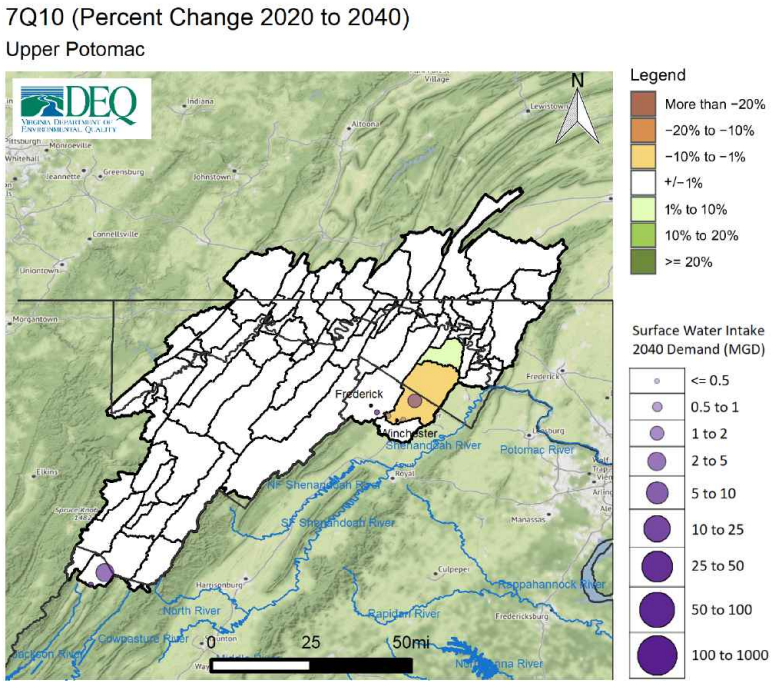

Figure 255: Change in 7Q10 between 2020 and 2040 demand scenarios within the Upper Potomac Minor Basin

The figures above show a comparison between two scenarios. An additional way to evaluate impacts to streamflow is to examine the total reduction in streamflow resulting from all withdrawals within a river segment, as well as losses due to evapotranspiration, while taking into consideration any discharges back to the source. To use a common industry term, the overall change in flow metric evaluates "consumptive use", or the amount of water removed from the river that is not returned through discharges. This can help describe potential impacts to downstream withdrawals, while also providing a basis for evaluating impacts to aquatic life. In general, total reductions in streamflow can result in a reduction in aquatic biodiversity [102]. The relation between streamflow and aquatic biodiversity is discussed in more detail in Chapter 4. Figure 256 shows the overall change in streamflow for the 2030 Demand Scenario, while figure 257 shows the overall change in streamflow for 2040 Demand Scenario.

[102] Rapp, J.L., R. Burgholzer, J. Kleiner, D. Scott, and E. Passero. 2020. "Application of a New Species-Richness Based Flow Ecology Framework for Assessing Flow Reduction Effects on Aquatic Communities." Journal of the American Water Resources Association 1–14.https://doi.org/10.1111/1752-1688.12877.

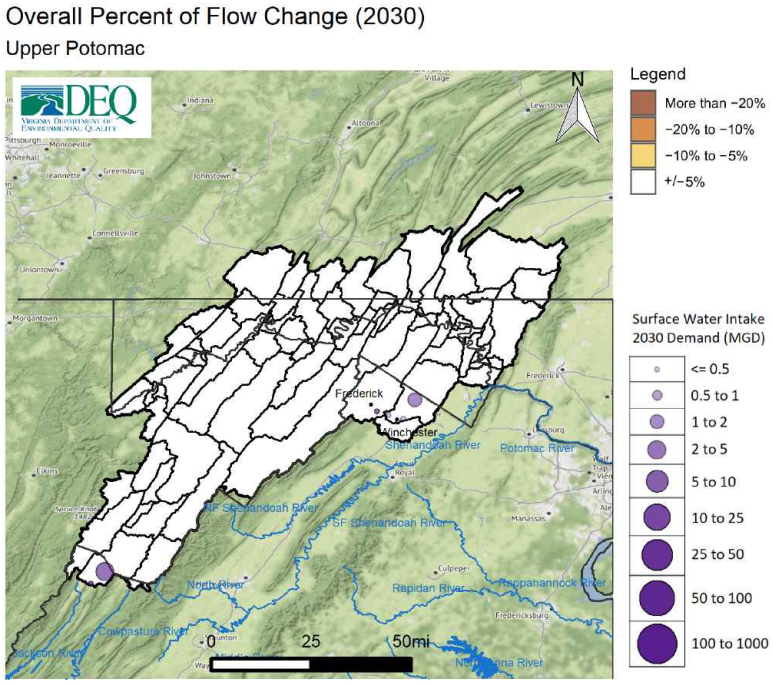

Figure 256: Overall change in flow in percent for 2030 demand scenario within the Upper Potomac Minor Basin

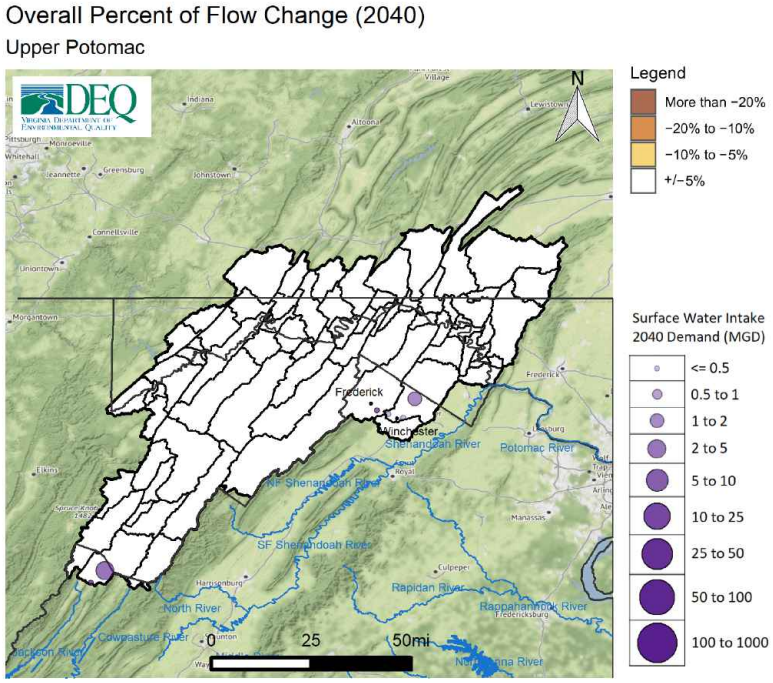

Figure 257: Overall change in flow in percent for 2040 demand scenario within the Upper Potomac Minor Basin

Climate Scenarios: Three scenarios that simulate impacts to streamflow in response to changes in temperature and climate were completed for areas in the state where climate data was available, which includes the portions of the Commonwealth located in the Chesapeake Bay drainage. Details on the methods and assumptions employed for these scenarios can be found in Chapter 4. In short, the three scenarios can be described as dry, median, and wet scenarios. Virginia is expected to experience a range of precipitation and temperature changes that may vary spatially and from year to year. The potential for both more severe and prolonged droughts as well as for higher intensity and more frequent rain events must be considered. These three scenarios are not intended as predictions of future climate conditions, but as representations of several possibilities that climate change models indicate could occur. Should they occur, these results provide an evaluation of how streamflows may be impacted. Their purpose is to build upon existing climate modeling to provide a foundation for state and local government, as well as other stakeholders, to better evaluate what practical water resource challenges may be associated with the range of climate conditions Virginia could experience.

Figure 258 depicts the percent change in the L30 for the dry climate scenario in conjunction with 2040 demands, as compared to the current climate and demand scenario. Reductions in streamflow in this scenario may be caused by reduced precipitation, increased demand, or as is generally the case, a combination of both. Figures 259 and 260 depict the L30 for the median and wet climate scenarios (in conjunction with 2040 demands) as compared to the current climate and demand scenario.

Figure 261 depicts the percent change in the L90 for the dry climate scenario in conjunction with 2040 demands, as compared to the current climate and demand scenario. Figures 259 and 263 depict the L30 and L90 for the median and wet climate scenarios (in conjunction with 2040 demands) as compared to the current climate and demand scenario.

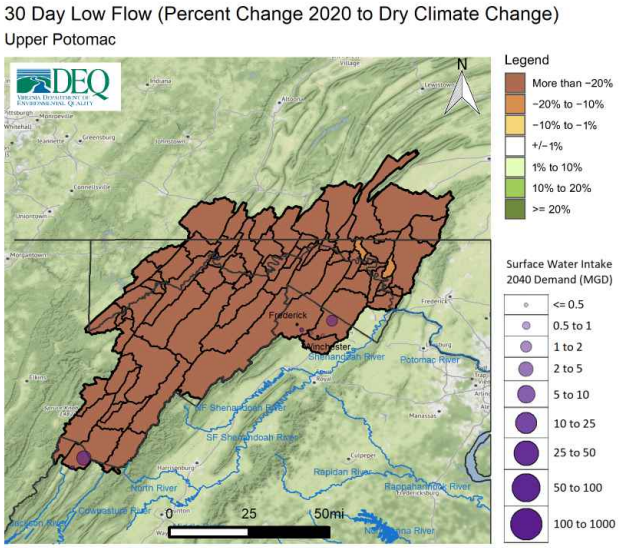

Figure 258: Change in 30 day low flow between current climate/demand scenario and the dry climate/2040 demand scenario within the Upper Potomac Minor Basin

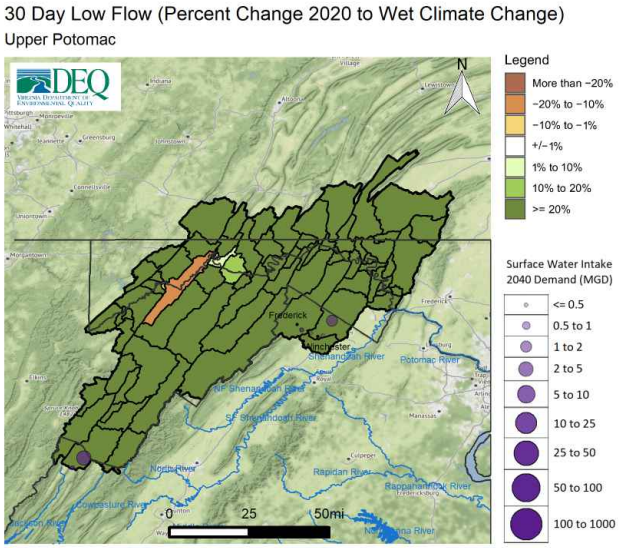

Figure 260: Change in 30 day low flow between current climate/demand scenario and the wet climate/2040 demand scenario within the Upper Potomac Minor Basin

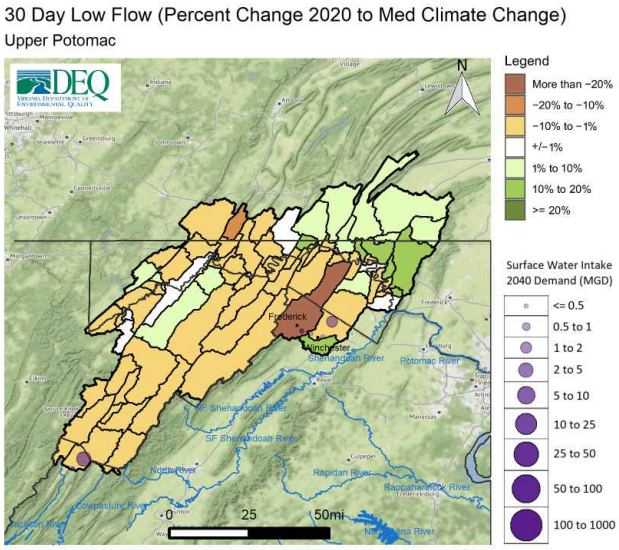

Figure 259: Change in 30 day low flow between current climate/demand scenario and the median climate/2040 demand scenario within the Upper Potomac Minor Basin

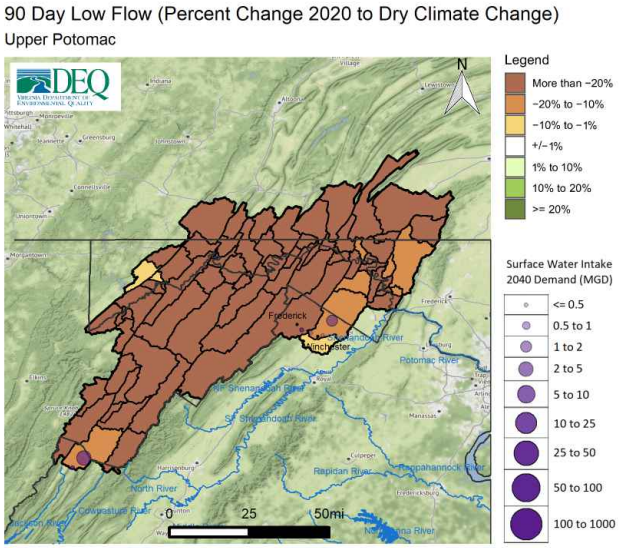

Figure 261: Change in 90 day low flow between current climate/demand scenario and the dry climate/2040 demand scenario within the Upper Potomac Minor Basin

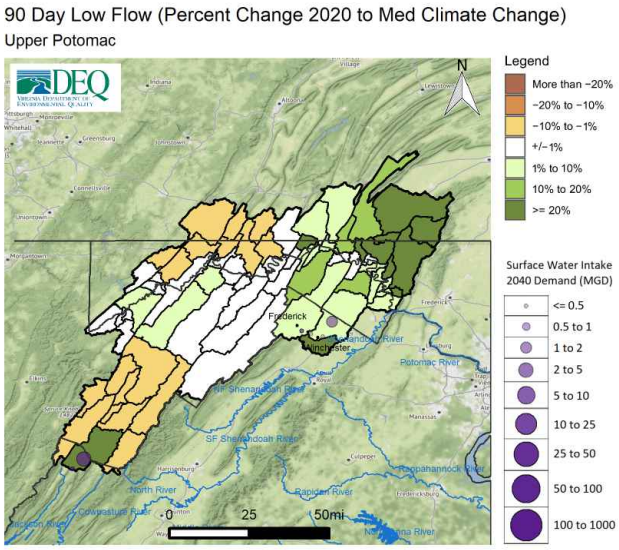

Figure 262: Change in 90 day low flow between current climate/demand scenario and median climate/2040 demand scenario within the Upper Potomac Minor Basin

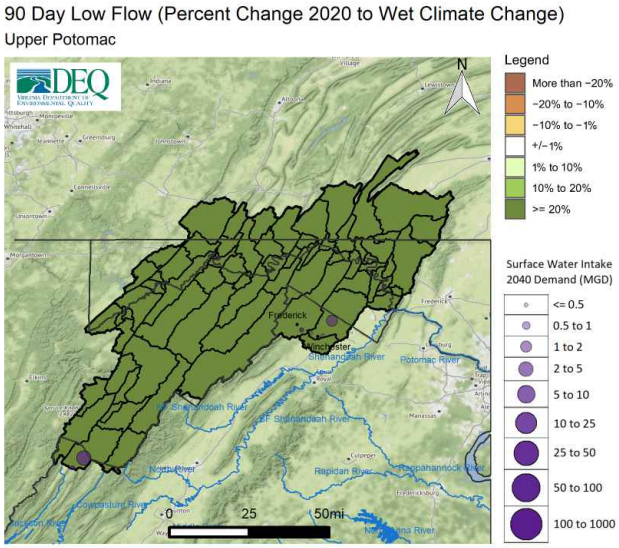

Figure 263: Change in 90 day low flow between current climate/demand scenario and wet climate/2040 demand scenario within the Upper Potomac Minor Basin

Exempt User Scenario: The exempt user scenario simulates the maximum possible exempt demand for users excluded from Virginia Water Protection permitting requirements per 9VAC25-210-310, in combination with the permitted withdrawal limits for those users that are permitted. A more detailed discussion of the data and assumptions used in this scenario can be found in Appendix B. Note that this scenario uses current climate conditions. Figure 264 depicts the percent change in 30 day low flow between the exempt user scenario and current (2020) demand. Figure 265 depicts the percent change in 90 day low flow between the exempt user scenario and current (2020) demand. Figure 266 depicts the percent change in the 7Q10 between the exempt user scenario and current (2020) demand. Finally, figure 267 depicts the overall change in flow in percent (consumptive use) for the exempt user scenario.

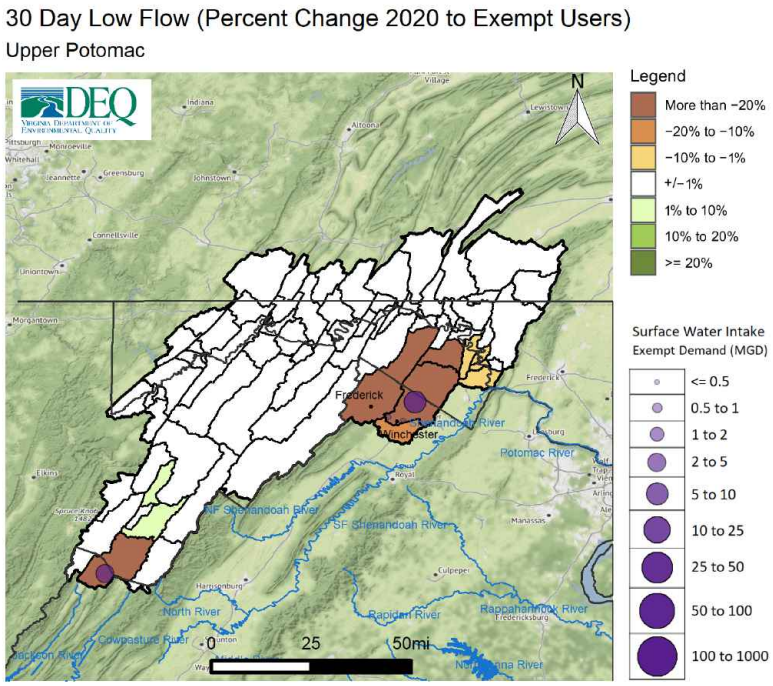

Figure 264: Change in 30 day low flow between current demand scenario and exempt User scenario within the Upper Potomac Minor Basin

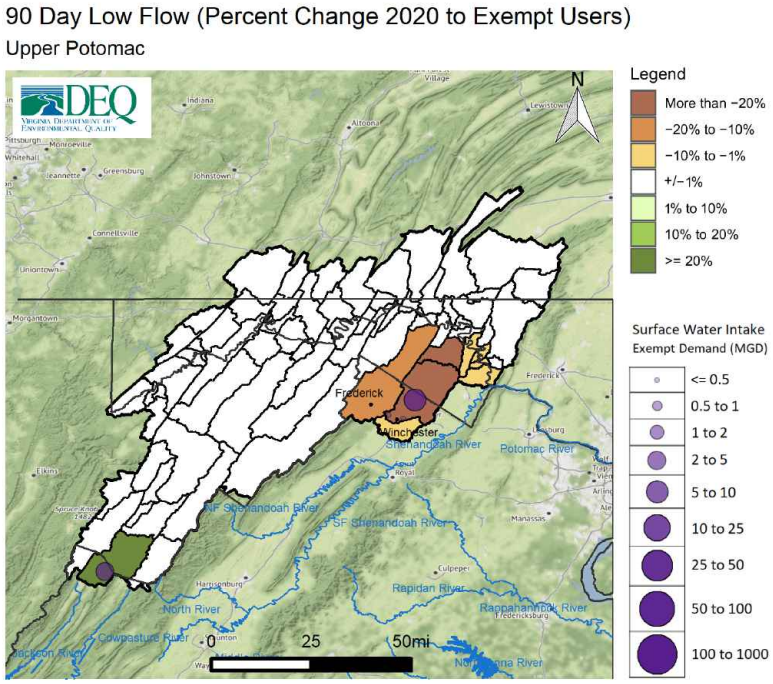

Figure 265: Change in 90 day low flow between current demand scenario and exempt User scenario within the Upper Potomac Minor Basin

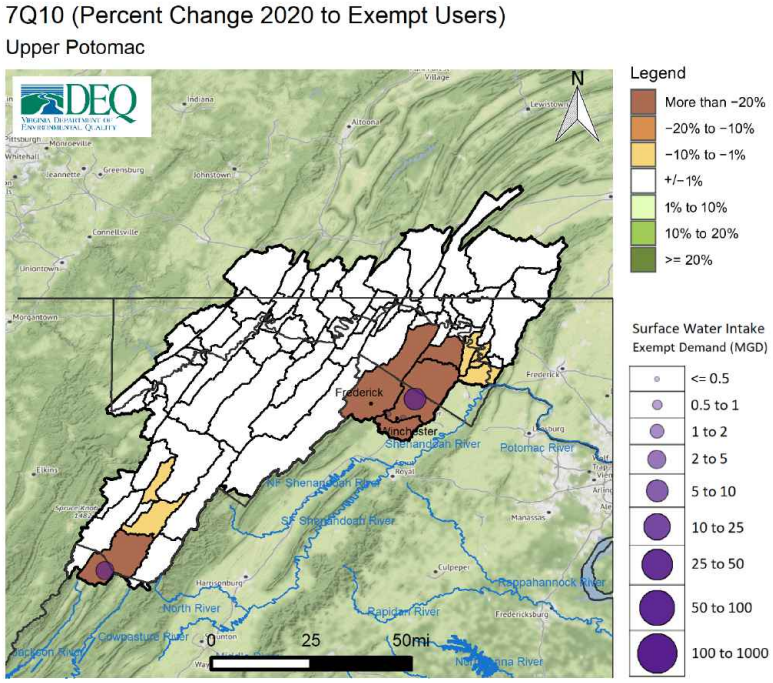

Figure 266: Change in 7Q10 between current demand scenario and exempt User scenario within the Upper Potomac Minor Basin

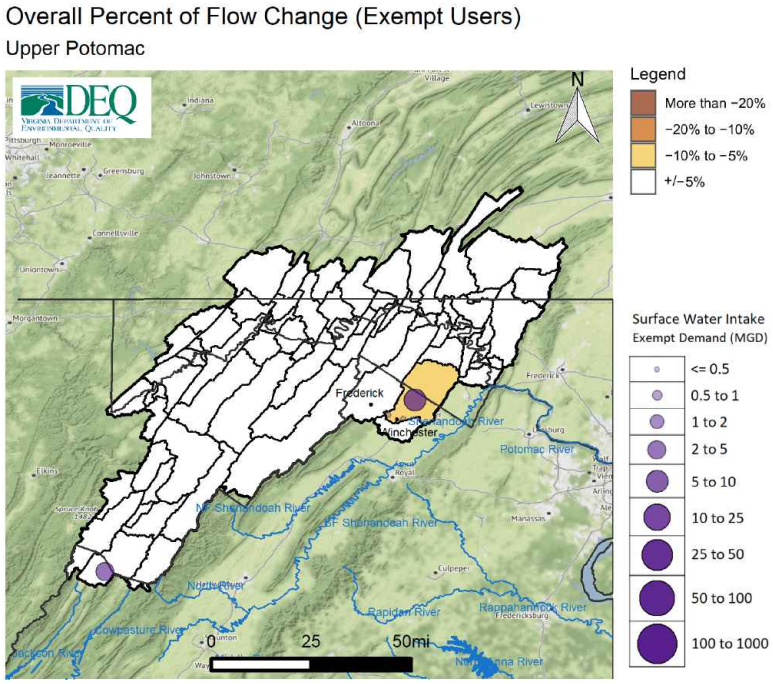

Figure 267: Overall change in flow in percent for exempt user scenario within the Upper Potomac Minor Basin

Potential Unmet Demand: Potential unmet demand was evaluated for all facilities within the basin for each scenario. Potential unmet demand is the portion of surface water demand for a specific facility that is limited by available streamflow as simulated in a given model scenario, including any known operational limits such as flow-by requirements. This unmet demand, if realized, could be managed through water conservation, through alternative sources, operational changes, or from available storage. Absent of these or other options, this portion of demand could remain unmet. As with all scenarios, demand requirements were determined using demand projections provided in the water supply plans. In the case of the exempt user scenario, the highest demand amount among the data sets described in the exempt user scenario documentation in Chapter 4 was used for users exempt from VWP permitting requirements.

This metric is useful for evaluating where the results seen in the above figures may result in challenges in meeting future demands under a variety of conditions including increasing demands in the basin, changing climate, or withdrawals from users exempt from permitting requirements. Table 68 provides for each facility the highest average daily potential unmet demand over a 30 day period over the course of the simulation for the following scenarios: 2020 demand, 2030 demand, 2040 demand, dry climate, and exempt User. Only facilities showing potential unmet demand in at least one scenario appear on this table. The dry climate scenario is selected among the climate scenarios as the dry scenario represents the potential for increased drought intensity and frequency, and therefore poses the greatest challenge for water supply. Additional information on the potential unmet demand metric can be found in Chapter 4.

Table 68: Change in Highest 30 Day Potential Unmet Demand (MGD) in Upper Potomac Minor Basin

Facility	**2020 Demand**	**2030 Demand**	**2040 Demand**	**Dry Climate**	**Exempt User**
FCSA Opequon Intake	0.00	0.00	0.00	2.3	3.13
Carpers Valley Golf Course	0.00	0.00	0.00	0.03	0.02
Gore Plant	0.00	0.00	0.00	0.04	0.00
Winchester Plant	0.00	0.00	0.00	0.02	0.00

* Climate scenarios were not completed in areas located outside of the Chesapeake Bay watershed

Note: Potential unmet demand is the portion of surface water demand for a specific facility that is limited by available streamflow as simulated in a given model scenario, including any known operational limits such as flow-by requirements. This unmet demand, if realized, could be managed through water conservation, alternative sources, operational changes, or from available storage.

A.12.6 Trends and Goals

The Code of Virginia mandates that the State Water Control Board should consider as principle that "adequate and safe supplies shall be preserved and protected for human consumption, while conserving maximum supplies for other beneficial uses".[103] This principle is the key driver of the challenges in water resource management, which is that all beneficial uses must be adequately considered when evaluating impacts to surface water resources. The State Water Control Board is tasked with insuring that water supply quantity needs are met at all times while also protecting Virginia's natural resources, and furthermore, ensuring equitable allocation during a time of shortage.[104] While evaluating and planning for the long-term sustainability of water supply for Virginia is the primary goal for the State Plan, evaluating and limiting impacts to in-stream beneficial uses such as aquatic habitat life is also part of DEQ's responsibility.

The primary purpose of this section is to identify where the most significant challenges to long-term sustainability of water supply and other beneficial uses are indicated based on the CIA and information collated from local water supply plans within this basin. Goals for future planning and areas for additional data collection or analysis are also suggested where appropriate.

The CIAs were completed using the best available data and methods known to DEQ. This discussion focuses on the evaluation of trends - in other words the prevailing tendency or inclination. This means evaluating whether streamflow is simulated to increase or decrease in a given scenario, and by how much. A relative trend indicating reductions of greater than or equal to 10% in streamflow, whether driven by demand increases, changing climate conditions, or exempt user demands was considered a threshold for potential impacts to beneficial uses. The following summarize the key trends or goals for this basin. Note once again that this section will primarily focus on areas of the Upper Potomac that are within Virginia.

- **Demand Scenarios:** Total demand within the Virginia portion of the basin is only projected to increase by around 4.5 MGD between 2020 and 2040, with only 1.27 MGD of that coming from surface water sources. As a result, the 2040 demand scenario does not show significant streamflow reductions compared to the 2020 demand scenario in any metric in any river segments. In other words, the projected demands as presented in the regional and local water supply plans do not indicate any additional impacts to future water supply availability and in-stream beneficial uses within the basin. This does not suggest that impacts to water supply are not already occurring during drought periods, but that increased impacts due to demand alone are not expected. It's also worth noting that in the Virginia portion of the basin, groundwater provides more than half of total demand. Frederick County Sanitation Authority, the largest CWS facility in the Virginia portion of the basin, is projected to increase demand by more than 1 MGD. However, much of that demand is met by groundwater, which can actually result in an increase to streamflows in some conditions when it is discharged from municipal treatment plants into surface water sources - as seen in Opequon Creek.

- **Climate Scenarios:** The dry climate scenario simulates potential reductions in streamflow of more than 20% throughout the basin during short-term (L30) and long-term drought (L90) metrics. The dry scenario also results in potential unmet demand for several facilities including Frederick County Sanitation Authority's Opequon Intake. Where in the future climate conditions resemble this dry scenario, the simulations indicate drought conditions more severe than the current drought of record will be experienced for most of the basin. Simulations show short-term and long-term droughts with potential reductions in streamflows greater than 20% lower than those experience during the drought of record, which would result in broad impacts to public water supply as well as aquatic life and other beneficial uses during these periods.

- **Exempt User Scenario:** The exempt user scenario, which models the cumulative maximum possible exempt demands from all users exempt from VWP permitting requirements, shows several areas with significant reductions in streamflow compared to the 2020 demand scenario for both the 30 day low flow and 90 day low flow. The largest reductions are found in the Opequon Creek area, driven by

[103] § 62.1-44.36 of the Code of Virginia
[104] 9VAC25-390-20.1

exempt withdrawals from Frederick County Sanitation Authority's Clearbrook Quarry. This quarry is not currently modeled as a quarry/reservoir and so the extent to which this withdrawal would impact streamflows in Opequon Creek, if at all, is not clear. More resources will need to be invested to develop models that handle conjunctive use systems such as this more robustly.

A.13 Middle Potomac Basin

A.13.1 Watershed Overview

The Potomac River is one of the primary contributors to the Chesapeake Bay and its drainage spans across four states including Virginia, Maryland, Pennsylvania, and West Virginia. The Potomac River runs 405 miles beginning in West Virginia and draining into the Chesapeake Bay. The Potomac River is fed by several smaller rivers, including the Shenandoah River which meets the Potomac at Harper's Ferry, West Virginia. The Middle Potomac Minor Basin as a whole is characterized by a mix of mountainous terrain in the western headwaters which gradually give way to rolling hills, and finally into an increasingly urbanized region as the river meets the fall-line and flows into the D.C. metropolitan area and suburban portions of Virginia and Maryland. The Middle Potomac Minor Basin begins in southern Pennsylvania flowing south

through Maryland, and into the northernmost portion of Virginia. The spatial area of the basin occupies 2,207 square miles and includes all or portions of the localities listed in Table 69. The Middle Potomac is one of the highest populated watersheds in Virginia, with major population centers including the City of Fairfax and Fairfax, Loudoun, and Prince William counties. Topography of the basin is largely gently sloping hills with mountains to the west. Land cover is increasingly urban and impervious in the vicinity of the Washington D.C. metro area. Agricultural and forested land cover has decreased over time as development has increased in this basin.

Note that while much of the Middle Potomac basin is outside of Virginia, the following sections focus on demands and impacts within Virginia only.

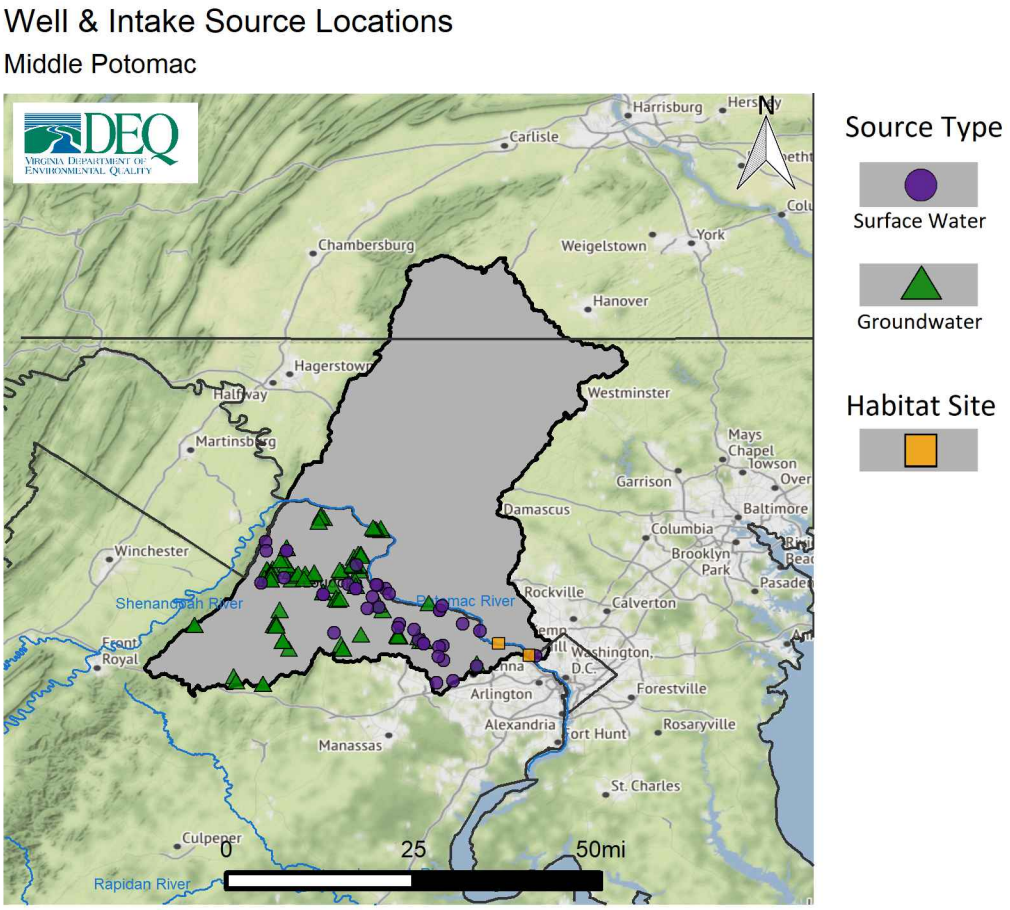

Figure 268: Spatial distribution of groundwater wells and intakes in the Middle Potomac Basin

A.13.2 Existing Water Sources

Major surface water sources within the basin primarily include the Potomac River and Goose Creek Reservoir. Groundwater within the basin is primarily withdrawn from bedrock aquifers. Surface water withdrawals are the most prevalent source of supply serving all major Community Water System (CWS) facilities; groundwater sources most commonly supply small residential users.

Withdrawals within the basin are primarily used for public water supply, industrial/manufacturing, and commercial uses. The location of wells and surface water intakes identified to DEQ within the basin are shown in Figure 268. This figure does not include private or domestic wells. Surface and groundwater withdrawal locations are focused within Fairfax and Loudoun counties and adjacent to the Potomac River.

Table 69: Population Trend by Locality in Middle Potomac Basin

Localities	20 Year % Change
Clarke	9.19
Fairfax County	12.54
Fauquier	18.85
Loudoun	55.39
Prince William	37.24
Warren	17.78
Fairfax City	9.34

A.13.3 Existing Water Use

The following section discusses existing (current) water use within the basin, which is based on existing demand information submitted to DEQ in water supply plans. Table 70 provides a summary of all demands within the basin including demand associated with power generation. Note that withdrawals related to power generally dwarf other demand categories and can therefore make evaluating trends for other categories more challenging. Most power generation withdrawals are also largely non-consumptive; water is withdrawn for cooling purposes and then discharged back into the source stream with minimal loss. The Virginia portions of this basin do not include any power generation associated withdrawals facilities that withdraw water; however the Panda Stonewall Power Project is supplied through reuse from Town of Leesburg's wastewater treatment plant. Panda Stonewall's demands therefore do have an impact on streamflow in the Potomac River through the reduction of water that would otherwise be discharged by the Town of Leesburg.

Table 70: Summary of Middle Potomac Minor Basin Water Demand by Source Type and System Type

System Type	Source Count	2020 Demand (MGD)	2030 Demand (MGD)	2040 Demand (MGD)	20 Year Percent Change
Surface Water					
Agriculture	0	4.77	4.77	4.77	0.00
CWS	9	239.23	255.72	272.21	13.79
Large SSU	22	1.91	2.13	2.36	23.80
Small SSU	N/A	0.00	0.00	0.00	0.00
Total SW	**31**	**245.91**	**262.62**	**279.34**	**13.59**
Groundwater					
Agriculture	0	0.62	0.62	0.62	0.00
CWS	73	1.44	1.97	2.50	73.18
Large SSU	19	0.48	0.55	0.61	25.77
Small SSU	N/A	4.13	4.69	5.24	26.82
Total GW	**92**	**6.67**	**7.83**	**8.97**	**34.48**
Total (SW + GW)					
Agriculture	0	5.40	5.40	5.40	0.00
CWS	82	240.68	257.69	274.71	14.14
Large SSU	41	2.39	2.68	2.97	24.20
Small SSU	N/A	4.13	4.69	5.24	26.82
Minor Basin Total	**123**	**252.60**	**270.46**	**288.32**	**14.14**

* Small SSU demands are county-wide estimates of private well usage below 300,000 gallons a month. The number of private wells is not known.

The total existing demand from all surface and groundwater sources is approximately 252.60 MGD, with groundwater supplying approximately 6.67 MGD or 2.7% of total water demands. Surface water demand within the basin totals approximately 245.91 MGD, or 97.3% of current demands. Surface water demand is primarily driven by CWS, currently approximately 239.23 MGD or 97% of all surface water demands in the watershed. Surface water demands for Agricultural Self-Supplied User (AG) facilities and Large Self-Supplied Users (Large SSUs) are minimal in comparison to CWS in the basin. Groundwater demand is estimated at 6.67 MGD, with 4.13 MGD, or 61.9% of current groundwater demands from private individual well owners for residential supply.

The five largest facility demands for each source type are provided in Table 71. Note that the "% Total Surface Water" column includes only intakes in Virginia and/or intakes outside of Virginia that voluntarily report to Virginia. The largest groundwater demands include several smaller town service areas such as the towns of Purcellville, Round Hill, Middleburg, Lovettsville, and Leesburg. Each CWS provides drinking water to smaller service areas in the basin not supplied by the largest public water systems such as Fairfax Water and Loudoun Water.

The largest surface water demands all serve CWS facilities and distribute drinking water throughout the basin and Washington D.C. metropolitan area. Surface water demand is driven primarily by the two largest CWS facilities in Virginia, the Corbalis and Dalecarlia WTPs. The Corbalis WTP is operated by Fairfax Water and is currently responsible for 97.68, or approximately 40.5%, of all CWS demands in the basin. The Dalecarlia WTP is a part of the Washington Aqueduct system, a federally owned and operated water supply agency. Current demands from the Dalecarlia WTP are 128.61 MGD, or approximately 51.2% of total surface water demands in the basin. Note that the majority of water withdrawn by the Washington Aqueduct system is used in Maryland or the District of Columbia. Combined, the two systems represent more than 89% of all current water demands in the watershed.

Table 71: Top 5 Users in 2040 by Source Type in the Middle Potomac Minor Basin

Facility Name	System Type	Locality	2020 Demand (MGD)	2030 Demand (MGD)	2040 Demand (MGD)	20 Year Percent Change	% of Total Surface Water
Surface Water							
Dalecarlia WTP	CWS	Arlington	128.61	135.91	143.2	11.34	51.26
Corbalis WTP	CWS	Fairfax County	97.68	104.3	110.93	13.56	39.71
Potomac River Water Supply Project (Central System)	CWS	Loudoun	8.04	9.12	10.2	26.87	3.65
Leesburg WTP	CWS	Loudoun	4.64	5.96	7.27	56.68	2.6
Purcellville Service Area	CWS	Loudoun	0.24	0.42	0.6	150	0.21
Total SW			239.21	255.71	272.2	13.79	97.44
Groundwater							**% of Total Groundwater**
Purcellville Service Area	CWS	Loudoun	0.33	0.58	0.82	148.48	9.14
Round Hill Service Area	CWS	Loudoun	0.39	0.42	0.45	15.38	5.02
Middleburg Service Area	CWS	Loudoun	0.23	0.28	0.32	39.13	3.57
Lovettsville Service Area	CWS	Loudoun	0.14	0.21	0.28	100	3.12
Leesburg WTP	CWS	Loudoun	0.14	0.18	0.22	57.14	2.45
Total GW			1.23	1.67	2.09	69.92	23.3

Table 70 also provides the proportion of each use category that is supplied by either surface water or groundwater. Use categories include Community Water System (CWS), Large Self-Supplied User (Large SSU), Small Self-Supplied User (Small SSU), and Agricultural Self-Supplied User (AG). These categories are defined below. Surface water demand is almost entirely comprised of demands from CWS with minimal agriculture and Large SSU demands in the basin. Groundwater demands are primarily comprised of domestic well withdrawals by Small SSUs and CWS demands.

The CWS category includes any public and private waterworks that serve at least 15 service connections used by year-round residents or regularly serve at least 25 year-round residents, and are regulated under the Virginia Department of Health's Waterworks Regulation (12VAC5-590). In the Middle Potomac Basin, approximately 1.44 MGD of groundwater demand and 239.23 MGD of surface water demand is from CWS facilities. Significant groundwater users within this category include: the towns of Leesburg, Lovettsville, Middleburg, Purcellville, and Round Hill. Groundwater is not a primary water source for CWS in the basin. Surface water is the primary water source for CWS with significant surface water users from this category including: the Corbalis, Dalcarlia, Leesburg, and Loudoun WTPs. Note that the Corbalis and Dalcarlia WTPs demands represent approximately 89% of current surface water demands in the basin.

Large SSUs include any non-CWS or AG who withdraw more than 300,000 gallons per month from a well or surface water intake. In the Middle Potomac Basin, approximately 0.48 MGD of groundwater demand and 1.91 MGD of surface water demand is from Large SSUs. Significant groundwater users within this category include numerous golf courses throughout the watershed that rely on groundwater to irrigate turf grass. Significant surface water users from this category are also primarily large country clubs and golf courses that irrigate their properties. Large SSUs report the lowest demands of all water use categories in the basin.

Small SSUs include any users who withdraw less than 300,000 gallons per month from wells. Small SSUs generally consist of residential or domestic use for those who live outside service areas and provide their own water. In the Potomac Middle Basin, approximately 4.13 MGD of groundwater demand is from Small SSUs. Demand within the category is almost entirely concentrated within Loudoun County, with over 98% of all Small SSU demands estimated in the County. The towns of Herndon and Leesburg contribute the remaining 2% to the category. Demands from Small SSUs represent the largest demand of groundwater in the basin currently and are expected to increase through 2040.

The AG category includes crop farms, livestock operations, aquaculture and other agricultural facilities. In the Potomac Middle Basin, approximately 0.62 MGD of groundwater demand and 4.77 MGD of surface water demand is from AG. Significant groundwater and surface water users within this category are limited. AG withdrawals in the basin represent the sum of withdrawals from existing AG in the basin that rely on groundwater or surface water. AG demands are primarily limited to rural areas of the basin.

A.13.4 Projected Population and Water Use

Projected Population: Trends in water use are generally driven by trends in population change or economic development. Increasing population within an area generally means increased connections for CWS or additional demands from homeowners that construct wells. Increasing population in an area also tends to incentivize both new and expanded industrial and commercial water use. Alternatively, the addition of new economic opportunities such as a large employer may include additional water withdrawals for operational needs. Reviewing short and long-term population projections can inform water supply planning efforts.

For reference, Table 69 shows the projected change in population for each locality partially or fully within the watershed. The basin's proximity to the Washington D.C. metro area makes the watershed one of the highest and most densely populated in Virginia. All localities fully or partially within the basin are projected to increase in population over the planning period. The basin includes Fairfax County, the highest populated locality in the Commonwealth with over 1.1 million current residents. The basin also includes Loudoun County, the fastest growing locality in the Commonwealth with the population expected to increase by more than 55% by 2040. With significant population growth and large population centers throughout the basin, water demand increases to support the rapid growth are also projected to occur.

Projected Water Use: The following section discusses projected water use through 2040 within the Potomac Middle Basin, based on projections provided in local and regional water supply plans. Table 70, included in the existing demand section above, is the basis for information discussed in this section.

Total demand within the basin is projected to increase from approximately 252.60 MGD in 2020 to 288.32 MGD in 2040, a 14.1% increase. Projected demand increases are driven primarily by surface water demands for regional CWS needs over the planning period. As population grows in the basin, increased demands will be placed on public water suppliers within the basin. Surface water demand is projected to increase by approximately 33.4 MGD, or 13.5%, by 2040. Groundwater demand is projected to increase by approximately 2.3 MGD, or 34.48 %, by 2040. Increases in groundwater demands are primarily driven by estimated increases in residential well development in Loudoun County. The largest contributors to the increasing trend in total projected demand are public water suppliers in the basin including Fairfax Water, Loudoun Water, and the Washington Aqueduct system.

Demand from CWS users within the basin is projected to increase 14.14% by 2040. Within this category, surface water use is projected to increase by 13.79%, or approximately 32.9 MGD. Groundwater use is projected to increase by 73.18%, or approximately 1.06 MGD. While groundwater demands for CWS are projected to increase by more than 70%, surface water demand greatly outpaces groundwater demands by volume. CWS facilities are the largest use category in the Potomac Middle Basin with the greatest increase in volume projected over the planning period. As population and economic opportunities continue to attract individuals to the basin, surface water will continue to meet the majority of demands.

Demand from Large SSUs within the basin is projected to increase 24.20% by 2040. Within this category, surface water use is projected to increase by 23.80%, or approximately 0.45 MGD. Groundwater use is projected to increase by 25.7%, or approximately 0.13 MGD. Large SSUs in the basin are primarily composed of commercial golf courses and country clubs withdrawing water for irrigation purposes while typically retaining a connection to a CWS for potable water purposes. There are limited manufacturing or industrial users present in the basin.

Demand from Small SSUs within the basin is projected to increase 26.82% through 2040. This category, which represents primarily residential wells, is entirely met by groundwater and is projected to increase by 1.11 MGD. Demand increases in this category are driven by estimated increases in residential well development in Loudoun County.

Demand from AG within the basin is projected to remain constant with current demands throughout the planning period. Surface water is the primary source of supply with 4.77 MGD, while groundwater supplies 0.62 MGD.

A.13.5 Cumulative Impact Analysis

The following section provides a brief summary of the Cumulative Impact Analysis (CIA) modeling results in the Middle Potomac Minor Basin. Note that much of this basin lies outside of the Virginia. While the results do include areas outside of Virginia, only those river segments within Virginia will be evaluated here. Discussion of these results will primarily be found in the Trends and Goals section of this appendix. However a brief overview of the VAHydro model and the scenarios and metrics is provided below.

The VAHydro surface water model simulates streamflow using inputs such as precipitation, climate, land use, and topography, combined with data on all known withdrawals and discharges, and operational rules of major hydrologic features such as reservoirs. Each minor basin is broken into smaller hydrologic subsections, or river segments. The model simulates the water balance on a daily basis for each individual river segment, with each downstream segment being affected by the cumulative impact of streamflow changes occurring in upstream segments. The following figures help analyze this cumulative impact within the Middle Potomac Minor Basin (model results summarized by river segment). Note that this section is not intended to document in detail the methods and assumptions for the VAHydro model or for the scenarios and metrics discussed. More documentation of the model and assumptions can be found in Chapter 4.

The VAHydro surface water model was used to simulate streamflow under a variety of scenarios. Demand scenarios examine how streamflow is impacted under 2030 or 2040 demands as compared to current (2020) demands. Demands were calculated based on current and future demand information submitted through local and regional water supply plans. Climate change scenarios examine how streamflow is impacted when 2040 demands are simulated in conjunction with a range of precipitation and temperature conditions that may occur in the future due to changing climate (Dry, Median, Wet scenarios). Finally, the exempt user scenario examines impacts from users excluded, or exempt, from VWP permit requirements per Va. Code § 62.1-44.15:22 B. Exempt users were simulated at the maximum possible exempt demand identified through a review of demand justification values commonly asserted by exempt users, including but not limited to VDH pump capacity, maximum pre-1989 withdrawal, and maximum intake capacity. In order to effectively manage surface water resources and address the uncertainty related to these demands, DEQ determined the most conservative, or maximum possible, demand should be evaluated in this scenario. However, DEQ does not agree that the maximum values used in this scenario represent an allocation for, or the expectation of, a future withdrawal of that volume; nor does DEQ concede that any particular exempt user is necessarily entitled to withdraw any particular maximum value used in this scenario. The methods and assumptions for each of these modeling scenarios are discussed in more detail in Chapter 4.

For each scenario described above, different metrics can be used to evaluate the simulated streamflow. A metric is a method for measuring or evaluating a given set of data; different metrics can be evaluated to answer different questions. Within this section the following metrics will be discussed: the lowest 30 day flow (L30), the lowest 90 day flow (L90), 7Q10, and overall change in flow. The L30 describes the lowest

consecutive 30 day average daily streamflow over the simulation period. This metric is a representation of a short-term, or acute drought, and is a good metric for evaluating impacts to direct withdrawals without storage. Similarly the lowest 90 day flow represents the lowest consecutive 90 day average daily streamflow over the simulation period. This would represent a prolonged drought and is often used to evaluate impacts to reservoirs. The 7Q10 is the lowest 7 day average flow that occurs (on average) once every 10 years. 7Q10 is generally used in the evaluations of in-stream beneficial uses such as waste assimilative capacity. Overall change in flow describes the net loss of water from the riverine system as a result of off-stream use not otherwise returned through point source discharges, or losses due to evapotranspiration. This metric is useful for evaluating impacts to aquatic life and is discussed in more detail in Chapter 4.

Demand Scenarios: 2020 demand or current demand, 2030 demand, and 2040 demand scenarios were simulated. The following series of figures compares the 2030 and 2040 demand scenarios to the current demand scenario. The change in flow depicted on each map is the change expected when comparing two scenarios - in this case future demands compared to current demands. Each page includes two figures comparing either the 2030 or 2040 demand scenario to current demand using the L30, L90, and 7Q10 metrics. This allows for comparisons of simulated impacts between the 2030 and 2040 demand scenarios. The scenarios and metrics are identified in the paragraph below and in the figure captions. Figures 269 and

270 compare the lowest 30 day flow simulated with the current demand scenario with the lowest 30 day flow simulated in the 2030 and 2040 demand scenarios respectively. Figures 271 and 272 compare the lowest 90 day low flow simulated with the current demand scenario with the lowest 90 day flow simulated in the 2030 and 2040 demand scenarios respectively. Figures 273 and 274 compare the 7Q10 simulated with the current demand scenario with the 7Q10 simulated in the 2030 and 2040 demand scenarios respectively.

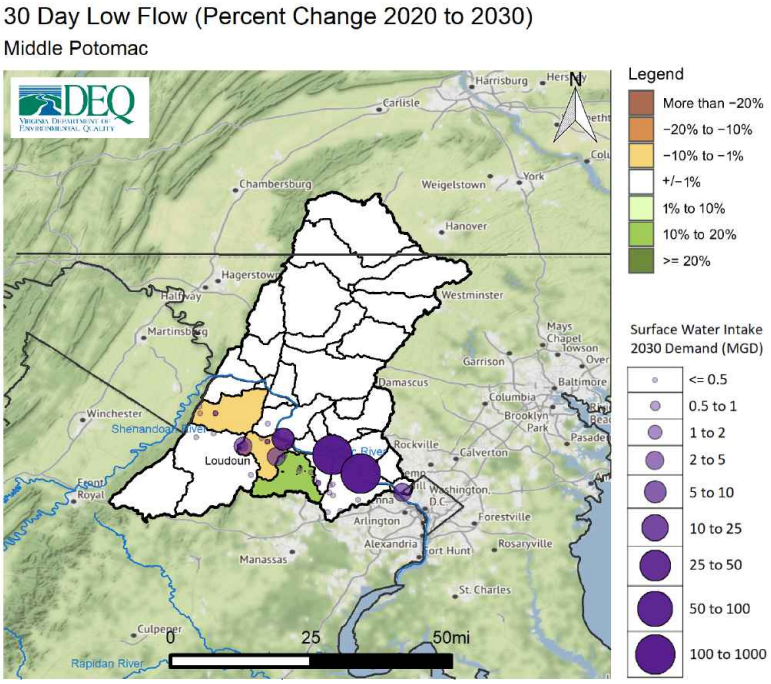

Figure 269: Change in 30 day low flow between 2020 and 2030 demand scenarios within the Middle Potomac Basin

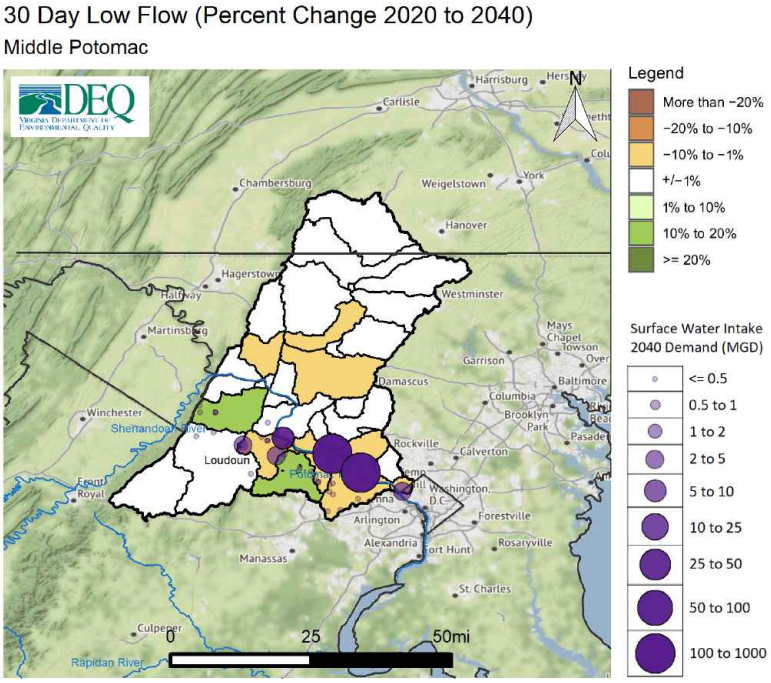

Figure 270: Change in 30 day low flow between 2020 and 2040 demand scenarios within the Middle Potomac Basin

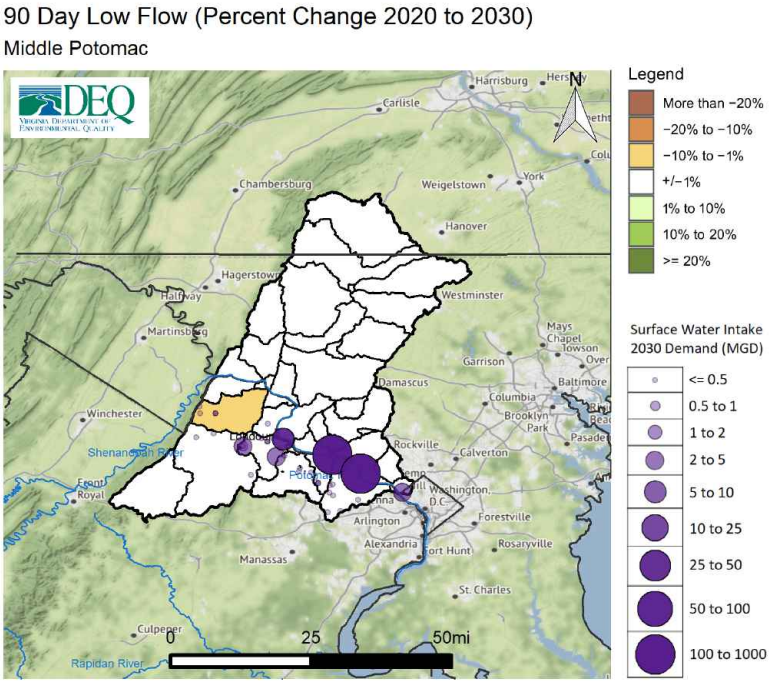

Figure 271: Change in 90 day low flow between 2020 and 2030 demand scenarios within the Middle Potomac Basin

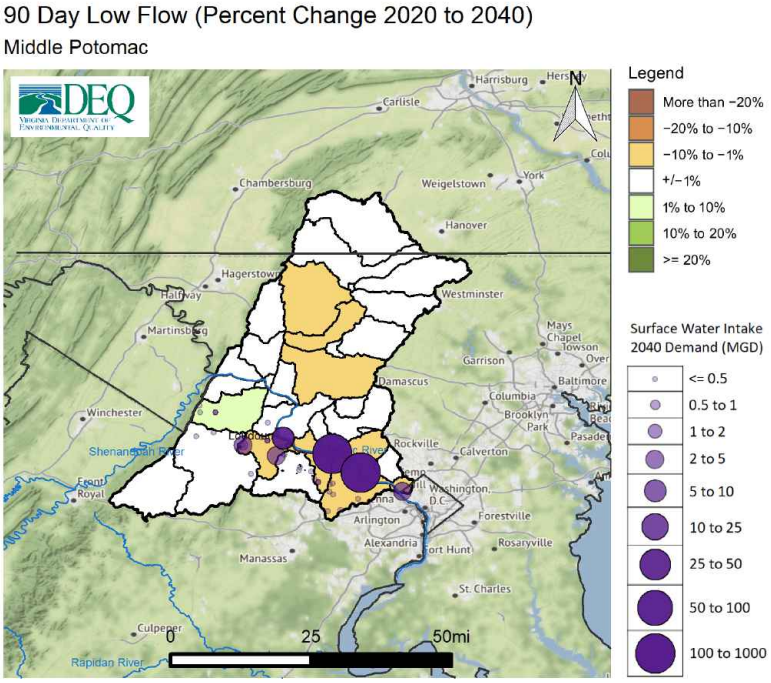

Figure 272: Change in 90 day low flow between 2020 and 2040 demand scenarios within the Middle Potomac Basin

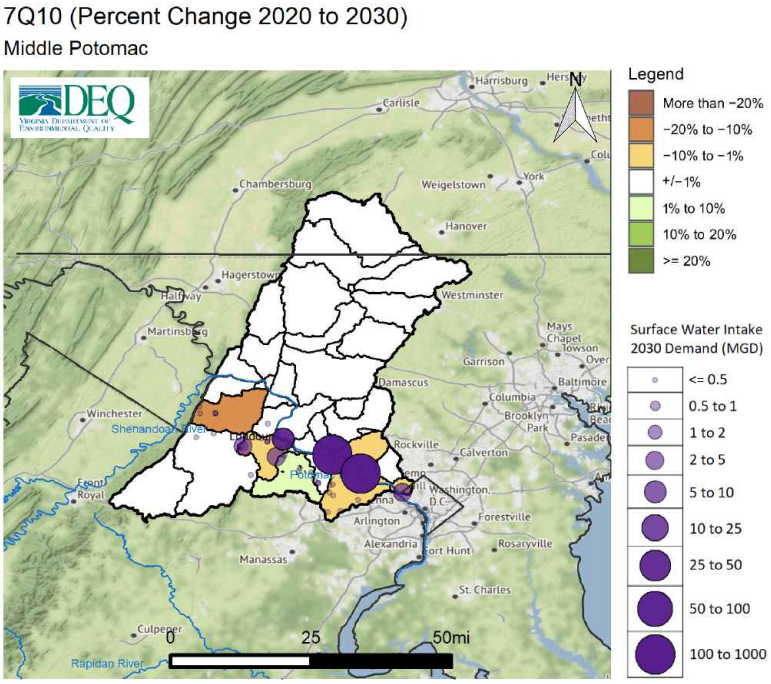

Figure 273: Change in 7Q10 between 2020 and 2030 demand scenarios within the Middle Potomac Basin

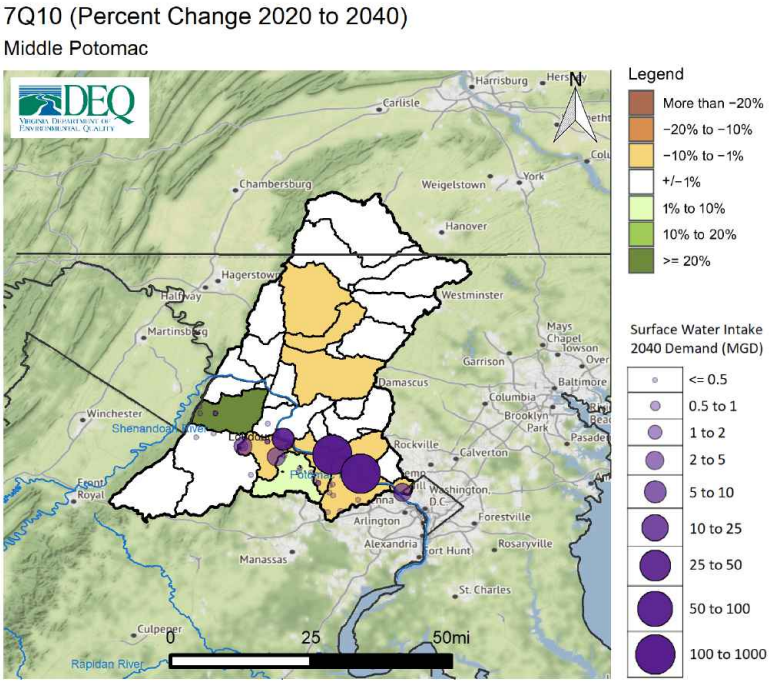

Figure 274: Change in 7Q10 between 2020 and 2040 demand scenarios within the Middle Potomac Basin

The figures above show a comparison between two scenarios. An additional way to evaluate impacts to streamflow is to examine the total reduction in streamflow resulting from all withdrawals within a river segment, as well as losses due to evapotranspiration, while taking into consideration any discharges back to the source. To use a common industry term, the overall change in flow metric evaluates "consumptive use", or the amount of water removed from the river that is not returned through discharges. This can help describe potential impacts to downstream withdrawals, while also providing a basis for evaluating impacts to aquatic life. In general, total reductions in streamflow can result in a proportional reduction in aquatic biodiversity [105]. The relationship between streamflow and aquatic biodiversity is discussed in more detail in Chapter 4. Figure 275 shows the overall change in streamflow for the 2030 Demand Scenario, while figure 276 shows the overall change in streamflow for the 2040 Demand Scenario.

[105] Rapp, J.L., R. Burgholzer, J. Kleiner, D. Scott, and E. Passero. 2020. "Application of a New Species-Richness Based Flow Ecology Framework for Assessing Flow Reduction Effects on Aquatic Communities." Journal of the American Water Resources Association 1–14.https://doi.org/10.1111/1752-1688.12877.

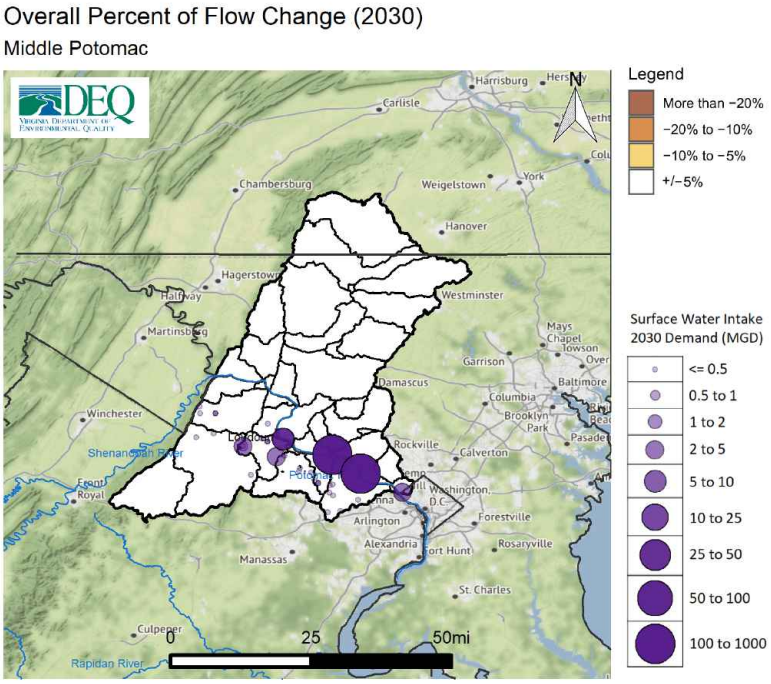

Figure 275: Overall change in flow in percent for 2030 demand scenario within the Middle Potomac Basin

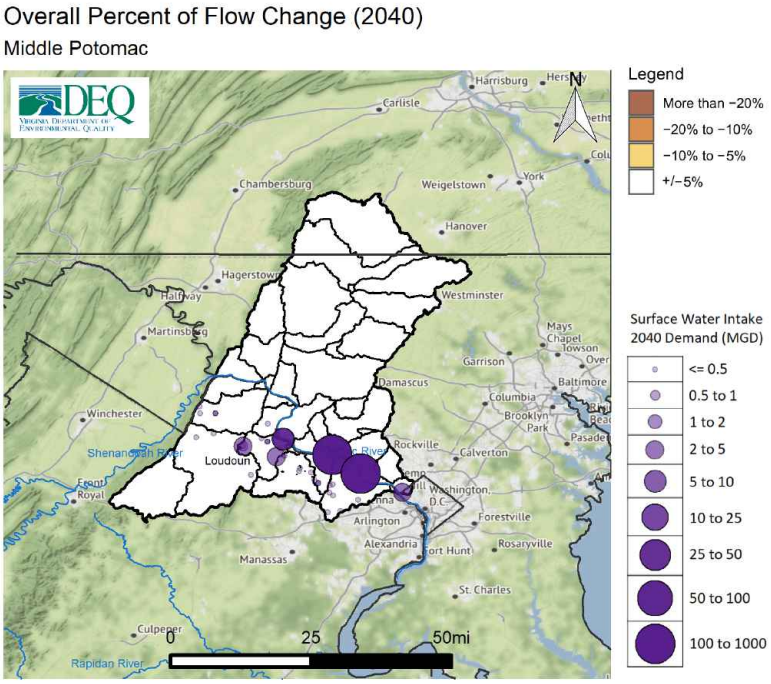

Figure 276: Overall change in flow in percent for 2040 demand scenario within the Middle Potomac Basin

Climate Scenarios: Three scenarios that simulate impacts to streamflow from climate change were also completed for areas in the state within the Chesapeake Bay watershed. These scenarios were not completed outside of the Chesapeake Bay watershed as the climate data is only currently available for those portions of the Commonwealth located in the Chesapeake Bay watershed. Details on the methods and assumptions used in these scenarios can be found in Chapter 4 and Appendix B. The three scenarios can be described as dry, median, and wet scenarios. Where changes in precipitation and temperature are concerned, Virginia is expected to experience a range, and must prepare for years with more severe and prolonged droughts as well as years with higher intensity and more frequent rain events. For the purpose of water supply planning, the greatest challenges are expected to be those years that correspond most closely with the dry scenario, where prolonged and more frequent droughts are expected.

Figure 277 depicts the percent change in the L30 for the dry climate scenario in conjunction with 2040 demands, as compared to the current climate and demand scenario. Reductions in streamflow in this scenario may be caused by reduced precipitation, increased demand, or as is generally the case, a combination of both. Figures 278 and 279 depict the L30 for the median and wet climate scenarios (in conjunction with 2040 demands) as compared to the current climate and demand scenario.

Figure 280 depicts the percent change in the L90 for the dry climate scenario in conjunction with 2040 demands, as compared to the current climate and demand scenario. Figures 281 and 282 depict the L30 for the median and wet climate scenarios (in conjunction with 2040 demands) as compared to the current climate and demand scenario.

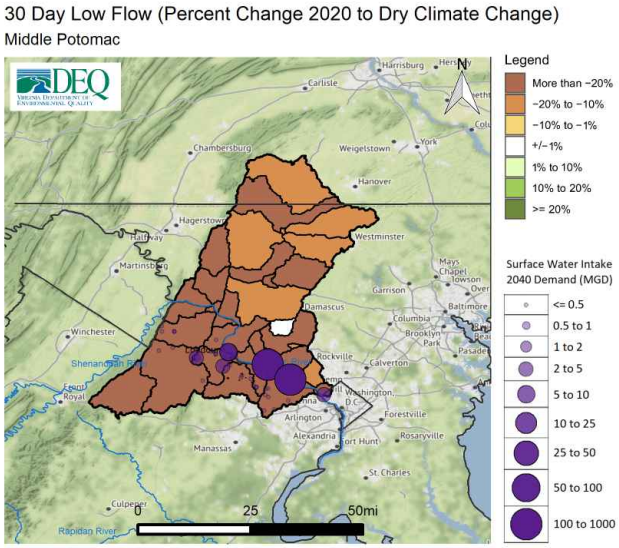

Figure 277: Change in 30 day low flow between current climate/demand scenario and the dry climate/2040 demand scenario within the Middle Potomac Basin

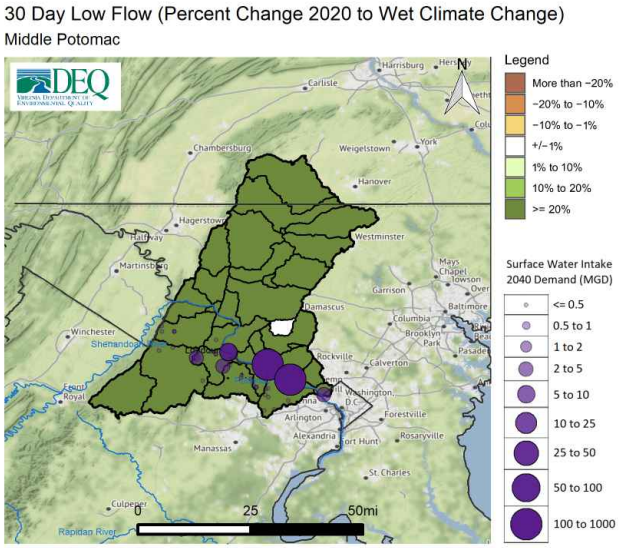

Figure 279: Change in 30 day low flow between current climate/demand scenario and the wet climate/2040 demand scenario within the Middle Potomac Basin

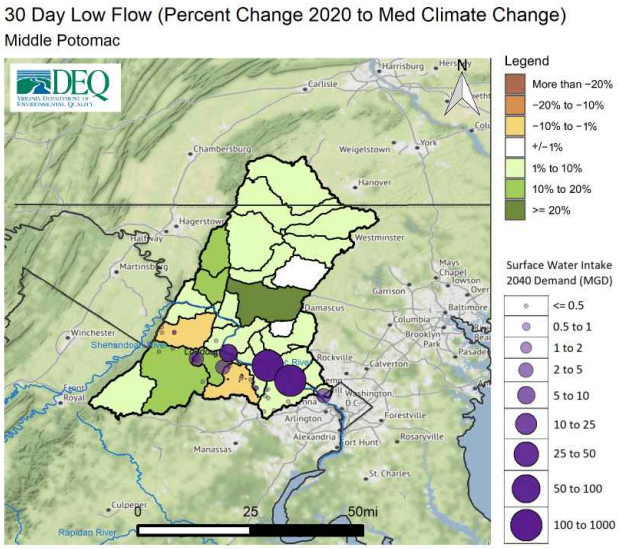

Figure 278: Change in 30 day low flow between current climate/demand scenario and the median climate/2040 demand scenario within the Middle Potomac Basin

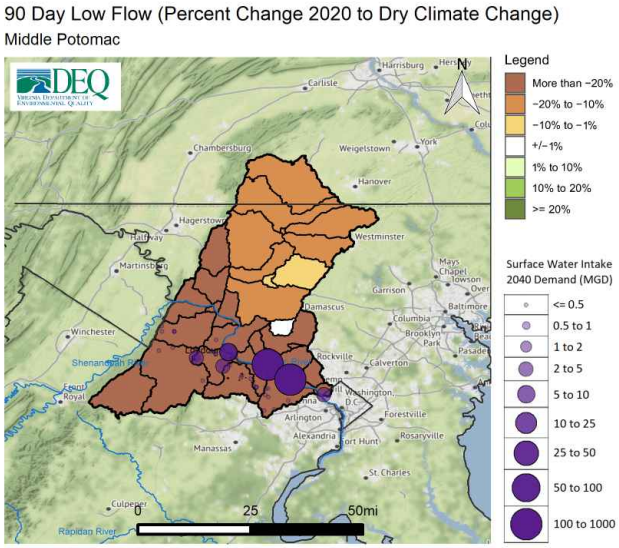

Figure 280: Change in 90 day low flow between current climate/demand scenario and the dry climate/2040 demand scenario within the Middle Potomac Basin

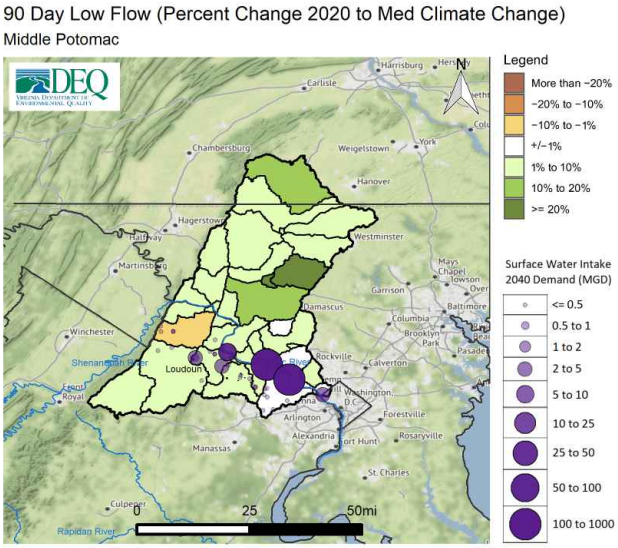

Figure 281: Change in 90 day low flow between current climate/demand scenario and median climate/2040 demand scenario within the Middle Potomac Basin

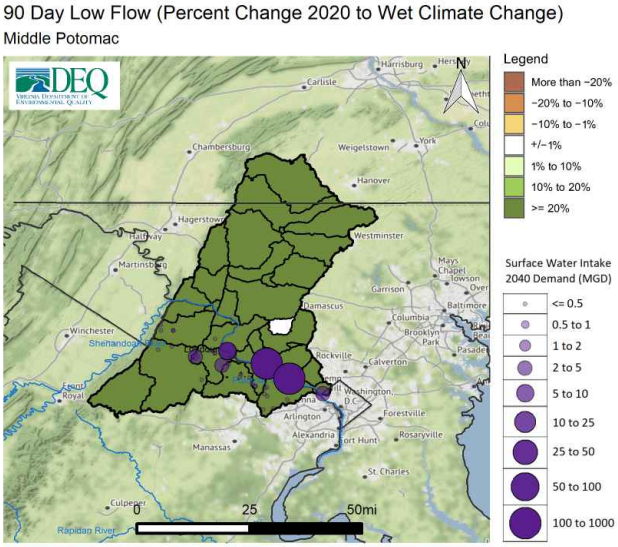

Figure 282: Change in 90 day low flow between current climate/demand scenario and wet climate/2040 demand scenario within the Middle Potomac Basin

Exempt User Scenario: The exempt user scenario simulates the maximum possible exempt demand for users excluded from Virginia Water Protection permitting requirements per Va. Code § 62.1-44.15:22 B, in combination with the permitted withdrawal limits for those users that are permitted. A more detailed discussion of the data and assumptions used in this scenario can be found in Appendix B. Note that this scenario uses current climate conditions. Figure 283 depicts the percent change in the Lowest 30 Day Flow between the exempt user scenario and current (2020) demand. Figure 284 depicts the percent change in the Lowest 90 Day Flow between the exempt user scenario and current (2020) demand. Figure 285 depicts the percent change in the 7Q10 between the exempt user scenario and current (2020) demand. Finally, figure 286 depicts the overall change in flow in percent (consumptive use) for the exempt user scenario.

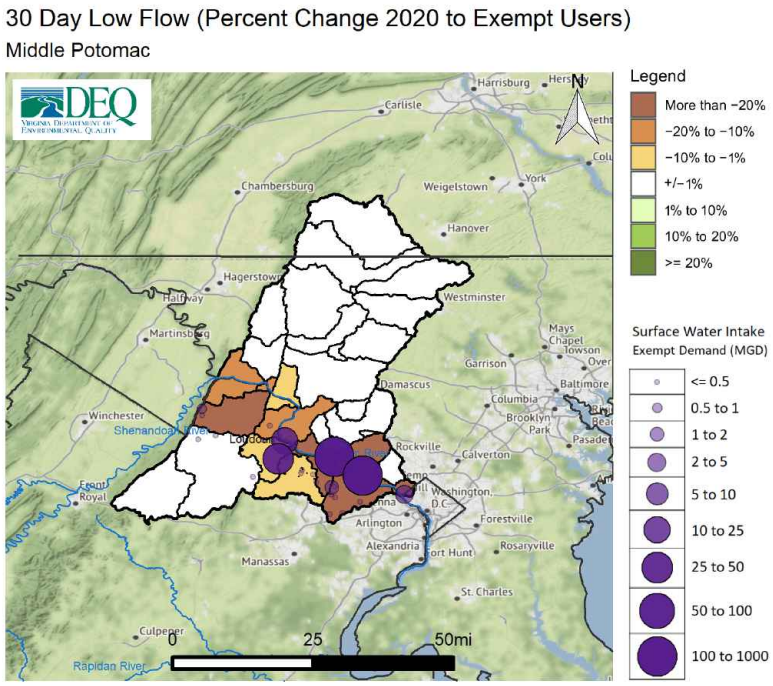

Figure 283: Change in 30 day low flow between current demand scenario and exempt user scenario within the Middle Potomac Basin

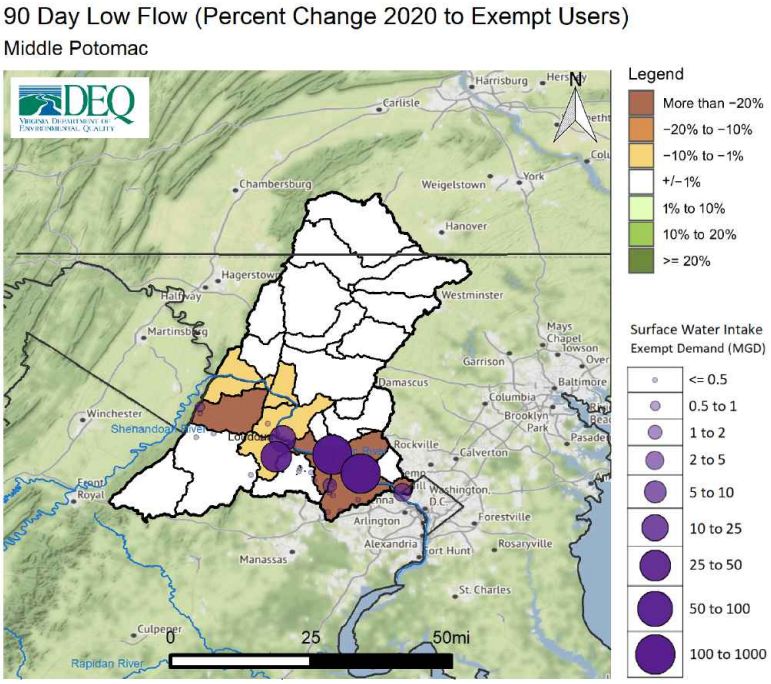

Figure 284: Change in 90 day low flow between current demand scenario and exempt user scenario within the Middle Potomac Basin

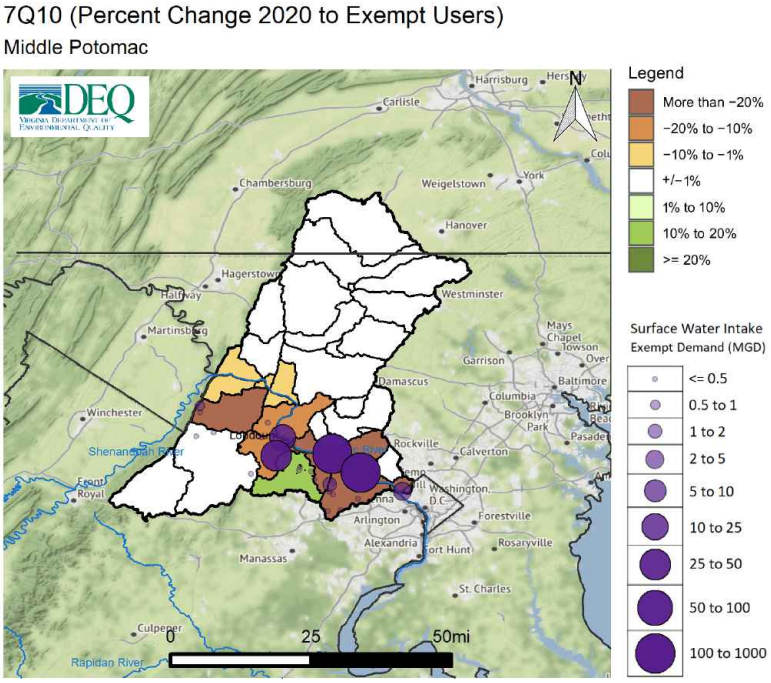

Figure 285: Change in 7Q10 between current demand scenario and exempt user scenario within the Middle Potomac Basin

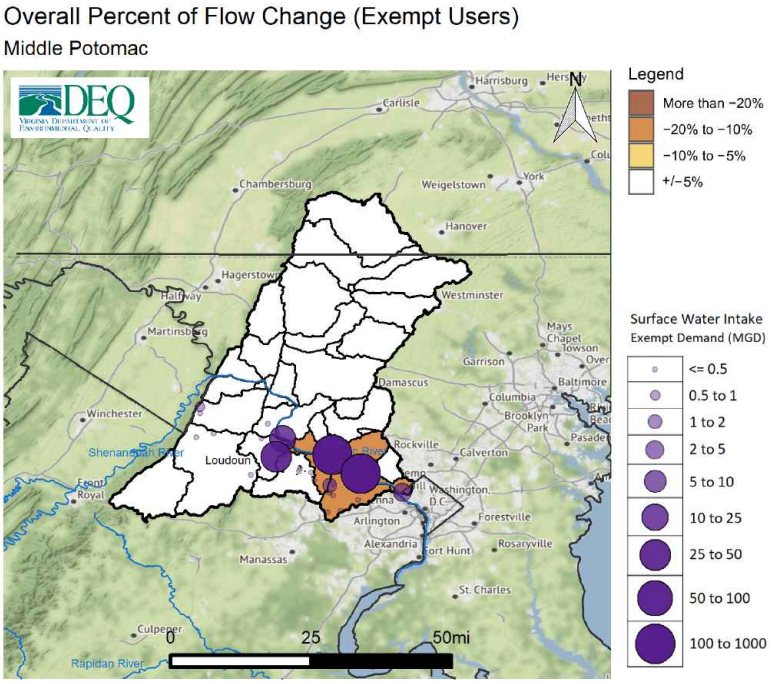

Figure 286: Overall change in flow in percent for exempt user scenario within the Middle Potomac Basin

Potential Unmet Demand: Potential unmet demand was evaluated for all facilities within the basin for each scenario. Potential unmet demand is the portion of surface water demand for a specific facility that is limited by available streamflow as simulated in a given model scenario, including any known operational limits such as flow-by requirements. This unmet demand, if realized, could be managed through water conservation, through alternative sources, operational changes, or from available storage. Absent of these or other options, this portion of demand could remain unmet. As with all scenarios, demand requirements were determined using demand projections provided in the water supply plans. In the case of the exempt user scenario, the highest possible withdrawal amount was used for users exempt from VWP permitting requirements

This metric is useful for evaluating where the results seen in the above figures may result in challenges in meeting future demands under a variety of conditions including increasing demands in the basin, changing climate, or withdrawals from users exempt from permitting requirements. Table 72 provides for each facility the highest average daily potential unmet demand over a 30 day period over the course of the simulation for the following scenarios: 2020 demand, 2030 demand, 2040 demand, dry climate, and exempt User. Only facilities showing potential unmet demand in at least one scenario appear on this table. The dry climate scenario is selected among the climate scenarios as the dry scenario represents the potential for increased drought intensity and frequency, and therefore poses the greatest challenge for water supply. Only facilities showing potential unmet demand in at least one scenario appear on this table. Additional information on the potential unmet demand metric can be found in Appendix B.

Table 72: Change in Highest 30 Day Potential Unmet Demand (MGD) in Middle Potomac Minor Basin

Facility	**2020 Demand**	**2030 Demand**	**2040 Demand**	**Dry Climate**	**Exempt User**
Corbalis WTP	0.00	0.00	0.00	0.00	329.68
Dalecarlia WTP	22.45	24.45	28.52	70.21	200.11
Loudoun Water	0.00	0.00	0.00	0.00	30.6
Purcellville Service Area	0.05	0.12	0.00	0.21	0.74
Belmont Country Club	0.04	0.05	0.05	0.06	0.1
1757 Golf Club	0.04	0.04	0.05	0.06	0.04
Dickerson Power Station	0.00	0.00	0.00	7.71	0.00

* Climate scenarios were not completed in areas located outside of the Chesapeake Bay watershed

Note: Potential unmet demand is the portion of surface water demand for a specific facility that is limited by available streamflow as simulated in a given model scenario, including any known operational limits such as flow-by requirements. This unmet demand, if realized, could be managed through water conservation, alternative sources, operational changes, or from available storage.

A.13.6 Spatial Overview of Groundwater Demands

The cumulative impact analysis figures above provide an overview of surface water demands in the basin but did not include groundwater demands. Figure 287 identifies the location and size of projected groundwater demands in the basin for 2040 based on information provided by localities in water supply plans.

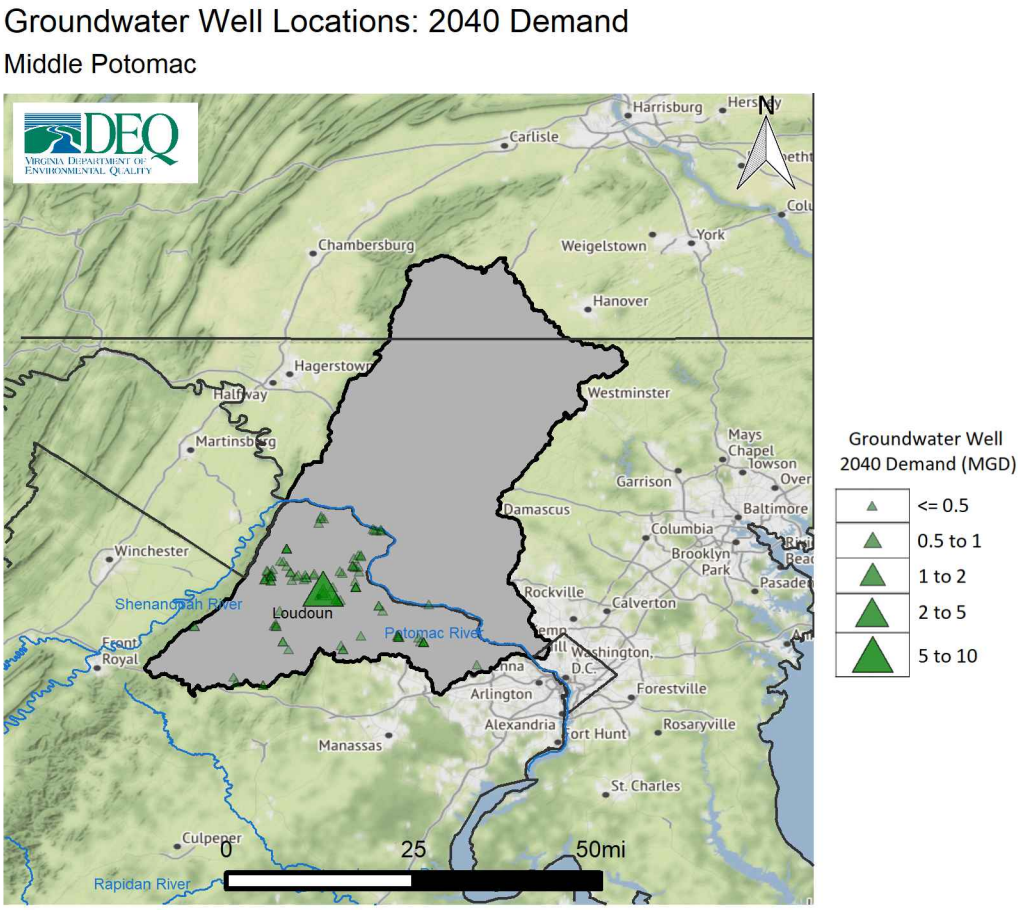

Figure 287: Projected 2040 Groundwater Demands in the Middle Potomac Minor Basin

A.13.7 Trends and Goals

The Code of Virginia mandates that the State Water Control Board should take into consideration the principle that "adequate and safe supplies shall be preserved and protected for human consumption, while conserving maximum supplies for other beneficial uses".[106] This principle is the key driver of the challenges in water resource management, which is that all beneficial uses must be adequately considered when evaluating impacts to surface water resources. The State Water Control Board is tasked with ensuring that water supply quantity needs are met at all times while also protecting Virginia's natural resources, and furthermore, ensuring equitable allocation during a time of shortage.[107] While evaluating and planning for the long-term sustainability of water supply for Virginia is the primary goal for the State Plan, evaluating and limiting impacts to in-stream beneficial uses such as aquatic habitat life is also part of DEQ's responsibility.

The primary purpose of this section is to identify where the most significant challenges to long-term sustainability of water supply and other beneficial uses are indicated based on the CIA and information collated from local water supply plans within this basin. Goals for future planning and areas for additional data collection or analysis are also suggested where appropriate.

The CIAs were completed using the best available data and methods known to DEQ. This discussion focuses on the evaluation of trends - in other words the prevailing tendency or inclination. This means evaluating whether streamflow is simulated to increase or decrease in a given scenario, and by how much. A relative trend indicating reductions of greater than or equal to 10% in streamflow, whether driven by demand increases, changing climate conditions, or exempt user demands was considered a threshold for potential impacts to beneficial uses. The following summarize the key trends or goals for this basin:

- **Demand Scenarios:** Demands in the Middle Potomac Minor Basin are projected to increase approximately 14% through 2040, and are driven by growth from community water systems. However, most of those demand increases are from the three major water suppliers and are somewhat mitigated by the network of storage on the Potomac River. When comparing the 2040 demand scenario to the 2020 demand scenario, stream flow reductions of more than 10% were not simulated within the basin for either the long-term drought (L90), short-term drought (L30), or 7Q10 metrics as a result of projected increases in demand within the basin. Overall Percent of Flow Change (consumptive use) also was not simulated to exceed 10% in any river segment in either the current (2020) or future (2040) demand scenarios. This indicates that much of the water withdrawn is ultimately returned to the source through discharges. The greatest consumptive use in the basin was seen in Goose Creek and the Potomac River near Great Falls and Little Falls. Potential unmet demands were simulated in the 2040 scenario at the Dalecarlia WTP, however, this system has storage and alternatives available to mitigate this demand in most cases. The Dalecarlia WTP primarily withdrawals from the Potomac River near Great Falls. Currently a 300 MGD flow by is required at Great Falls. During the 2040 scenario if the flow by could not be met at Great Falls, the secondary intake at Little Falls could be used to meet unmet demands. Currently, a 100 MGD flow by is required at Little Falls, allowing Dalecarlia to load balance withdrawals between the intakes to meet the flow by at each location. Other major water suppliers in the basin including Fairfax Water and Loudoun Water were not simulated to have a potential unmet demand in the 2040 demand scenario. In summary, although demands are projected to increase in the region, the current regional planning and resource management structures are effective in managing increased demands based on these simulations.

- **Climate Scenarios:** The dry climate scenario simulates potential reductions in streamflow of more than 20% throughout the basin during short-term (L30) and long-term drought (L90) metrics. The dry scenario also results in potential unmet demand for the Washington Aqueduct Dalecarlia WTP that serves the greater Washington D.C. metropolitan area. However, as noted above, this system relies on several upstream storage facilities that function to mitigate low flows and could potentially resolve any

[106] § 62.1-44.36 of the Code of Virginia
[107] 9VAC25-390-20.1

unmet demand simulated in these scenarios. However, where in the future climate conditions resemble this dry scenario, the simulations indicate drought conditions more severe than the current drought of record will be experienced for most of the basin. This could result in broad impacts to public water supply as well as aquatic life and other beneficial uses during these periods. These scenarios should be evaluated and considered by localities and users when evaluating existing sources and alternatives, as well as for broader planning and resource management efforts by all stakeholders whether state or local.

- **Exempt User Scenario:** The exempt user scenario, which models the maximum possible exempt demands from all users exempt from VWP permitting requirements, shows reductions in streamflow of more than 10% during short term (L30) and long term droughts (L90), as well as in the 7q10, for several river segments in the Virginia portion of the basin when compared to the current demand scenario. The most significant streamflow reductions are simulated in the Potomac River above Seneca Park, primarily driven by maximum possible exempt demands from the Corbalis WTP Potomac River intake. While most exempt users in the basin are located within the Potomac River in the Washington D.C. metropolitan area, significant reductions are shown upstream. Reductions in streamflow in the upper portion of the basin are driven by exempt user withdrawals upstream in the Shenandoah River Basin, which contribute to reductions in the Potomac River Basin. Reductions of more than 10% when compared to the 2020 scenario are also simulated in the Potomac River at Great Falls, Little Falls, and Point of Rocks. Potential unmet demands in the exempt scenario are simulated for Corbalis WTP, Dalecarlia WTP, and Loudoun Water. Each are major public water suppliers in the region that depend on the Potomac River as their primary water source. These results indicate that the maximum possible exempt demand in the basin exceed the water budget in many river segments. Unmet demands during the exempt scenario impact several of the largest public water suppliers. Managing water supply and preserving other beneficial uses will require managing these demands with respect to their cumulative impacts and in the context of the available resources in the basin.

A.14 Lower Potomac Minor Basin

A.14.1 Watershed Overview

The Potomac River is one of the primary contributors to the Chesapeake Bay and its drainage spans across four states including Virginia, Maryland, Pennsylvania, and West Virginia. The Potomac River runs 405 miles beginning in West Virginia and drains into the Chesapeake Bay. The Potomac River is fed by several smaller rivers, including the Shenandoah River which meets the Potomac River at Harper's Ferry, West Virginia. The basin as a whole is characterized by a mix of mountainous terrain in the western headwaters which gradually give way to rolling hills, and finally transition into an increasingly urbanized region as the river meets the fall-line and flows into the D.C. metropolitan area and suburban portions of Virginia and Maryland.

The Lower Potomac Minor Basin primarily comprises the portion of the tidal Potomac River beginning below Little Falls, as the river becomes increasingly tidally influenced as it moves through D.C. and begins to widen. The Lower Potomac Basin also includes non-tidal streams in the Northern Virginia region. The total spatial area of the basin occupies 3,126 sq. miles and includes all or portions of the localities listed in Table 73. The major population center within the basin is the D.C. metropolitan area, along with significant suburban areas in Virginia and Maryland.

A.14.2 Existing Water Sources

Major surface water sources within the basin include a number of reservoirs including the Occoquan, Smith Lake, Warrenton, and Lake Manassas reservoirs. Groundwater withdrawals that are west of the fall-line are from bedrock/fractured rock aquifers. The majority of groundwater withdrawals in the basin occur east of the fall-line in the Coastal Plain Aquifer system, primarily from the Potomac Aquifer. This portion of the basin is in the Eastern Virginia Groundwater Management Area and therefore groundwater withdrawals over 300,000 gallons in any month require a groundwater withdrawal permit.

Withdrawals within the basin are used for public water supply as well as for agriculture, irrigation, commercial, power generation, and industrial/manufacturing.

The location of wells and surface water intakes identified to DEQ within the basin are shown in Figure 288. This figure does not include private or domestic wells. Surface water intakes are found primarily in the non-tidal portions of the basin such as in Fairfax, Prince William, and Stafford counties as the tidal portions of the Potomac River are generally too high in salinity for use. Counties such as King George and Westmoreland, which border the tidal Potomac River, primarily rely on groundwater with few surface water withdrawals seen in this region.

Table 73: Population Trend by Locality in Lower Potomac Basin

Localities	20 Year % Change
Arlington	18.49
Fairfax County	12.54
Fauquier	18.85
King George	33.11
Loudoun	55.39
Northumberland	-5.42
Prince William	37.24
Richmond County	0.18
Stafford	35.79
Westmoreland	3.34
Alexandria	17.43
Fairfax City	9.34
Falls Church	25.54
Manassas	13.49
Manassas Park	35.51

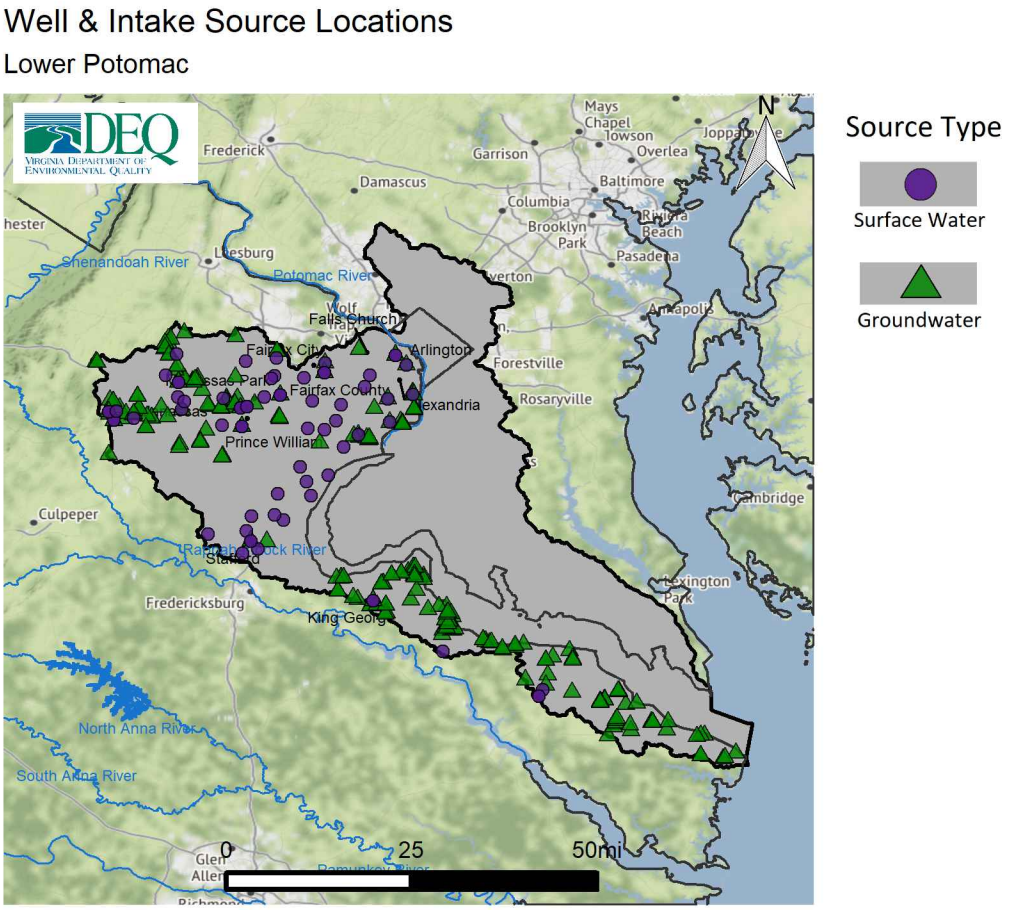

Figure 288: Spatial distribution of groundwater wells and intakes in the Lower Potomac Minor Basin

A.14.3 Existing Water Use

The following section discusses existing (current) water use within the basin, which is based on existing demand information submitted to DEQ in the water supply plans. Table 74 provides a summary of all demands within the basin by system type and source type including power generation. It also provides a count of surface water or groundwater sources associated with each system type.

Table 74: Summary of Lower Potomac Minor Basin Water Demand by Source Type and System Type (including Power Generation)

System Type	Source Count	2020 Demand (MGD)	2030 Demand (MGD)	2040 Demand (MGD)	20 Year Percent Change
Surface Water					
Agriculture	8	1.72	1.72	1.72	0.00
CWS	8	89.85	100.97	112.09	24.75
Large SSU	42	153.26	153.25	153.24	-0.01
Small SSU	N/A	0.00	0.00	0.00	0.00
Total SW	**58**	**244.83**	**255.94**	**267.05**	**9.08**
Groundwater					
Agriculture	4	0.17	0.17	0.17	1.23
CWS	158	2.43	2.92	3.41	40.30
Large SSU	77	0.46	0.48	0.51	10.91
Small SSU	N/A	21.59	24.31	27.03	25.20
Total GW	**239**	**24.65**	**27.88**	**31.12**	**26.25**
Total (SW + GW)					
Agriculture	12	1.89	1.89	1.89	0.11
CWS	166	92.28	103.89	115.50	25.16
Large SSU	119	153.72	153.73	153.75	0.02
Small SSU	N/A	21.59	24.31	27.03	25.20
Minor Basin Total	**297**	**269.48**	**283.82**	**298.17**	**10.65**

* Small SSU demands are county-wide estimates of private well usage below 300,000 gallons a month. The number of private wells is not known.

The total existing demand from all surface and groundwater sources excluding power generation is approximately 269.48 MGD, with groundwater supplying approximately 24.65 MGD or 9% of total water demands. Surface water demand within the basin totals approximately 244.83 MGD, or 91% of current demands. A large portion of these surface water demands (153 MGD) are from the Possum Point Power Station, which is a tidal withdrawal in the Potomac River. As noted above, groundwater demands are most prevalent in the portions of the basin located in the Eastern Virginia Groundwater Management Area.

The five largest facility demands for each source type including power generation are provided in Table 75. The largest groundwater demands include several municipal facilities including the Town of Colonial Beach WTP and the New Baltimore Regional WTP. The largest surface water demands include Possum Point Power Station, which withdraws from the tidal Potomac River, followed by Fairfax Water's Griffith WTP in the Occoquan.

Table 75: Top 5 Users in 2040 by Source Type in the Lower Potomac Minor Basin (including Power Generation)

Facility Name	System Type	Locality	2020 Demand (MGD)	2030 Demand (MGD)	2040 Demand (MGD)	20 Year Percent Change	% of Total Surface Water
Surface Water							
Possum Point Power Station	Large SSU	Prince William	151.13	151.13	151.13	0.00	56.59
Griffith WTP	CWS	Prince William	71.32	76.15	80.99	13.56	30.33
Manassas WTP & Service Area	CWS	Manassas	11.99	16.22	20.45	70.56	7.66
Smith Lake WTP	CWS	Stafford	4.12	5.97	7.81	89.56	2.92
Warrenton New WTP	CWS	Fauquier	1.15	1.36	1.56	35.65	0.58
Total SW			239.71	250.83	261.94	9.27	98.09
Groundwater							**% of Total Groundwater**
New Baltimore Regional	CWS	Fauquier	0.45	0.62	0.8	77.78	2.57
Colonial Beach, Town Of	CWS	Westmoreland	0.49	0.51	0.54	10.2	1.74
Dahlgren Base	CWS	King George	0.42	0.42	0.42	0.00	1.35
Marshall Service Area	CWS	Fauquier	0.07	0.23	0.39	457.14	1.25
Buckland Water & Sanitation Assets Corporation	CWS	Fauquier	0.12	0.16	0.21	75	0.67
Total GW			1.55	1.94	2.36	52.26	7.58

Table 74 also provides the proportion of each use category that is supplied by either surface water or groundwater. Use categories include Community Water System (CWS), Large Self-Supplied USer (Large SSU), Small Self-Supplied User (Small SSU), and Agricultural Self-Supplied User (AG). These categories are defined below. Surface water demand is primarily comprised of CWS and Large SSU demands. Groundwater demand is primarily comprised of CWS and Small SSU demands.

The CWS category includes any public and private waterworks that serve at least 15 service connections used by year-round residents or regularly serve at least 25 year-round residents, and are regulated under the Virginia Department of Health's Waterworks Regulation (12VAC5-590). In the Lower Potomac Minor Basin, approximately 2.43 MGD of groundwater demand and 89.85 MGD of surface water demand is from CWS. Significant groundwater users within this category include the New Baltimore Regional WTP, Colonial Beach, and Dahlgren Base. Significant surface water users from this category include Griffith WTP, City of Manassas WTP, and Stafford County's Smith Lake WTP.

Large SSUs include any non-CWS or AG who withdraw more than 300,000 gallons per month from a well or surface water intake. In the Lower Potomac Minor Basin, approximately 0.46 MGD of groundwater demand and 153.26 MGD of surface water demand is from Large SSUs. Significant groundwater users within this category include several country clubs. Significant surface water users from this category include Possum Point Power Station and country clubs.

Small SSUs include any users who withdraw less than 300,000 gallons per month from wells. Small SSUs generally consist of residential or domestic use for those who lives outside service areas and provide their

own water. Small SSU demand is generally met with groundwater. In the Lower Potomac Minor Basin, approximately 21.59 MGD of groundwater demand is estimated for Small SSUs. Localities within the basin with the greatest estimated demands from Small SSUs include Fairfax, Prince William, Fauquier, Stafford, and King George counties.

The AG category includes crop farms, livestock operations, aquaculture and other agricultural facilities. In the Lower Potomac Minor Basin, approximately 0.17 MGD of groundwater demand and 1.72 MGD of surface water demand is estimated from AG. Localities within the basin with the greatest estimated AG demands include Prince William, Stafford, and King George counties.

A.14.4 Projected Population and Water Use

Projected Population: Trends in water use are generally driven by trends in population change or economic development. Increasing population within an area generally means increased connections for community water systems or additional groundwater demand from homeowners that construct wells. Increasing population in an area also tends to incentivize both new and expanded industrial and commercial water use.

Table 73 shows the projected change in population by percent between 2020 and 2040 for each locality located partly or wholly within this minor basin. The Lower Potomac Minor Basin is already highly developed with significant urban and suburban areas. Population is projected to continue to increase significantly across the basin. The greatest projected increases in population are projected in Loudoun, Prince William, and Stafford counties. Note that many of these counties are only partially contained in this basin so not all growth will occur within the Lower Potomac Minor Basin. Population is not projected to grow as significantly in the Northern Neck of Virginia in counties such as Westmoreland and Northumberland.

Projected Water Use: The following section discusses projected water use through 2040 within the Lower Potomac Minor Basin, based on projections provided in local and regional water supply plans. Table 74, included in the existing demand section above, is the basis for information discussed in this section.

Total demand within the basin is projected to increase from 269.48 MGD in 2020 to 298.17 MGD in 2040. The major drivers of this projected increase is from CWS facilities and increasing Small SSU use. Surface water demand is projected to increase by 22.22 MGD, or 9%, by 2040, driven by increasing CWS demands. Groundwater demand is projected to increase by 6.47 MGD, or 26.2%, by 2040, driven by projected increases in Small SSU demands.

Demand from CWS users within the basin is projected to increase by 25.16% by 2040. Within this category, surface water use is projected to increase by 24.75%, while groundwater use is projected to increase by 40.30%. Fairfax Water's Griffith WTP is projected to have the largest demand increases for CWS, followed by the City of Manassas Lake Manassas WTP, and Stafford County's Smith Lake WTP. The towns of Warrenton, New Baltimore, and Colonial Beach are projected to have the largest increases in groundwater demand, although by volume these increases are much smaller than surface water increases.

Demand from Large SSUs within the basin is not projected to change significantly. This is partially due to projection for the Possum Point Power Station showing no change in demand. The Station comprises the vast majority of Large SSU demand in the basin and therefore is a good indicator of overall trends. Possum Point has reduced water use in recent year as units have been put into cold storage or retired.

Demand from Small SSUs within the basin is projected to increase by 25.20% by 2040. As noted previously, Small SSU demand is entirely met with groundwater and represents domestic/residential use. Prince William, Fauquier, and King George counties project the largest increases in Small SSU demands between 2020 and 2040. Projected increases in water demand from Small SSUs align with projected increases in population over the planning period.

Demand from AG users within the basin is projected to remain generally consistent. No increases in surface water AG demand was projected and a single facility projected a marginal increase in groundwater AG demands. With continued loss of agricultural lands in the basin, most facilities projected water demands to remain constant over the planning period.

A.14.5 Cumulative Impact Analysis

The following section provides a brief summary of the Cumulative Impact Analysis (CIA) modeling results in the Lower Potomac Minor Basin. Discussion of these results will primarily be found in the Trends and Goals section of this appendix. However a brief overview of the VAHydro model and the scenarios and metrics is provided below.

The VAHydro surface water model simulates streamflow using inputs such as precipitation, climate, land use, and topography, combined with data on all known withdrawals and discharges, and operational rules of major hydrologic features such as reservoirs. Each minor basin is broken into smaller hydrologic subsections, or river segments. The model simulates the water balance on a daily basis for each individual river segment, with each downstream segment being affected by the cumulative impact of streamflow changes occurring in upstream segments. The following figures help analyze this cumulative impact within the Lower Potomac Minor Basin. Note that this section is not intended to document in detail the methods and assumptions for the VAHydro model or for the scenarios and metrics discussed. More documentation of the model and assumptions can be found in Chapter 4.

The VAHydro surface water model was used to simulate streamflow under a variety of scenarios. Demand scenarios examine how streamflow is impacted under 2030 or 2040 demands as compared to current (2020) demands. Demands were calculated based on current and future demand information submitted through local and regional water supply plans. Climate change scenarios examine how streamflow is impacted when 2040 demands are simulated in conjunction with a range of precipitation and temperature conditions that may occur in the future due to changing climate (Dry, Median, Wet scenarios). Finally, the exempt user scenario examines impacts from users excluded, or exempt, from VWP permit requirements per Va. Code § 62.1-44.15:22 B. Exempt users were simulated at the maximum possible exempt demand identified through a review of demand justification values commonly asserted by exempt users, including but not limited to VDH pump capacity, maximum pre-1989 withdrawal, and maximum intake capacity. In order to effectively manage surface water resources and address the uncertainty related to these demands, DEQ determined the most conservative, or maximum possible, demand should be evaluated in this scenario. However, DEQ does not agree that the maximum values used in this scenario represent an allocation for, or the expectation of, a future withdrawal of that volume; nor does DEQ concede that any particular exempt user is necessarily entitled to withdraw any particular maximum value used in this scenario. The methods and assumptions for each of these modeling scenarios are discussed in more detail in Chapter 4.

For each scenario described above, different metrics can be used to evaluate the simulated streamflow. A metric is a method for measuring or evaluating a given set of data; different metrics can be evaluated to answer different questions. Within this section the following metrics will be discussed: the lowest 30 day flow (L30), the lowest 90 day flow (L90), 7Q10, and overall change in flow. The L30 describes the lowest consecutive 30 day average daily streamflow over the simulation period. This metric is a representation of a short-term, or acute drought, and is a good metric for evaluating impacts to direct withdrawals without storage. Similarly the lowest 90 day flow represents the lowest consecutive 90 day average daily streamflow over the simulation period. This would represent a prolonged drought and is often used to evaluate impacts to reservoirs. The 7Q10 is the lowest 7-day average flow that occurs (on average) once every 10 years. 7Q10 is generally used in the evaluations of in-stream beneficial uses such as waste assimilative capacity. Overall change in flow describes the net loss of water from the riverine system as a result of off-stream use not otherwise returned through point source discharges, or losses due to evapotranspiration. This metric is useful for evaluating impacts to aquatic life and is discussed in more detail in Chapter 4.

Demand Scenarios: 2020 demand or current demand, 2030 demand, and 2040 demand scenarios were simulated. The following series of figures compares the 2030 and 2040 demand scenarios to the current

demand scenario. The change in flow depicted on each map is the change expected when comparing two scenarios - in this case future demands compared to current demands. Each page includes two figures comparing either the 2030 or 2040 demand scenario to current demand using the L30, L90, and 7Q10 metrics. This allows for comparisons of simulated impacts between the 2030 and 2040 demand scenarios. The scenarios and metrics are identified in the paragraph below and in the figure captions.

Figures 289 and 290 compare the lowest 30 day flow simulated with the current demand scenario with the lowest 30 day flow simulated in the 2030 and 2040 demand scenarios respectively. Figures 291 and 292 compare the lowest 90 day low flow simulated with the current demand scenario with the lowest 90 day flow simulated in the 2030 and 2040 demand scenarios respectively. Figures 293 and 294 compare the 7Q10 simulated with the current demand scenario with the 7Q10 simulated in the 2030 and 2040 demand scenarios respectively.

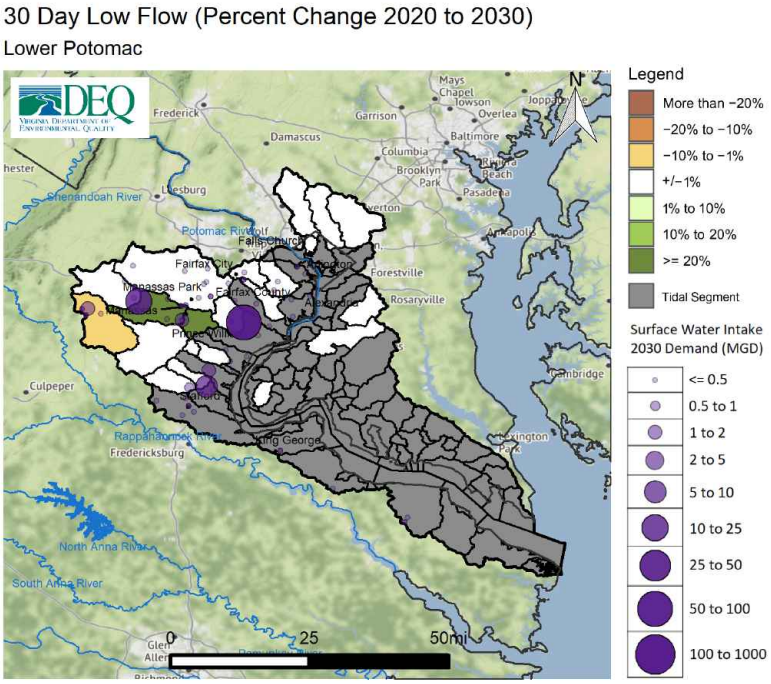

Figure 289: Change in 30 day low flow between 2020 and 2030 demand scenarios within the Lower Potomac Minor Basin

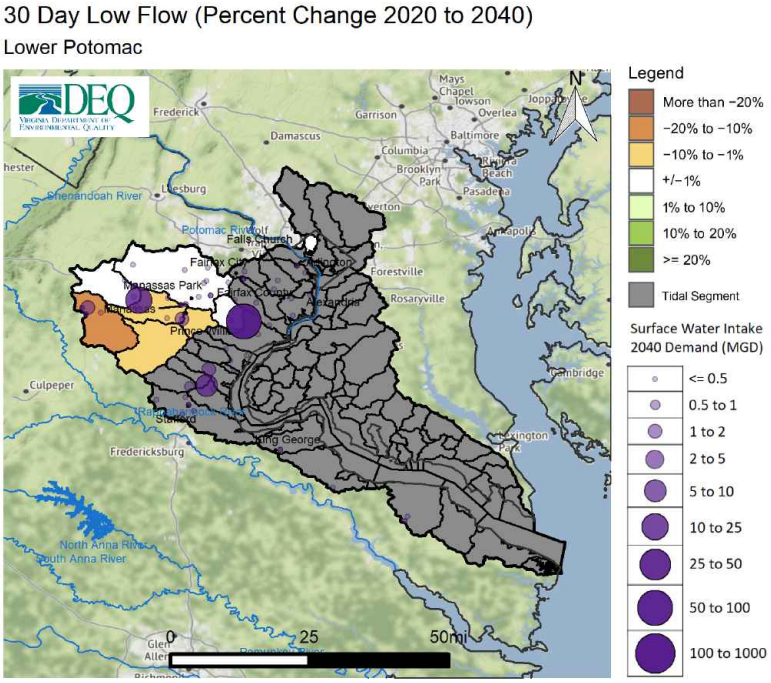

Figure 290: Change in 30 day low flow between 2020 and 2040 demand scenarios within the Lower Potomac Minor Basin

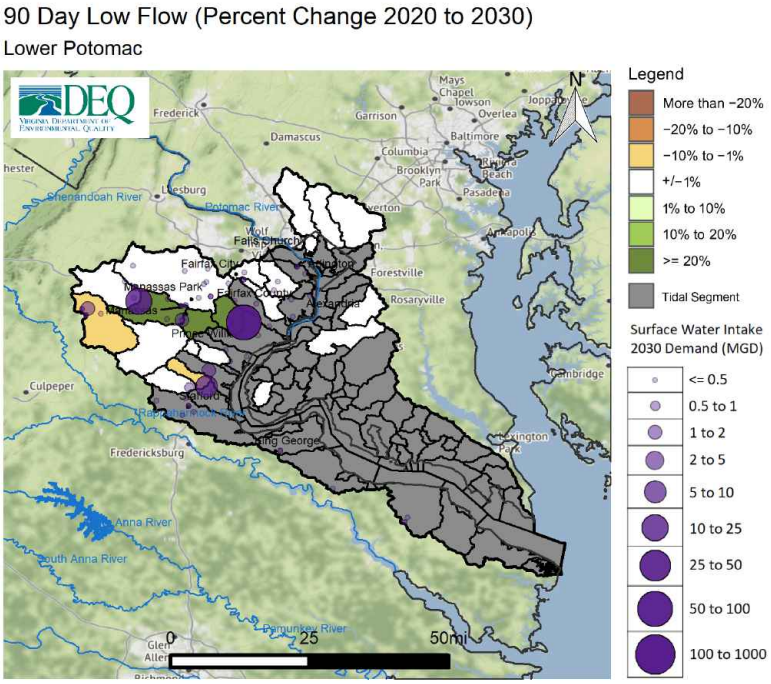

Figure 291: Change in 90 day low flow between 2020 and 2030 demand scenarios within the Lower Potomac Minor Basin

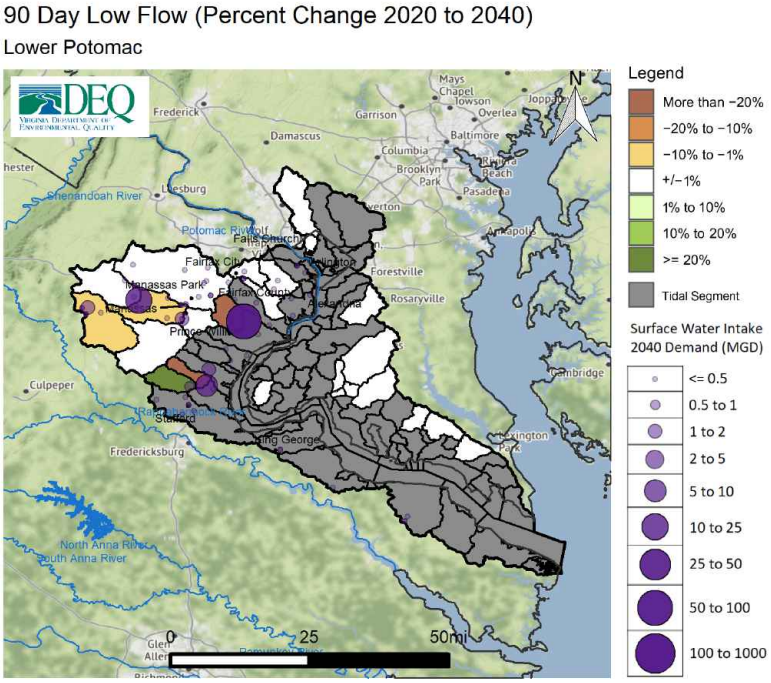

Figure 292: Change in 90 day low flow between 2020 and 2040 demand scenarios within the Lower Potomac Minor Basin

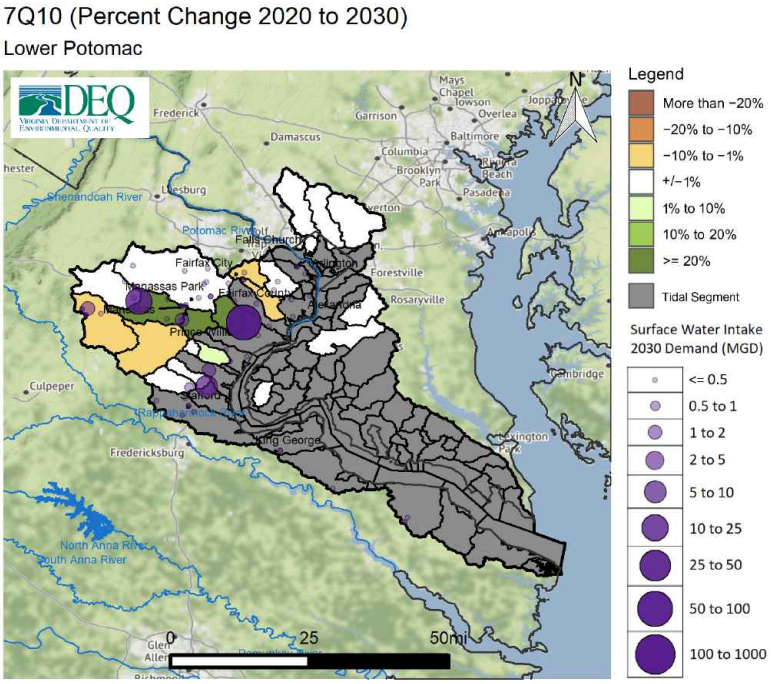

Figure 293: Change in 7Q10 between 2020 and 2030 demand scenarios within the Lower Potomac Minor Basin

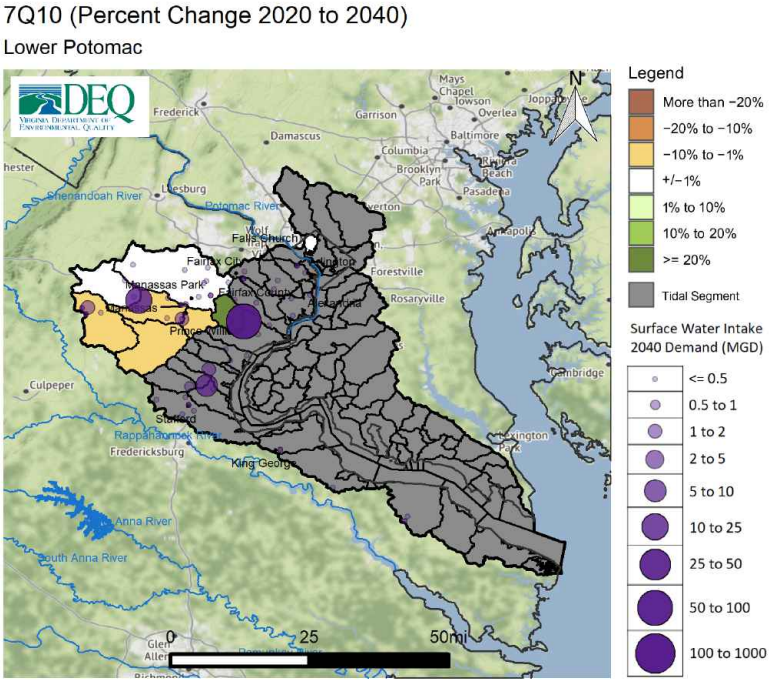

Figure 294: Change in 7Q10 between 2020 and 2040 demand scenarios within the Lower Potomac Minor Basin

The figures above show a comparison between two scenarios. An additional way to evaluate impacts to streamflow is to examine the total reduction in streamflow resulting from all withdrawals within a river segment, as well as losses due to evapotranspiration, while taking into consideration any discharges back to the source. To use a common industry term, the overall change in flow metric evaluates "consumptive use", or the amount of water removed from the river that is not returned through discharges. This can help describe potential impacts to downstream withdrawals, while also providing a basis for evaluating impacts to aquatic life. In general, total reductions in streamflow can result in a reduction in aquatic biodiversity [108]. The relation between streamflow and aquatic biodiversity is discussed in more detail in Chapter 4. Figure 295 shows the overall change in streamflow for the 2030 Demand Scenario, while figure 296 shows the overall change in streamflow for 2040 Demand Scenario.

[108] Rapp, J.L., R. Burgholzer, J. Kleiner, D. Scott, and E. Passero. 2020. "Application of a New Species-Richness Based Flow EcologyFramework for Assessing Flow Reduction Effects on Aquatic Communities." Journal of the American Water Resources Association 1–14.https://doi.org/10.1111/1752-1688.12877.

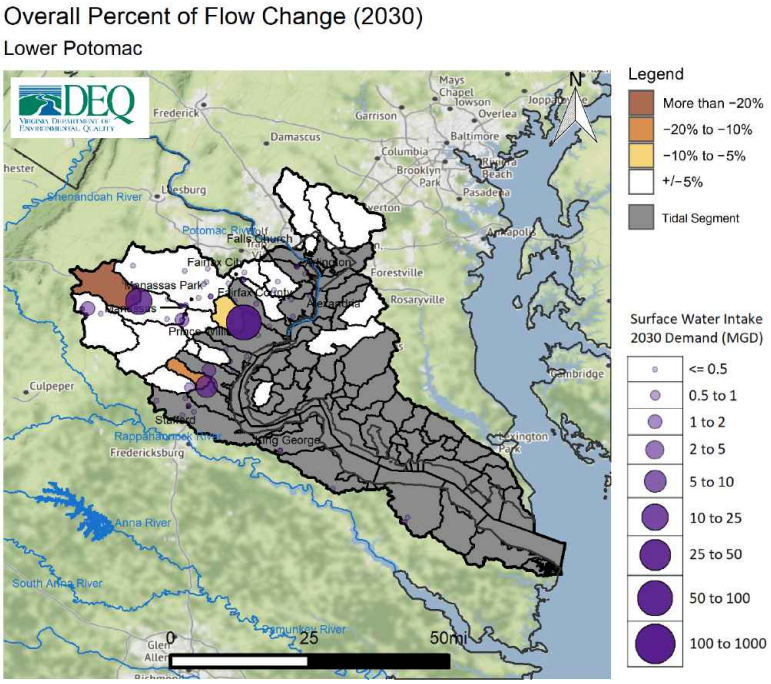

Figure 295: Overall change in flow in percent for 2030 demand scenario within the Lower Potomac Minor Basin

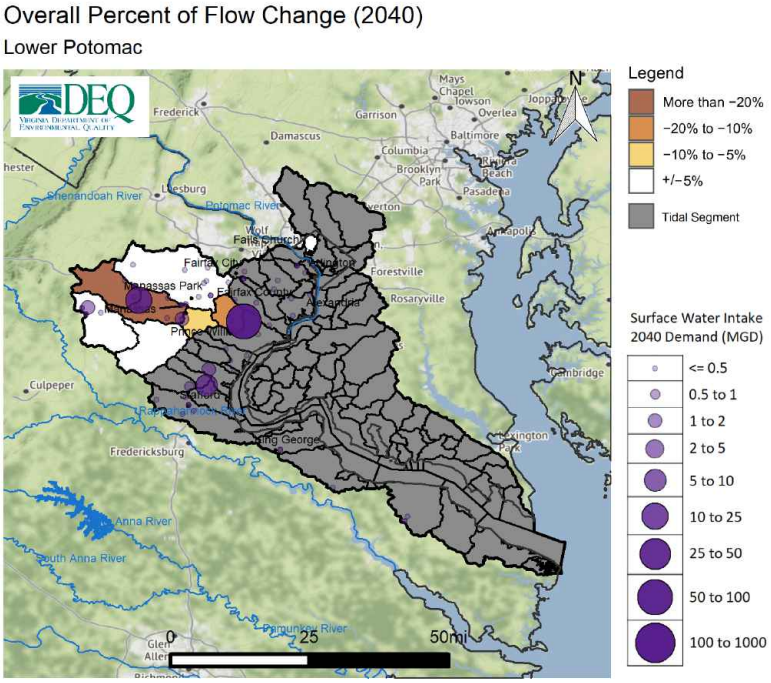

Figure 296: Overall change in flow in percent for 2040 demand scenario within the Lower Potomac Minor Basin

Climate Scenarios:Three scenarios that simulate impacts to streamflow in response to changes in temperature and climate were completed for areas in the state where climate data was available, which includes the portions of Virginia located in the Chesapeake Bay watershed. Details on the methods and assumptions employed for these scenarios can be found in Appendix B. The three scenarios can be described as dry, median, and wet scenarios. Virginia is expected to experience a range of precipitation and temperature changes that may vary spatially and from year to year. The potential for both more severe and prolonged droughts as well as for higher intensity and more frequent rain events must be considered. These three scenarios are not intended as predictions of future climate conditions, but as representations of several possibilities that climate change models indicate could occur. Should they occur, these results provide an evaluation of how streamflows may be impacted. Their purpose is to build upon existing climate modeling to provide a foundation for state and local government, as well as other stakeholders, to better evaluate what practical water resource challenges may be associated with the range of climate conditions Virginia could experience.

Figure 297 depicts the percent change in the L30 for the dry climate scenario in conjunction with 2040 demands, as compared to the current climate and demand scenario. Reductions in streamflow in this scenario may be caused by reduced precipitation, increased demand, or as is generally the case, a combination of both. Figures 298 and 299 depict the L30 for the median and wet climate scenarios (in conjunction with 2040 demands) as compared to the current climate and demand scenario.

Figure 300 depicts the percent change in the L90 for the dry climate scenario in conjunction with 2040 demands, as compared to the current climate and demand scenario. Figures 301 and 302 depict the L30 for the median and wet climate scenarios (in conjunction with 2040 demands) as compared to the current climate and demand scenario.

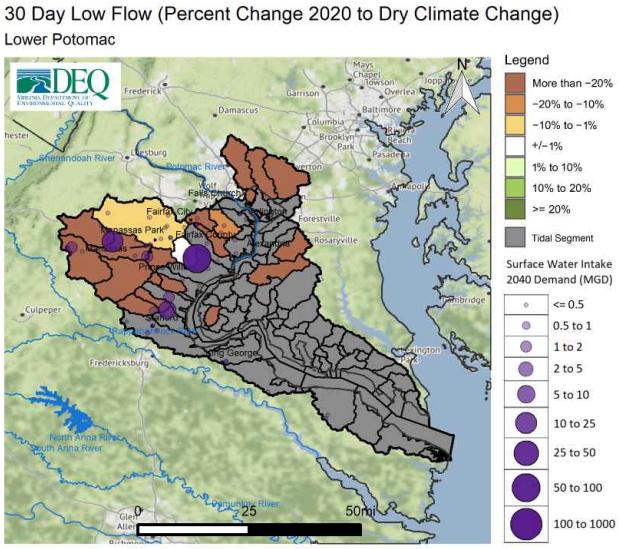

Figure 297: Change in 30 day low flow between current climate/demand scenario and the dry climate/2040 demand scenario within the Lower Potomac Minor Basin

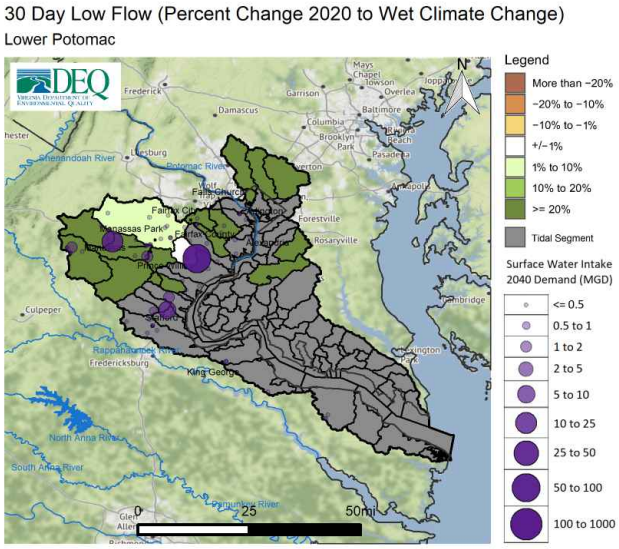

Figure 299: Change in 30 day low flow between current climate/demand scenario and the wet climate/2040 demand scenario within the Lower Potomac Minor Basin

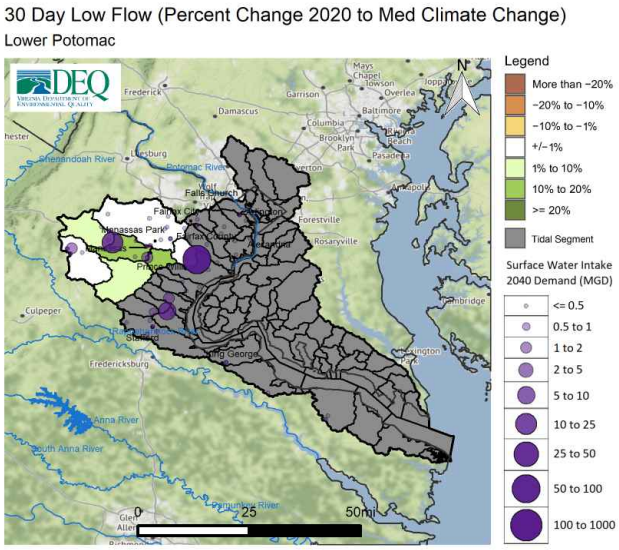

Figure 298: Change in 30 day low flow between current climate/demand scenario and the median climate/2040 demand scenario within the Lower Potomac Minor Basin

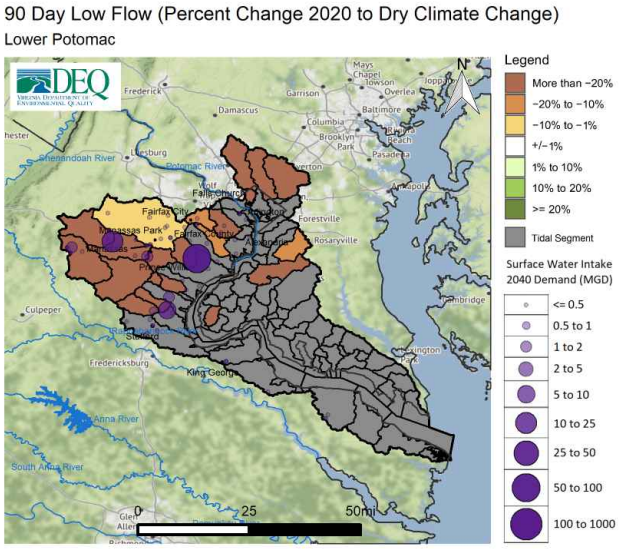

Figure 300: Change in 90 day low flow between current climate/demand scenario and the dry climate/2040 demand scenario within the Lower Potomac Minor Basin

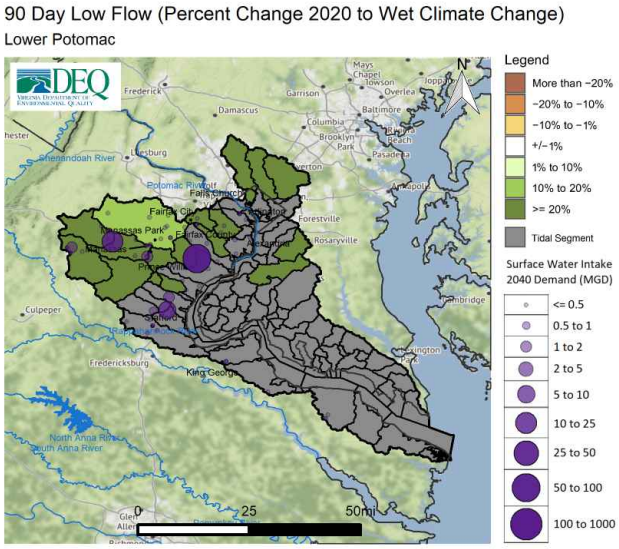

Figure 302: Change in 90 day low flow between current climate/demand scenario and wet climate/2040 demand scenario within the Lower Potomac Minor Basin

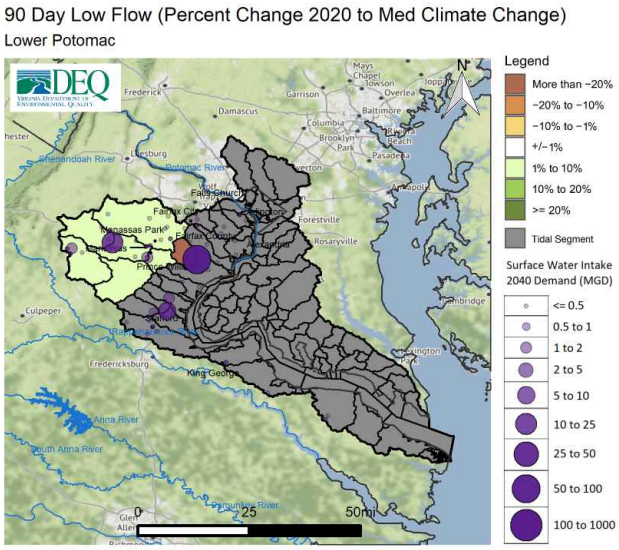

Figure 301: Change in 90 day low flow between current climate/demand scenario and median climate/2040 demand scenario within the Lower Potomac Minor Basin

Exempt User Scenario: The exempt user scenario simulates the maximum possible exempt demand for users excluded from Virginia Water Protection permitting requirements per Va. Code § 62.1-44.15:22 B, in combination with the permitted withdrawal limits for those users that are permitted. A more detailed discussion of the data and assumptions used in this scenario can be found in Appendix B. Note that this scenario uses current climate conditions. Figure 303 depicts the percent change in the Lowest 30 Day Flow between the exempt user scenario and current (2020) demand. Figure 304 depicts the percent change in the Lowest 90 Day Flow between the exempt user scenario and current (2020) demand. Figure 305 depicts the percent change in the 7Q10 between the exempt user scenario and current (2020) demand. Finally, figure 306 depicts the overall change in flow in percent (consumptive use) for the exempt user scenario.

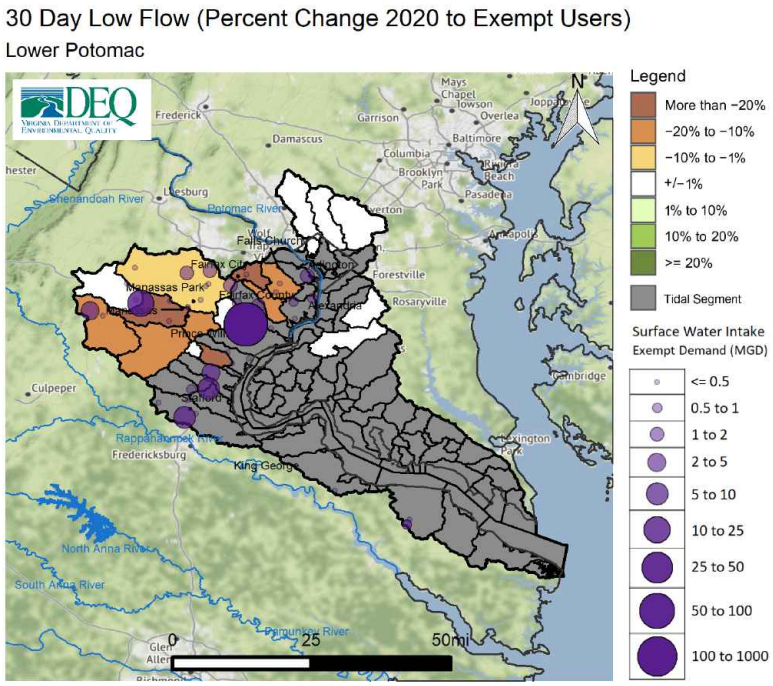

Figure 303: Change in 30 day low flow between current demand scenario and exempt User scenario within the Lower Potomac Minor Basin

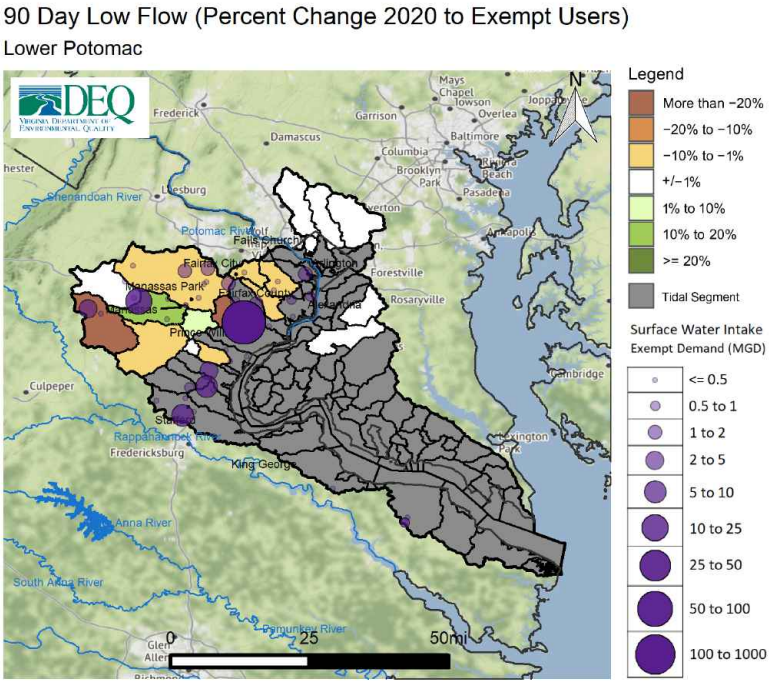

Figure 304: Change in 90 day low flow between current demand scenario and exempt User scenario within the Lower Potomac Minor Basin

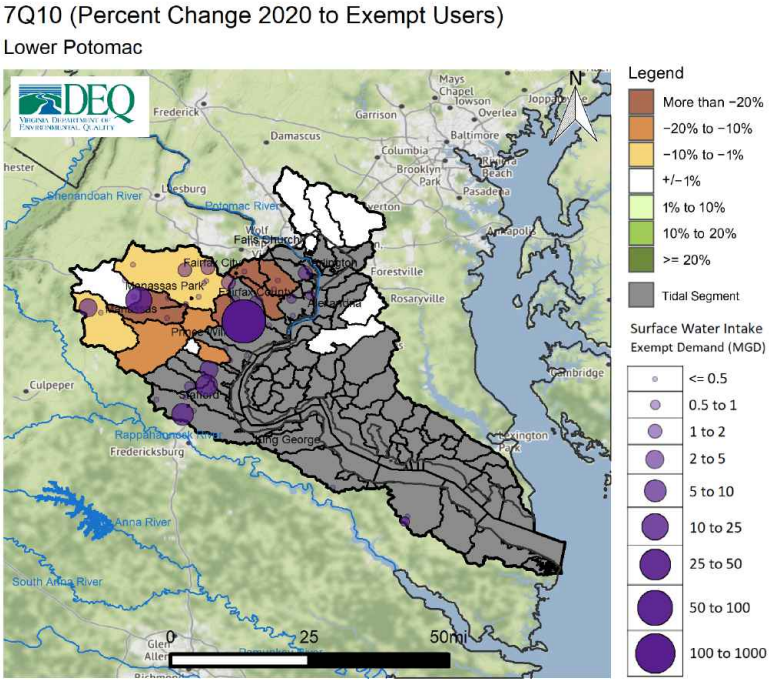

Figure 305: Change in 7Q10 between current demand scenario and exempt User scenario within the Lower Potomac Minor Basin

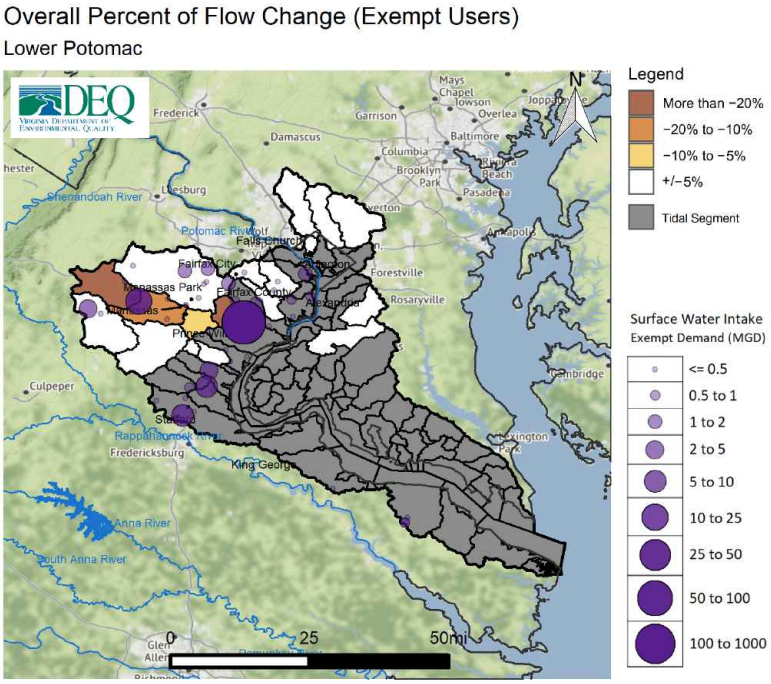

Figure 306: Overall change in flow in percent for exempt user scenario within the Lower Potomac Minor Basin

Potential Unmet Demand: Potential unmet demand was evaluated for all facilities within the basin for each scenario. Potential unmet demand is the portion of surface water demand for a specific facility that is limited by available streamflow as simulated in a given model scenario, including any known operational limits such as flow-by requirements. This unmet demand, if realized, could be managed through water conservation, through alternative sources, operational changes, or from available storage. Absent of these or other options, this portion of demand could remain unmet. As with all scenarios, demand requirements were determined using demand projections provided in the water supply plans. In the case of the exempt user scenario, the highest possible demand amount was used for users exempt from VWP permitting requirements.

This metric is useful for evaluating where the results seen in the above figures may result in challenges in meeting future demands under a variety of conditions including increasing demands in the basin, changing climate, or withdrawals from users exempt from permitting requirements. Table 76 provides for each facility the highest average daily potential unmet demand over a 30 day period over the course of the simulation for the following scenarios: 2020 demand, 2030 demand, 2040 demand, dry climate, and exempt User. Only facilities showing potential unmet demand in at least one scenario appear on this table. The dry climate scenario is selected among the climate scenarios as the dry scenario represents the potential for increased drought intensity and frequency, and therefore poses the greatest challenge for water supply. Additional information on the potential unmet demand metric can be found in Appendix B.

Table 76: Change in Highest 30 Day Potential Unmet Demand (MGD) in Lower Potomac Minor Basin

Facility	**2020 Demand**	**2030 Demand**	**2040 Demand**	**Dry Climate**	**Exempt User**
Griffith WTP	0.00	0.00	0.00	0.00	3882.45
Manassas WTP & Service Area (Reservoir)	0.00	9.48	21.63	15.26	2.92
Warrenton New WTP	0.49	0.45	0.85	0.85	1.65
Fairfax Golf Course	0.00	0.00	0.00	-	0.12
Dumfries Plant	0.00	0.00	0.00	-	0.05
Manassas WTP & Service Area	0.00	0.01	0.01	0.01	0.00
Smith Lake WTP	3.53	0.00	0.00	-	0.00
Stafford Plant	0.41	0.00	0.00	-	0.00

* Climate scenarios were not completed in areas located outside of the Chesapeake Bay watershed

Note: Potential unmet demand is the portion of surface water demand for a specific facility that is limited by available streamflow as simulated in a given model scenario, including any known operational limits such as flow-by requirements. This unmet demand, if realized, could be managed through water conservation, alternative sources, operational changes, or from available storage.

A.14.6 Spatial Overview of Groundwater Demands

The cumulative impact analysis figures above provide an overview of surface water demands in the basin but did not include groundwater demands. Figure 307 identifies the location and size of projected groundwater demands in the basin for 2040 based on information provided by localities in water supply plans.

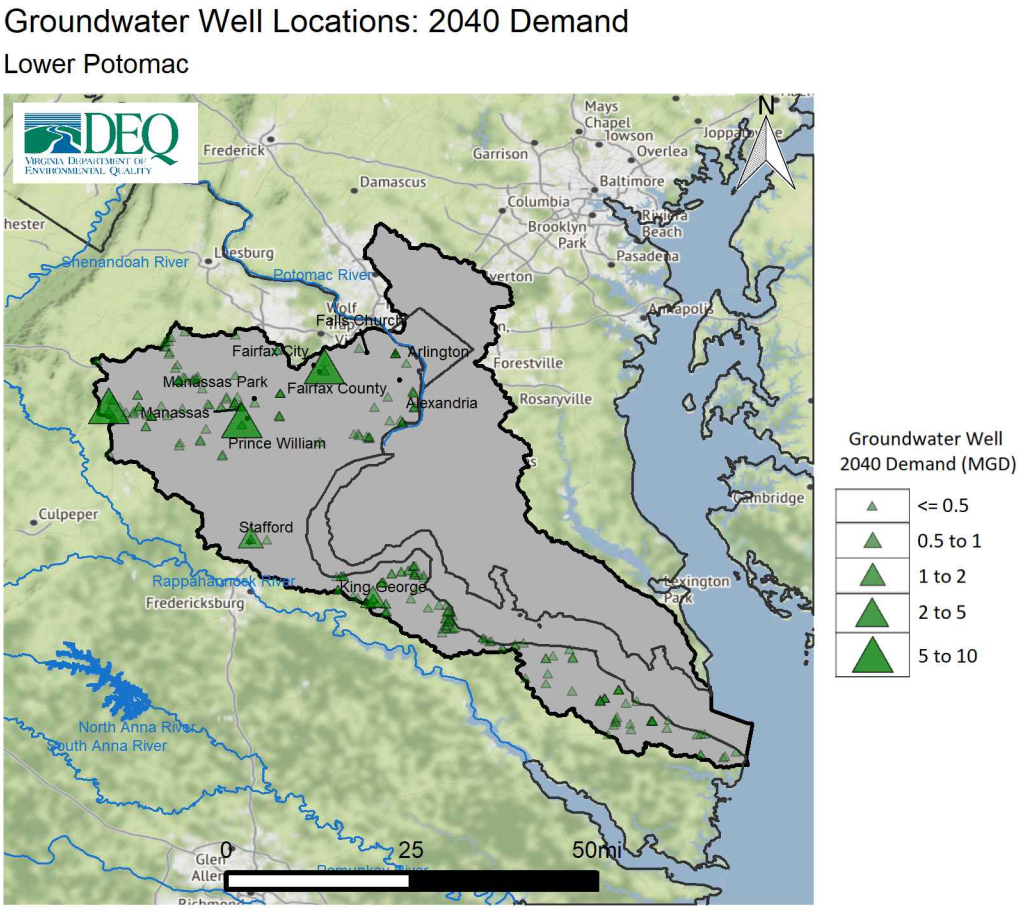

Figure 307: Projected 2040 Groundwater Demands in the Potomac Lower Minor Basin

A.14.7 Trends and Goals

The Code of Virginia mandates that the State Water Control Board should taking into consideration the principle that "adequate and safe supplies shall be preserved and protected for human consumption, while conserving maximum supplies for other beneficial uses".[109] This principle is the key driver of the challenges in water resource management, which is that all beneficial uses must be adequately considered when evaluating impacts to surface water resources. The State Water Control Board is tasked with insuring that water supply quantity needs are met at all times while also protecting Virginia's natural resources, and furthermore, ensuring equitable allocation during a time of shortage. [110] While evaluating and planning for the long-term sustainability of water supply for Virginia is the primary goal for the State Plan, evaluating and limiting impacts to in-stream beneficial uses such as aquatic habitat life is also part of DEQ's responsibility.

The primary purpose of this section is to identify where the most significant challenges to long-term sustainability of water supply and other beneficial uses are indicated based on the CIA and information collated from local water supply plans within this basin. Goals for future planning and areas for additional data collection or analysis are also suggested where appropriate.

The CIAs were completed using the best available data and methods known to DEQ. This discussion focuses on the evaluation of trends - in other words the prevailing tendency or inclination. This means evaluating whether streamflow is simulated to increase or decrease in a given scenario, and by how much. A relative trend indicating reductions of greater than or equal to 10% in streamflow, whether driven by demand increases, changing climate conditions, or exempt user demands was considered a threshold for potential impacts to beneficial uses. The following summarize the key trends or goals for this basin:

- **Demand Scenarios:** Surface water demands in the Lower Potomac Basin are projected to increase approximately 24% by 2040 with the majority of those demand increases coming from CWS facilities including Fairfax Water (Griffith WTP) and City of Manassas WTP. However, when comparing the 2040 demand scenario to the 2020 demand scenario, there are minimal reductions in simulated streamflow. Cedar Run at Elk Run Road shows a simulated reduction of more than 10% streamflow in the short-term drought (L30) comparing 2020 to 2040 demand. This is driven by increasing demands for the Town of Warrenton from the Warrenton Reservoir, however in total volume this represents less than one cfs reduction during extreme drought conditions. In a long-term drought (L90), comparison between the 2020 and 2040 demand scenarios shows reductions of more than 20% below the Occoquan Reservoir, and in Aquia Creek below the Smith Lake Reservoir. In the short-term drought (L30), no releases from the Occoquan Reservoir are simulated across all scenarios; no permit is in place requiring releases and the Occoquan Reservoir is tidal below the reservoir. Reductions below the Occoquan Reservoir are driven by increasing demands from Fairfax Water's Griffith WTP. These reductions will impact freshwater inflows into tidal sections, particularly during drought flows, and where reductions in freshwater inflows exceed 2 MGD, further evaluation may be warranted. Reductions in releases from Aquia Creek are driven by increasing demands from Stafford County's Smith Lake WTP which operates under a VWP permit which includes a minimum release requirement which is designed to minimize impacts to Aquia Creek, which is primarily tidal below the Smith Lake Reservoir. Significant potential unmet demand is simulated in the 2040 demand scenario for the City of Manassas' WTP in the Manassas Reservoir. In the short-term drought the simulated reservoir storage is depleted due to significant increases in demand projected for 2040. The projected demands exceed the current VDH pump capacity which suggests alternatives would need to be investigated to meet these projected demands. The Town of Warrenton is also simulated to have potential unmet demand in current and future demand scenarios. Finally, in evaluating the overall percent of flow reduction (consumptive use) in the 2040 demand scenario in this basin, more than a 20% reduction in total flow was simulated below the Warrenton Reservoir in Cedar Creek, below Lake Manassas on Broad Run, and below the Occoquan Reservoir. As noted, reduced downstream flows below the Occoquan Reservoir will impact freshwater flows into tidal portions of the Occoquan Reservoir but evaluating this potential requires

[109] § 62.1-44.36 of the Code of Virginia
[110] 9VAC25-390-20.1

tidal resource modeling. Withdrawals from all three of these reservoirs are exempt from VWP permitting and minimum releases are not required by a VWP permit, although both Lake Manassas and the Warrenton Reservoir were modeled with voluntary minimum releases. The simulated reductions of overall flow of more than 20% in non-tidal segments such as Broad Run and Cedar Creek in the 2040 demand scenario suggests the potential for impacts to aquatic life and species bio-diversity in these segments.

- **Climate Scenarios:** Current climate modeling suggests Virginia will generally receive more precipitation on average in the future. However, the data also suggests the possibility of more severe droughts despite this overall trend of increasing precipitation. The dry climate scenario shows significant reductions in streamflow in both short-term drought (L30) and long-term drought (L90) compared to current climate in the entire Cedar Run watershed, as well as in Broad Run below Lake Manassas, and below the Occoquan Reservoir. The dry climate scenario results in potential unmet demand for several CWS facilities including the Lake Manassas WTP and Warrenton WTP, which withdraws from the Warrenton Reservoir. Where future climate conditions resemble this dry scenario, the simulations indicate drought conditions more severe than the current drought of record will be experienced for portions of the basin. Reductions in the short-term (L30) and long-term drought (L90) metrics of 10-40% were simulated in the dry climate scenario compared to the current meteorological conditions. The potential for more severe droughts must be evaluated and considered by localities and users when evaluating existing sources and alternatives, as well as for broader planning and resource management efforts by all stakeholders whether state or local.

- **Exempt User Scenario:** When compared to the 2020 demand scenario, the exempt user scenario shows simulated reductions in short-term drought flows (L30) of more than 10% across most of the non-tidal portions of the basin including Cedar Run, Broad Run, Holmes Run, and below the Occoquan and Warrenton reservoirs. The most significant reductions by percent in the L30 are in Broad Run below the Lake Manassass Reservoir, although the reduction by volume is less than 1 cfs during acute drought flows. When comparing the exempt user scenario to 2020 demands, the most significant reductions by volume in the L90 are seen below the Occoquan Reservoir, during periods where storage is depleted as a result of Fairfax Water's Griffith WTP maximum possible exempt demand amount, and below the Warrenton Reservoir, which is driven by the Town of Warrenton's maximum possible exempt demand. Potential unmet demand in the exempt scenario is simulated for Fairfax Water's Griffith WTP, as the maximum possible exempt demand exceeds capacity of the reservoir during droughts. Potential unmet demand is also simulated for both the City of Manassas and the Town of Warrenton in the exempt scenario, as their available storage is not sufficient to sustain their maximum possible exempt demand amounts during a drought. These results indicate that the maximum possible exempt demands in the basin exceed the water budget in many river segments as well as in the key reservoirs used for public water supply. Preserving water supply and other beneficial uses will require managing these demands with respect to their cumulative impacts and in the context of the available resources in the basin.

- **Coastal Plain Groundwater Demand Scenarios:** Below the fall-line, the Lower Potomac Basin is tidally influenced and increasing salinity limits use of the Potomac River as a water source. As with other parts of the Virginia Coastal Plain, freshwater streams are limited in size and most demand is met through groundwater withdrawals from confined aquifers such as the Potomac Aquifer. Counties such as King George, Northumberland, and Westmoreland rely on groundwater withdrawals from confined aquifers for the majority of their demands. CIA groundwater modeling of the 2020 and 2040 demand scenarios was completed using the VAHydro Virginia Coastal Plain Groundwater Model for the State Plan. Reviewing the methods, assumptions, and resulting figures for these simulations in Chapter 4, section 4.3.3(Virginia Coastal Plain Model Results) may be helpful prior to reading the following discussion.

- With respect to the Lower Potomac Minor Basin, the following are the key trends identified in the groundwater simulation results. In the 2020 demand scenario, water levels throughout the Coastal Plain in the Potomac Aquifer are expected to recover gradually from 2020 through 2050, before declining marginally from 2050-2070. However, in the 2040 demand scenario, due to increasing domestic (Small SSU) and permitted use, water levels decline consistently through the length of the fifty year

simulation. In both the 2020 and 2040 scenarios, water levels in the Potomac, Aquia, and Piney Point aquifers are simulated to fall below the critical surface by 2070 in this area. This is most prevalent in the localities along the fall-line, where the aquifers are shallower and thinner. In the 2040 demand scenario, additional critical cells are created in the Potomac Aquifer in both Stafford and King George counties. While most of Stafford County's demands are met by surface water, King George County relies on groundwater from the Potomac Aquifer for most of its demands. In addition to increasing permitted use, domestic use in King George County alone is projected to more than double between 2020 and 2040. The scenarios indicate the potential for challenges in permitting existing and future groundwater withdrawals in King George County, and an increasing potential for similar challenges for larger withdrawals in nearby counties such as Westmoreland.

- The Eastern Virginia Groundwater Management Area was expanded to include the Northern Neck and Middle Peninsula in 2014. Compared to other parts of the management area, less historic withdrawal and water level monitoring data is available. The hydrogeology of the region is also less understood as one of the major mechanisms through which geophysical investigations have been completed in the Coastal Plain is through groundwater permits, which have only recently been issued in this area. The hydrogeology around King George County is particularly complex with evidence of significant faulting that can impact both the quantity and quality of water. This area as a whole must be a priority for additional characterization to better understand the aquifer system. Similarly, few real-time water level monitoring wells are present in this area. Adding additional wells to the network will be necessary to evaluate the long-term water level trends in this area.

A.15 Upper Rappahannock Minor Basin

A.15.1 Watershed Overview

The Rappahannock River is formed at Chester Gap on the eastern slope of the Blue Ridge Mountains. The river runs southeast across the Piedmont province, before crossing the fall-line in the City of Fredericksburg. From there it is tidally influenced as it flows through the Coastal Plain of Virginia before entering the Chesapeake Bay 20 miles south of the Potomac River. The Upper Rappahannock Minor Basin consists of the non-tidal portions of the river as it flows off the Blue Ridge Mountains and through the Piedmont. The largest tributary to the Rappahannock River is the Rapidan River, which begins in Greene County and converges with the Rappahannock River above the fall line. Other significant tributaries include the Hazel, Thorton, and Robinson rivers. The majority of the basin is forested with land uses ranging from low-density residential, forestry, and agriculture. Mixed use and urban development are also found in or around population centers.

The total spatial area of the Upper Rappahannock Minor Basin is 1,623 sq. miles and includes all or portions of the localities listed in Table 77. The major population centers within the basin include the the Town of Culpeper, and portions of the Town of Warrenton and the City of Fredericksburg. Many counties within this basin are well-populated, particularly those that are within commuting distance to Northern Virginia and the D.C. metropolitan area.

A.15.2 Existing Water Sources

Major surface water sources within the basin include the Rappahannock and Rapidan rivers as well as several impoundments including Mott's Run, Lake MooneyRocky Pen Run, Hunting Run, and Lake Pelham. Groundwater within the basin is primarily withdrawn from fractured rock aquifers.

Withdrawals within the basin are primarily used for public water supply as well as for agriculture, irrigation, commercial, and industrial/manufacturing.

The location of wells and surface water intakes identified to DEQ within the basin are shown in Figure 308. This figure does not include private or domestic wells. This map also shows locations of any Instream Flow Incremental Method (IFIM) studies completed in the basin, which are relevant to the discussion of ecological impacts in a later section of this appendix. The majority of surface water intakes are located along the Rappahannock and Rapidan rivers while wells are generally located in the northern and central portions of the basin.

Table 77: Population Trend by Locality in Upper Rappahannock Basin

Localities	20 Year % Change
Albemarle	24.72
Culpeper	31.16
Fauquier	18.85
Greene	21.16
Madison	2.35
Orange	25.12
Page	-0.82
Rappahannock	-0.25
Rockingham	14.04
Spotsylvania	30.24
Stafford	35.79
Warren	17.78
Fredericksburg	29.56

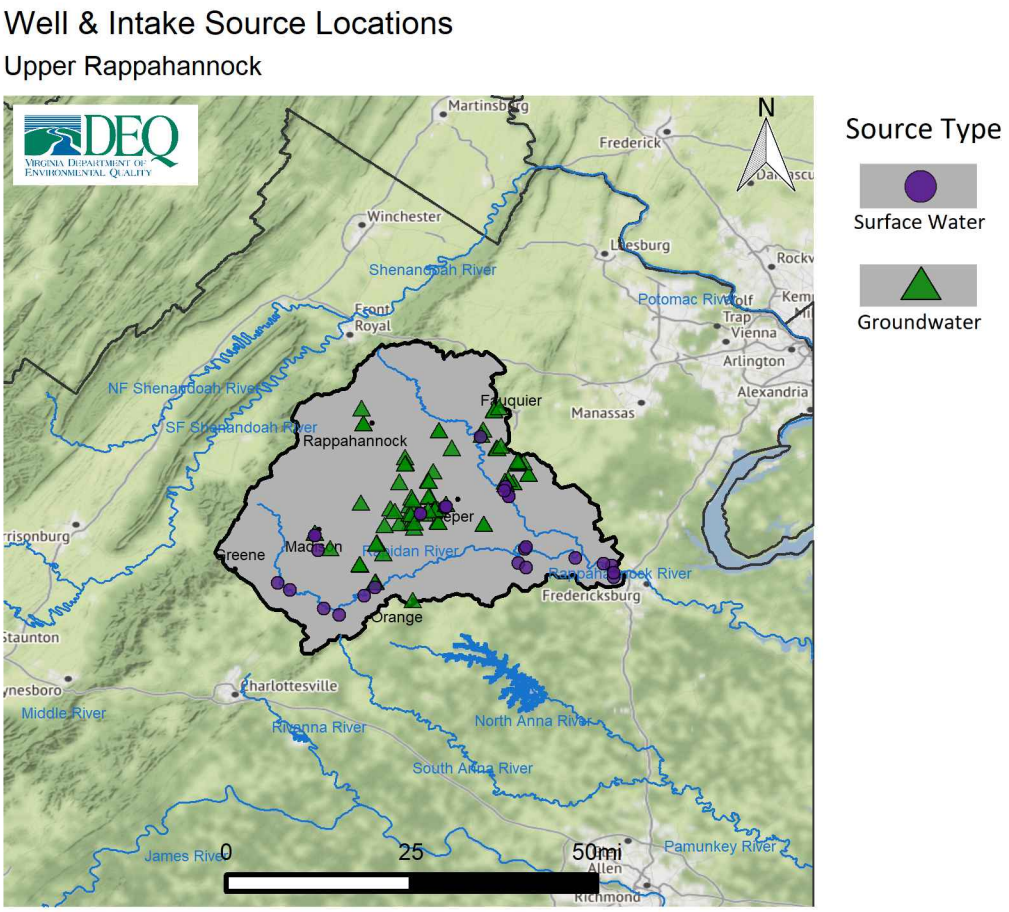

Figure 308: Spatial distribution of groundwater wells and intakes in the Upper Rappahannock Minor Basin

A.15.3 Existing Water Use

The following section discusses existing (current) water use within the basin, which is based on existing demand information submitted to DEQ in the water supply plans. Table 78 provides a summary of all demands within the basin by system type and source type including power generation.

Table 78: Summary of Upper Rappahannock Minor Basin Water Demand by Source Type and System Type (including Power Generation)

System Type	Source Count	2020 Demand (MGD)	2030 Demand (MGD)	2040 Demand (MGD)	20 Year Percent Change
Surface Water					
Agriculture	6	0.70	0.70	0.70	0.00
CWS	10	15.86	22.84	29.82	88.08
Large SSU	8	0.37	0.45	0.54	48.67
Small SSU	N/A	0.00	0.00	0.00	0.00
Total SW	**24**	**16.93**	**23.99**	**31.06**	**83.46**
Groundwater					
Agriculture	2	0.58	0.58	0.58	0.00
CWS	68	1.73	2.69	3.64	110.81
Large SSU	10	0.09	0.09	0.09	0.00
Small SSU	N/A	5.33	8.21	11.08	107.74
Total GW	**80**	**7.73**	**11.57**	**15.39**	**99.09**
Total (SW + GW)					
Agriculture	8	1.28	1.28	1.28	0.00
CWS	78	17.58	25.53	33.47	90.31
Large SSU	18	0.45	0.54	0.63	39.47
Small SSU	N/A	5.33	8.21	11.08	107.74
Minor Basin Total	**104**	**24.64**	**35.56**	**46.46**	**88.56**

* Small SSU demands are county-wide estimates of private well usage below 300,000 gallons a month. The number of private wells is not known.

The total existing demand from all surface and groundwater sources is approximately 24.64 MGD, with groundwater supplying approximately 7.73 MGD or 31% of total water demands. Surface water demand within the basin totals approximately 16.93 MGD, or 69% of current demands. Groundwater demands in the basin primarily supply Small Self-Supplied Users (Small SSUs) reliant on individual wells and Community Water System (CWS) facilities. Surface water is almost entirely demands by CWS with 18.86 MGD or over 93% of total surface water demands in the basin.

The five largest withdrawals for each source type are provided in Table 79. The largest groundwater demands include the Town of Culpeper WTP, Bealeton Regional Water System, and New Baltimore Regional Service Area. The largest surface water demands include Mott's Run WTP, Lake Mooney WTP, and the Town of Culpeper's Lake Pelham intake.

Table 79: Top 5 Users in 2040 by Source Type in the Upper Rappahannock Minor Basin (including Power Generation)

Facility Name	System Type	Locality	2020 Demand (MGD)	2030 Demand (MGD)	2040 Demand (MGD)	20 Year Percent Change	% of Total Surface Water
Surface Water							
Motts Run WTP	CWS	Spotsylvania	6.49	9.26	12.03	85.36	38.73
Lake Mooney WTP	CWS	Stafford	6.03	8.72	11.41	89.22	36.74
Culpeper (Town) WTP	CWS	Culpeper	1.56	2.73	3.9	150	12.56
Wilderness Service Area	CWS	Orange	0.48	0.84	1.2	150	3.86
Orange (Town) WTP	CWS	Orange	0.48	0.75	1.02	112.5	3.28
Total SW			15.04	22.3	29.56	96.54	95.17
Groundwater							**% of Total Groundwater**
Culpeper (Town) WTP	CWS	Culpeper	0.73	1.28	1.83	150.68	11.89
Bealeton Regional Water System	CWS	Fauquier	0.34	0.6	0.86	152.94	5.59
New Baltimore Regional	CWS	Fauquier	0.16	0.23	0.29	81.25	1.88
Remington Service Area	CWS	Fauquier	0.08	0.11	0.13	62.5	0.84
Marsh Run Mobile Home Park	CWS	Fauquier	0.09	0.1	0.11	22.22	0.71
Total GW			1.4	2.32	3.22	130	20.92

Table 78 also provides the proportion of each use category that is supplied by either surface water or groundwater. Use categories including Community Water System (CWS), Large Self-Supplied User (SSU), Small Self-Supplied User (Small SSU), and Agricultural Self-Supplied User (AG). These categories are defined below. The majority of surface water demand is from CWS facilities. For groundwater, Small SSU is the major use type.

The CWS category includes any public and private waterworks that serve at least 15 service connections used by year-round residents or regularly serve at least 25 year-round residents, and are regulated under the Virginia Department of Health's Waterworks Regulation (12VAC5-590). In the Upper Rappahannock Minor Basin, approximately 1.73 MGD of groundwater demand and 15.86 MGD of surface water demand is from CWS. Significant groundwater users include the Town of Culpeper WTP, Bealeton Regional Water System, and New Baltimore Regional Service Area. Significant surface water users from this category include Spotysylvania County's Motts Run WTP, Stafford County's Lake Mooney WTP, and the Town of Culpeper's Lake Pelham intake. Surface water is the most viable source of supply for CWS facilities in the watershed. Large SSUs include any non-CWS or AG who withdraw more than 300,000 gallons per month from a well or surface water intake. In the Upper Rappahannock, approximately 0.09 MGD of groundwater demand and 0.37 MGD of surface water demand is from Large SSUs. The largest demands in the category supply golf and country clubs throughout the basin.

Small SSUs include any users who withdraw less than 300,000 gallons per month from wells. Small SSUs generally consist of residential or domestic use for those who live outside service areas and provide their own water. Small SSU demand is generally met with groundwater. In the Upper Rappahannock Basin, approximately 5.33 MGD of groundwater demand is from Small SSUs. Localities within the basin with the greatest contribution from Small SSU's include Culpeper, Madison, and Rappahannock counties. With

significant increases in population throughout the basin, the projected increases in Small SSU demand align with increases in population in the basin.

The AG category includes crop farms, livestock operations, aquaculture and other agricultural facilities. In the Upper Rappahannock Basin, approximately 0.58 MGD of groundwater demand and 0.70 MGD of surface water demand is from AG. The majority of AG demand is projected in Madison and Rappahannock counties with both groundwater and surface water use.

A.15.4 Projected Population and Water Use

Projected Population: Trends in water use are generally driven by trends in population change or economic development. Increasing population within an area generally means increased connections for community water systems or additional groundwater demands from homeowners that construct wells. Increasing population in an area also tends to incentivize both new and expanded industrial and commercial water use.

Table 77 shows the projected change in population by percent between 2020 and 2040 for each locality located partly or wholly within this minor basin. Much of this basin is projected to experience moderate to significant population growth. Population tends to increase nearer to interstate corridors and within areas closest to Northern Virginia and Washington D.C. Both Stafford and Spotsylvania counties, although mostly located outside of this basin, are projected to grow by more than 30%. Other counties with significant projected population growth include Culpeper, Rockingham, Orange, and Greene counties. Increases in Small SSU demands from increased private well development is projected to more than double by 2040.

Projected Water Use: The following section discusses projected water use through 2040 within the Upper Rappahannock Minor Basin, based on projections provided in local and regional water supply plans. Table 78, included in the existing demand section above, is the basis for information discussed in this section.

Total demand within the basin is projected to increase from 24364 MGD in 2020 to 46.46 MGD in 2040. Growth is focused within surface water demands supporting CWS, and groundwater demands for Small SSUs in the basin. Significant increases in population in the basin over the planning period is the primary driver of projected water demands. Surface water demand is projected to increase by 14.13 MGD, or 83.4% %, by 2040. Groundwater demand is projected to increase by 7.66 MGD, or 99.09% by 2040.

The largest contributors to trends in total projected demand include significant increases from Small SSUs in Culpeper County, Motts Run WTP, Lake Mooney WTP, and the Town of Culpeper WTP. The largest demand increases in the watershed are in support of public water supplies or domestic water use.

Demand from CWS users within the basin is projected to increase by 90.31% by 2040. Within this category, surface water use is projected to increase by 88.08%, while groundwater use is projected to increase by 110.81%. Surface water demands are the primary water source for CWS in the basin. Significant increases in water demands are projected for major surface water users including the Motts Run WTP, Lake Mooney WTP, the Town of Culpeper WTP, and the Town of Orange WTP. Groundwater demands in the category are also projected to significantly increase during the planning period. Significant increases in groundwater demands are projected for the Town of Culpeper, Bealeton Regional Water System, and New Baltimore Regional.

Demand from Large SSUs within the basin is projected to increase by 39.47%% by 2040. Within this category, surface water use is projected to increase by 48.67%, while groundwater use is projected to remain constant over the planning period. Surface water is the only water source projecting increases over the planning period with the largest increases in demand projected for the Rapidan Golf Club, Lake of the Woods Country Club, and Green Hills Club.

Demand from Small SSUs within the basin is projected to increase by 107.74% by 2040. As noted previously, Small SSU demand is entirely met with groundwater. The greatest demand increases are projected to occur

within Culpeper, Madison, and Rappahannock counties. Significant population increases influenced by proximity to the Washington D.C. and Richmond metropolitan areas is the primary driver of increased demands in the category. Projected water demand increases align with projected population increases in the basin.

Demand from AG within the basin are projected to remain consistent throughout the planning period with no growth or declines projected by 2040. Within this category surface water and groundwater use is will remain constant.

A.15.5 Cumulative Impact Analysis

The following section provides a brief summary of the Cumulative Impact Analysis (CIA) modeling results in the Upper Rappahannock Minor Basin. Discussion of these results will primarily be found in the Trends and Goals section of this appendix. However a brief overview of the VAHydro model and the scenarios and metrics is provided below.

The VAHydro surface water model simulates streamflow using inputs such as precipitation, climate, land use, and topography, combined with data on all known withdrawals and discharges, and operational rules of major hydrologic features such as reservoirs. Each minor basin is broken into smaller hydrologic subsections, or river segments. The model simulates the water balance on a daily basis for each individual river segment, with each downstream segment being affected by the cumulative impact of streamflow changes occurring in upstream segments. The following figures help analyze this cumulative impact within the Upper Rappahannock Minor Basin (model results summarized by river segment). Note that this section is not intended to document in detail the methods and assumptions for the VAHydro model or for the scenarios and metrics discussed. More documentation of the model and assumptions can be found in Chapter 4.

The VAHydro surface water model was used to simulate streamflow under a variety of scenarios. Demand scenarios examine how streamflow is impacted under 2030 or 2040 demands as compared to current (2020) demands. Demands were calculated based on current and future demand information submitted through local and regional water supply plans. Climate change scenarios examine how streamflow is impacted when 2040 demands are simulated in conjunction with a range of precipitation and temperature conditions that may occur in the future due to changing climate (Dry, Median, Wet scenarios). Finally, the exempt user scenario examines impacts from users excluded, or exempt, from VWP permit requirements per Va. Code § 62.1-44.15:22 B. Exempt users were simulated at the maximum possible demand identified through a review of demand justification values commonly asserted by exempt users, including but not limited to VDH pump capacity, maximum pre-1989 withdrawal, and maximum intake capacity. In order to effectively manage surface water resources and address the uncertainty related to these demands, DEQ determined the most conservative, or maximum possible, demand should be evaluated in this scenario. However, DEQ does not agree that the maximum values used in this scenario represent an allocation for, or the expectation of, a future withdrawal of that volume; nor does DEQ concede that any particular exempt user is necessarily entitled to withdraw any particular maximum value used in this scenario. The methods and assumptions for each of these modeling scenarios are discussed in more detail in Chapter 4.

For each scenario described above, different metrics can be used to evaluate the simulated streamflow. A metric is a method for measuring or evaluating a given set of data; different metrics can be evaluated to answer different questions. Within this section the following metrics will be discussed: the lowest 30 day flow (L30), the lowest 90 day flow (L90), 7Q10, and overall change in flow. The L30 describes the lowest consecutive 30 day average daily streamflow over the simulation period. This metric is a representation of a short-term, or acute drought, and is a good metric for evaluating impacts to direct withdrawals without storage. Similarly the lowest 90 day flow represents the lowest consecutive 90 day average daily streamflow over the simulation period. This would represent a prolonged drought and is often used to evaluate impacts to reservoirs. The 7Q10 is the lowest 7-day average flow that occurs (on average) once every 10 years. 7Q10 is generally used in the evaluations of in-stream beneficial uses such as waste assimilative capacity. Overall change in flow describes the net loss of water from the riverine system as a result of off-stream use

not otherwise returned through point source discharges, or losses due to evapotranspiration. This metric is useful for evaluating impacts to aquatic life and is discussed in more detail in Chapter 4.

Demand Scenarios: 2020 demand or current demand, 2030 demand, and 2040 demand scenarios were simulated. The following series of figures compares the 2030 and 2040 demand scenarios to the current demand scenario. The change in flow depicted on each map is the change expected when comparing two scenarios - in this case future demands compared to current demands. Each page includes two figures comparing either the 2030 or 2040 demand scenario to current demand using the L30, L90, and 7Q10 metrics. This allows for comparisons of simulated impacts between the 2030 and 2040 demand scenarios. The scenarios and metrics are identified in the paragraph below and in the figure captions.

Figures 309 and 310 compare the lowest 30 day flow simulated with the current demand scenario with the lowest 30 day flow simulated in the 2030 and 2040 demand scenarios respectively. Figures 311 and 312 compare the lowest 90 day low flow simulated with the current demand scenario with the lowest 90 day flow simulated in the 2030 and 2040 demand scenarios respectively. Figures 313 and 314 compare the 7Q10 simulated with the current demand scenario with the 7Q10 simulated in the 2030 and 2040 demand scenarios respectively.

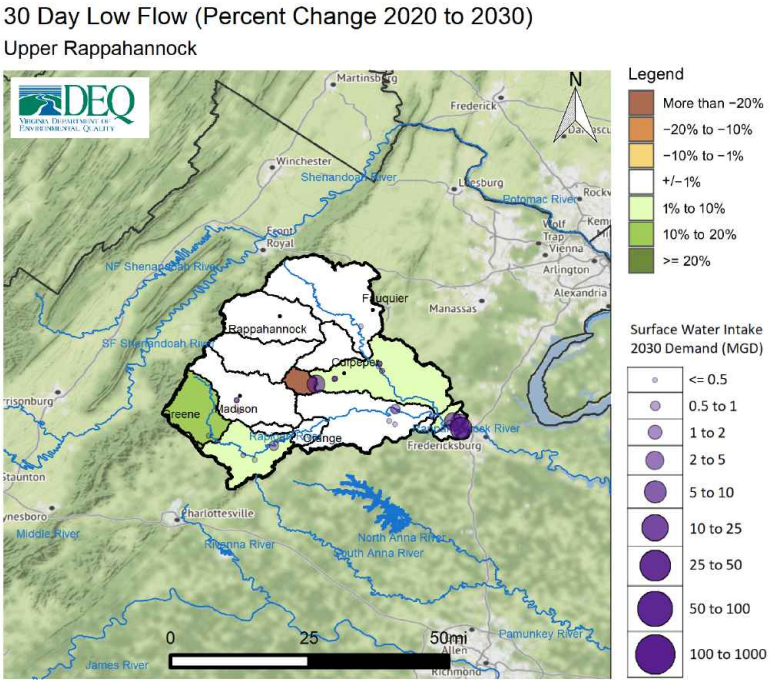

Figure 309: Change in 30 day low flow between 2020 and 2030 demand scenarios within the Upper Rappahannock Minor Basin

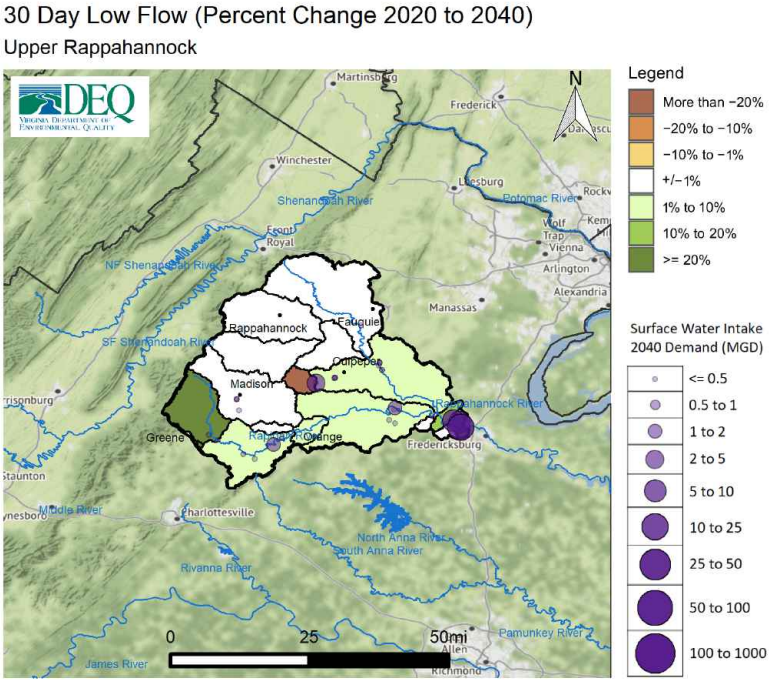

Figure 310: Change in 30 day low flow between 2020 and 2040 demand scenarios within the Upper Rappahannock Minor Basin

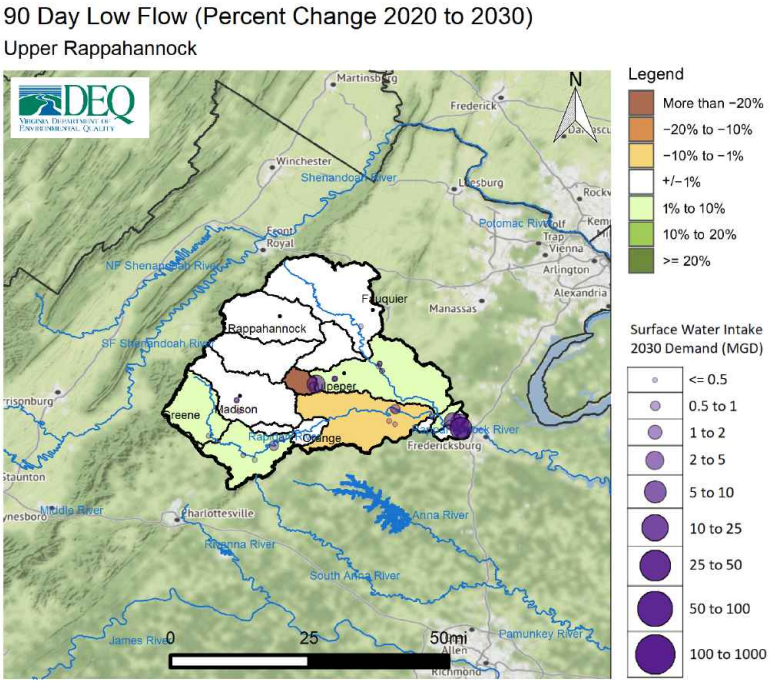

Figure 311: Change in 90 day low flow between 2020 and 2030 demand scenarios within the Upper Rappahannock Minor Basin

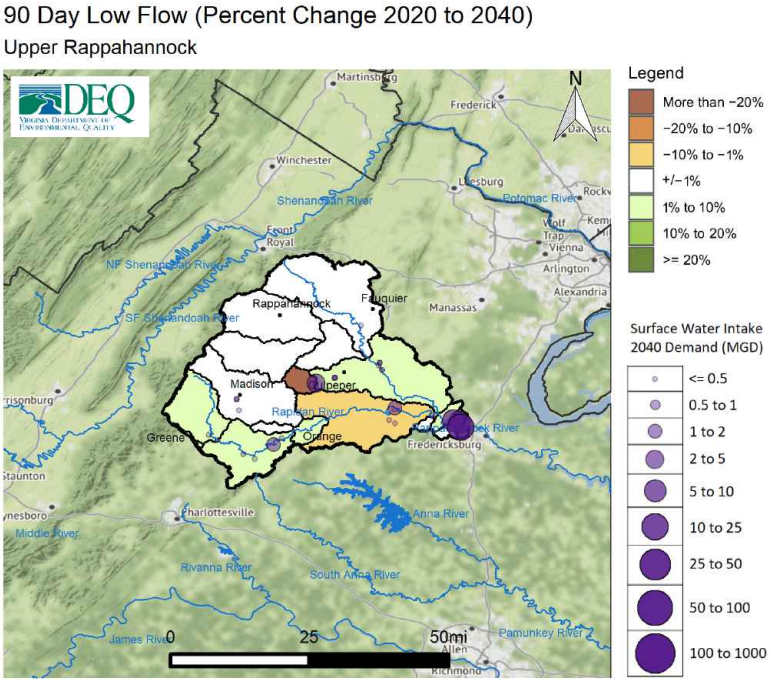

Figure 312: Change in 90 day low flow between 2020 and 2040 demand scenarios within the Upper Rappahannock Minor Basin

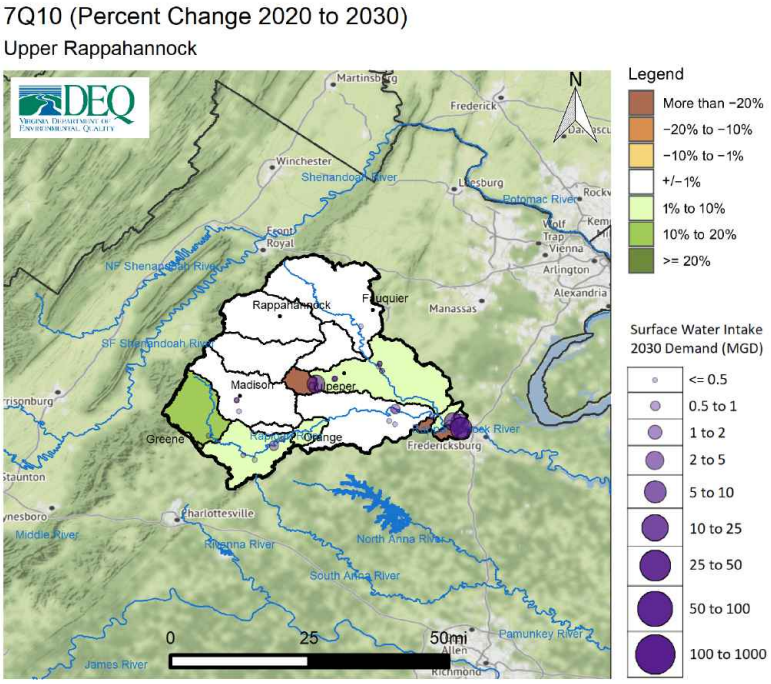

Figure 313: Change in 7Q10 between 2020 and 2030 demand scenarios within the Upper Rappahannock Minor Basin

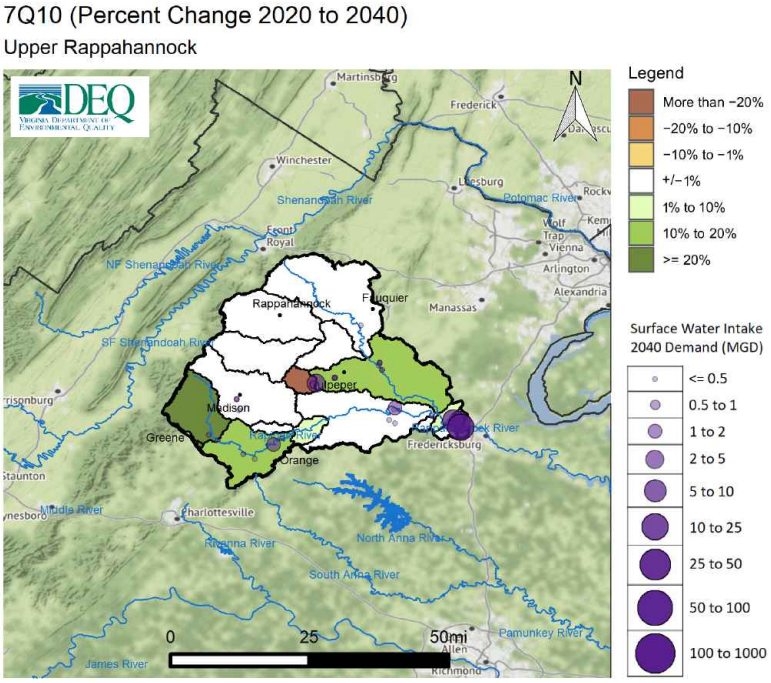

Figure 314: Change in 7Q10 between 2020 and 2040 demand scenarios within the Upper Rappahannock Minor Basin

The figures above show a comparison between two scenarios. An additional way to evaluate impacts to streamflow is to examine the total reduction in streamflow resulting from all withdrawals within a river segment, as well as losses due to evapotranspiration, while taking into consideration any discharges back to the source. To use a common industry term, the overall change in flow metric evaluates "consumptive use", or the amount of water removed from the river that is not returned through discharges. This can help describe potential impacts to downstream withdrawals, while also providing a basis for evaluating impacts to aquatic life. In general, total reductions in streamflow can result in a reduction in aquatic biodiversity [111]. The relation between streamflow and aquatic biodiversity is discussed in more detail in the "Analysis of Ecological Impacts" section below and in Chapter 5. Figure 315 shows the overall change in streamflow for the 2030 Demand Scenario, while figure 316 shows the overall change in streamflow for 2040 Demand Scenario.

[111] Rapp, J.L., R. Burgholzer, J. Kleiner, D. Scott, and E. Passero. 2020. "Application of a New Species-Richness Based Flow EcologyFramework for Assessing Flow Reduction Effects on Aquatic Communities." Journal of the American Water Resources Association 1–14.https://doi.org/10.1111/1752-1688.12877.

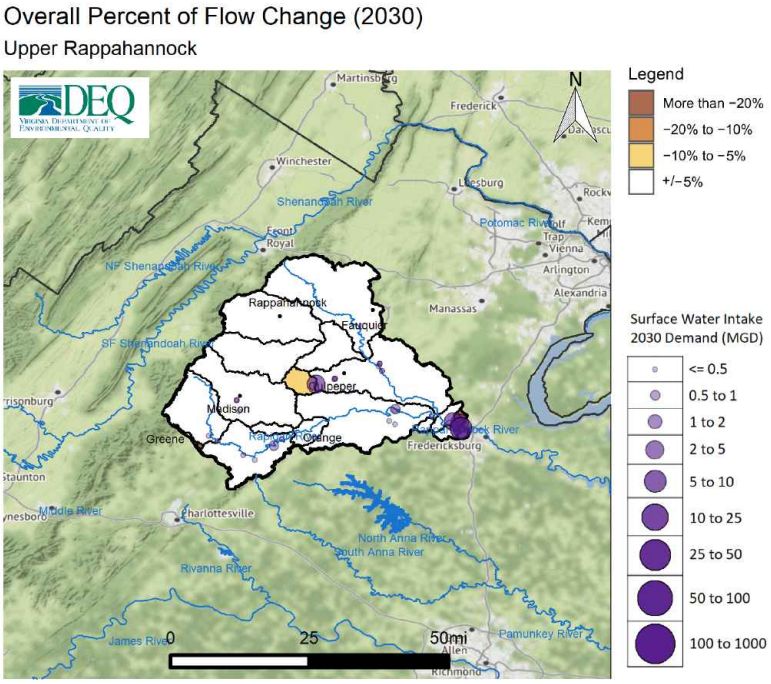

Figure 315: Overall change in flow in percent for 2030 demand scenario within the Upper Rappahannock Minor Basin

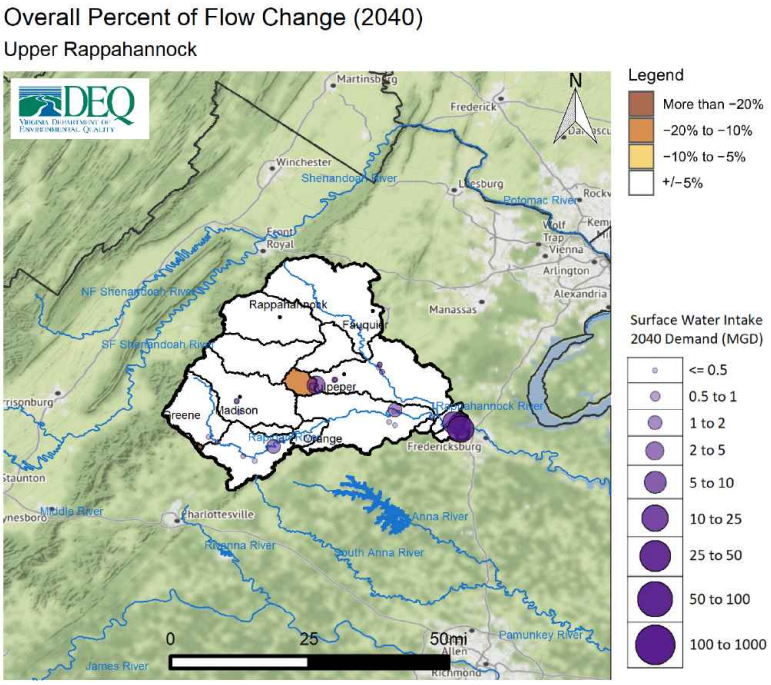

Figure 316: Overall change in flow in percent for 2040 demand scenario within the Upper Rappahannock Minor Basin

Climate Scenarios:Three scenarios that simulate impacts to streamflow in response to changes in temperature and climate were completed for areas in the state where climate data was available, which includes the portions of the Commonwealth located in the Chesapeake Bay watershed. Details on the methods and assumptions employed for these scenarios can be found in Appendix B. The three scenarios can be described as dry, median, and wet scenarios. Virginia is expected to experience a range of precipitation and temperature changes that may vary spatially and from year to year. The potential for both more severe and prolonged droughts as well as for higher intensity and more frequent rain events must be considered. These three scenarios are not intended as predictions of future climate conditions, but as representations of several possibilities that climate change models indicate could occur. Should they occur, these results provide an evaluation of how streamflows may be impacted. Their purpose is to build upon existing climate modeling to provide a foundation for state and local government, as well as other stakeholders, to better evaluate what practical water resource challenges may be associated with the range of climate conditions Virginia could experience.

Figure 317 depicts the percent change in the L30 for the dry climate scenario in conjunction with 2040 demands, as compared to the current climate and demand scenario. Reductions in streamflow in this scenario may be caused by reduced precipitation, increased demand, or as is generally the case, a combination of both. Figures 318 and 319 depict the L30 for the median and wet climate scenarios (in conjunction with 2040 demands) as compared to the current climate and demand scenario.

Figure 320 depicts the percent change in the L90 for the dry climate scenario in conjunction with 2040 demands, as compared to the current climate and demand scenario. Figures 321 and 322 depict the L30 for the median and wet climate scenarios (in conjunction with 2040 demands) as compared to the current climate and demand scenario.

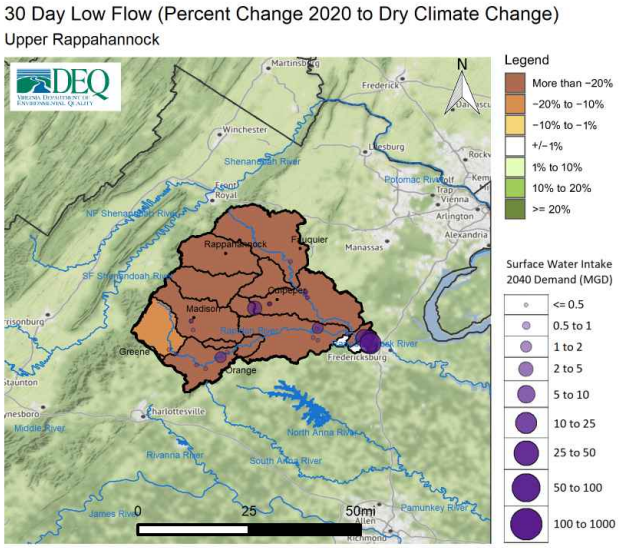

Figure 317: Change in 30 day low flow between current climate/demand scenario and the dry climate/2040 demand scenario within the Upper Rappahannock Minor Basin

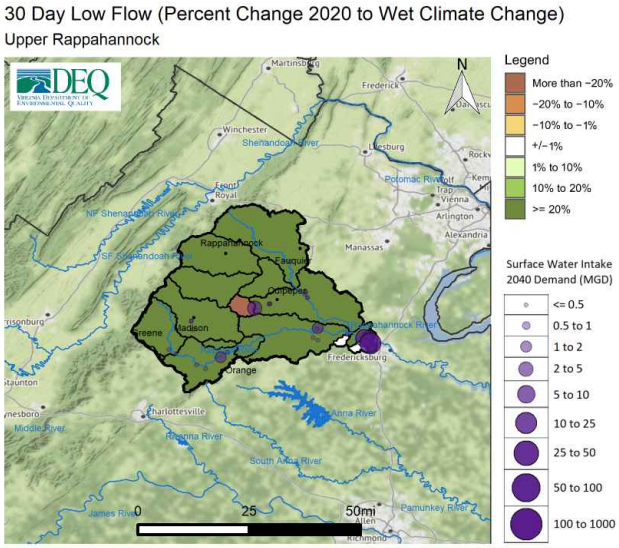

Figure 319: Change in 30 day low flow between current climate/demand scenario and the wet climate/2040 demand scenario within the Upper Rappahannock Minor Basin

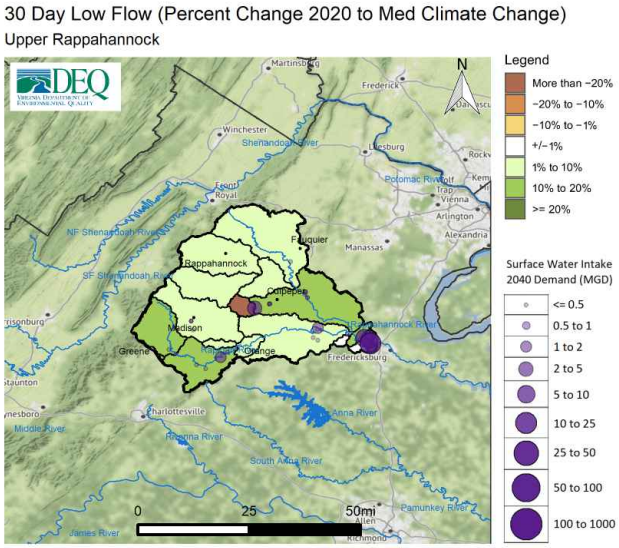

Figure 318: Change in 30 day low flow between current climate/demand scenario and the median climate/2040 demand scenario within the Upper Rappahannock Minor Basin

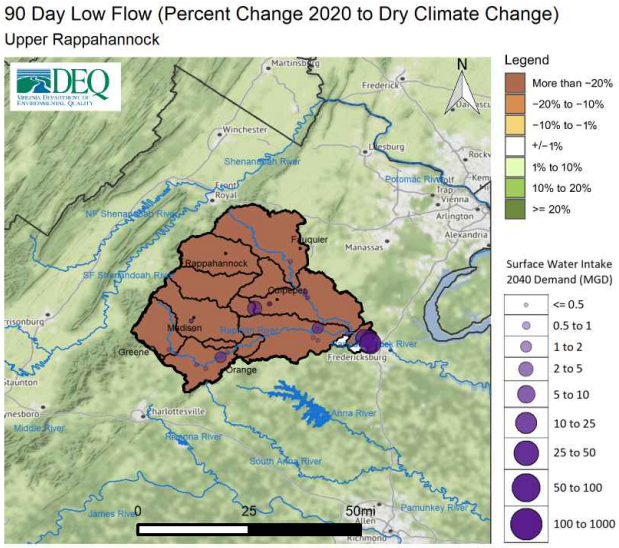

Figure 320: Change in 90 day low flow between current climate/demand scenario and the dry climate/2040 demand scenario within the Upper Rappahannock Minor Basin

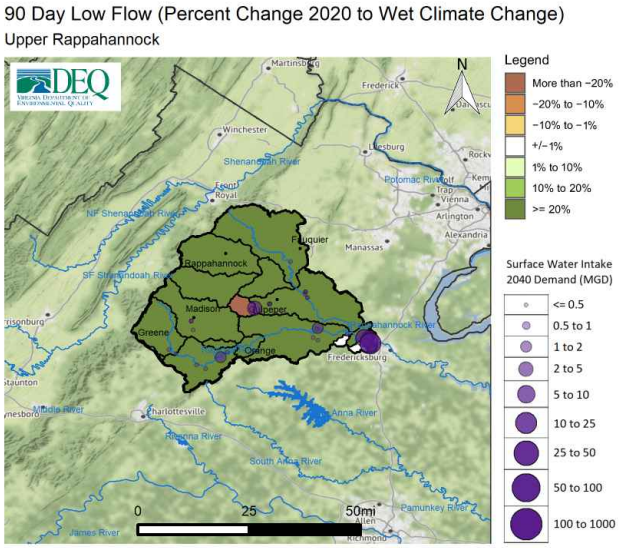

Figure 322: Change in 90 day low flow between current climate/demand scenario and wet climate/2040 demand scenario within the Upper Rappahannock Minor Basin

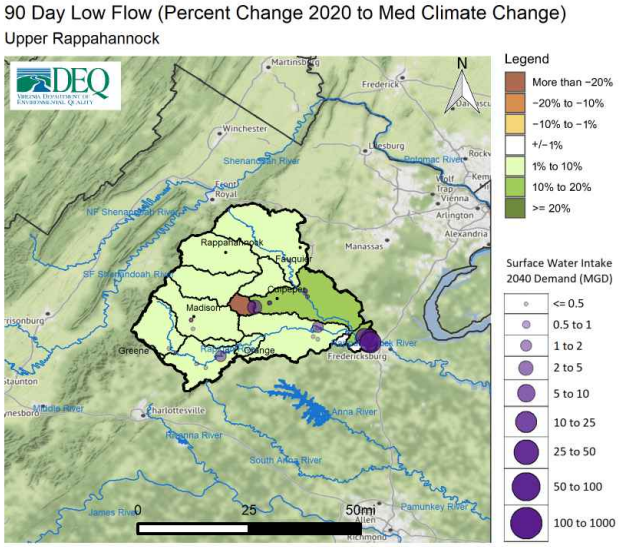

Figure 321: Change in 90 day low flow between current climate/demand scenario and median climate/2040 demand scenario within the Upper Rappahannock Minor Basin

Exempt User Scenario: The exempt user scenario simulates the maximum possible exempt demand by users excluded from Virginia Water Protection permitting requirements per per Va. Code § 62.1-44.15:22 B, in combination with the permitted withdrawal limits for those users that are permitted. A more detailed discussion of the data and assumptions used in this scenario can be found in Appendix B. Note that this scenario uses current climate conditions. Figure 323 depicts the percent change in the Lowest 30 Day Flow between the exempt user scenario and current (2020) demand. Figure 324 depicts the percent change in the Lowest 90 Day Flow between the exempt user scenario and current (2020) demand. Figure 325 depicts the percent change in the 7Q10 between the exempt user scenario and current (2020) demand. Finally, figure 326 depicts the overall change in flow in percent (consumptive use) for the exempt user scenario.

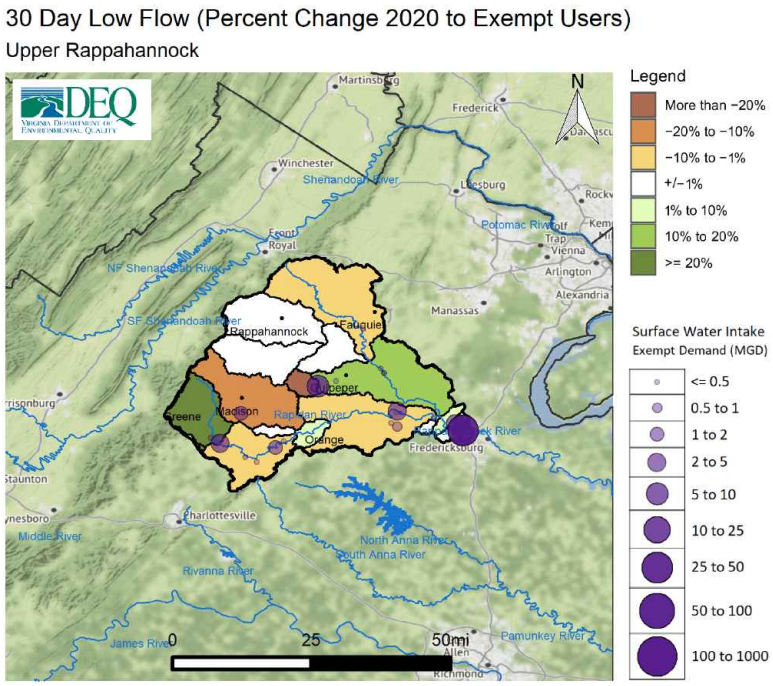

Figure 323: Change in 30 day low flow between current demand scenario and exempt user scenario within the Upper Rappahannock Minor Basin

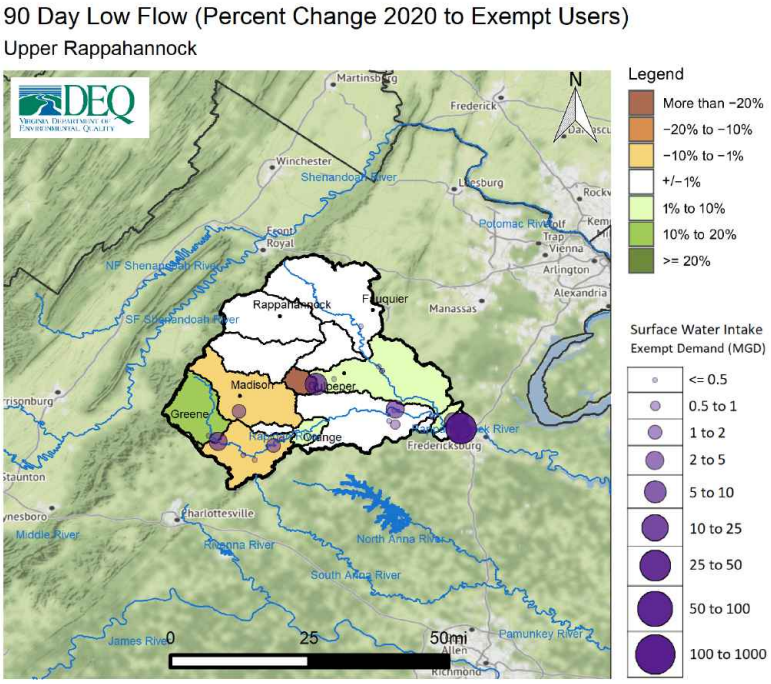

Figure 324: Change in 90 day low flow between current demand scenario and exempt user scenario within the Upper Rappahannock Minor Basin

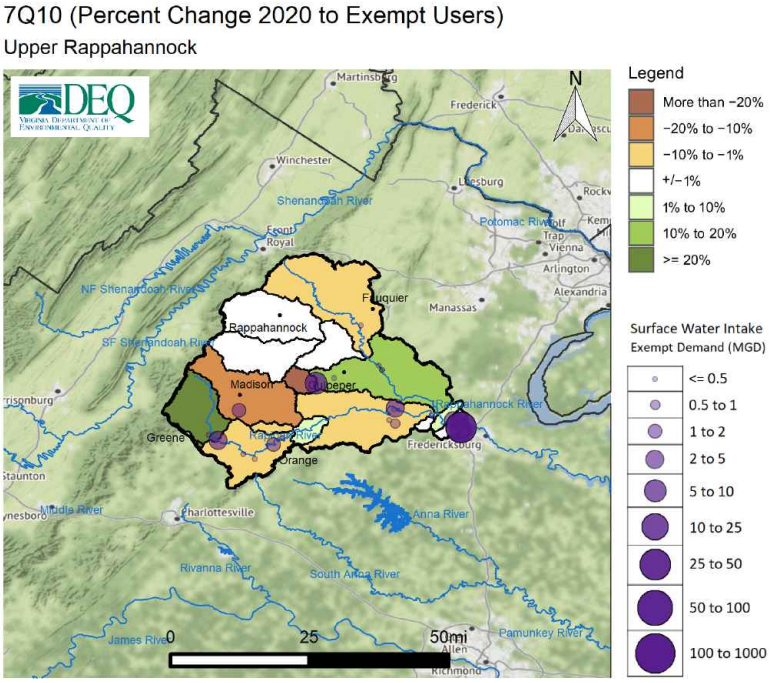

Figure 325: Change in 7Q10 between current demand scenario and exempt user scenario within the Upper Rappahannock Minor Basin

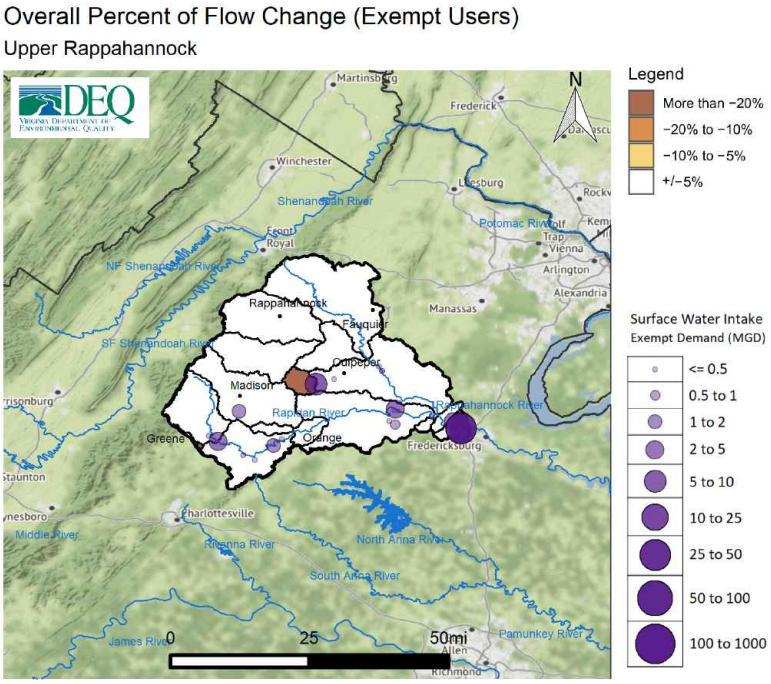

Figure 326: Overall change in flow in percent for exempt user scenario within the Upper Rappahannock Minor Basin

Potential Unmet Demand: Potential unmet demand was evaluated for all facilities within the basin for each scenario. Potential unmet demand is the portion of surface water demand for a specific facility that is limited by available streamflow as simulated in a given model scenario, including any known operational limits such as flow-by requirements. This unmet demand, if realized, could be managed through water conservation, through alternative sources, operational changes, or from available storage. Absent of these or other options, this portion of demand could remain unmet. As with all scenarios, demand requirements were determined using demand projections provided in the water supply plans. In the case of the exempt user scenario, the highest possible demand amount was used for users exempt from VWP permitting requirements.

This metric is useful for evaluating where the results seen in the above figures may result in challenges in meeting future demands under a variety of conditions including increasing demands in the basin, changing climate, or withdrawals from users exempt from permitting requirements. Table 80 provides for each facility the highest average daily potential unmet demand over a 30 day period over the course of the simulation for the following scenarios: 2020 demand, 2030 demand, 2040 demand, dry climate, and exempt User. Only facilities showing potential unmet demand in at least one scenario appear on this table. The dry climate scenario is selected among the climate scenarios as the dry scenario represents the potential for increased drought intensity and frequency, and therefore poses the greatest challenge for water supply. Additional information on the potential unmet demand metric can be found in Appendix B.

Table 80: Change in Highest 30 Day Potential Unmet Demand (MGD) in Upper Rappahannock Minor Basin

Facility	2020 Demand	2030 Demand	2040 Demand	Dry Climate	Exempt User
White Run Pumped Storage Reservoir	0.00	0.00	0.00	0.00	3.55

* Climate scenarios were not completed in areas located outside of the Chesapeake Bay Basin

Note: Potential unmet demand is the portion of surface water demand for a specific facility that is limited by available streamflow as simulated in a given model scenario, including any known operational limits such as flow-by requirements. This unmet demand, if realized, could be managed through water conservation, alternative sources, operational changes, or from available storage.

A.15.6 Trends and Goals

The Code of Virginia mandates that the State Water Control Board should take into consideration the principle that "adequate and safe supplies shall be preserved and protected for human consumption, while conserving maximum supplies for other beneficial uses".[112] This principle is the key driver of the challenges in water resource management, which is that all beneficial uses must be adequately considered when evaluating impacts to surface water resources. The State Water Control Board is tasked with ensuring that water supply quantity needs are met at all times while also protecting Virginia's natural resources, and furthermore, ensuring equitable allocation during a time of shortage. [113] While evaluating and planning for the long-term sustainability of water supply for Virginia is the primary goal for the State Plan, evaluating and limiting impacts to in-stream beneficial uses such as aquatic habitat life is also part of DEQ's responsibility.

The primary purpose of this section is to identify where the most significant challenges to long-term sustainability of water supply and other beneficial uses are indicated based on the CIA and information collated from local water supply plans within this basin. Goals for future planning and areas for additional data collection or analysis are also suggested where appropriate.

[112] § 62.1-44.36 of the Code of Virginia
[113] 9VAC25-390-20.1

The CIAs were completed using the best available data and methods known to DEQ. This discussion focuses on the evaluation of trends - in other words the prevailing tendency or inclination. This means evaluating whether streamflow is simulated to increase or decrease in a given scenario, and by how much. A relative trend indicating reductions of greater than or equal to 10% in streamflow, whether driven by demand increases, changing climate conditions, or exempt user demands was considered a threshold for potential impacts to beneficial uses. The following summarize the key trends or goals for this basin:

- **Demand Scenarios:** Despite projected surface water demand increases of more than 14 MGD between 2020 and 2040 within the basin, comparisons of the current and 2040 demand scenarios show minimal impacts to streamflow for short-term drought (L30), long-term drought (L90), and 7Q10 for the majority of the basin. Several reservoirs within the basin work to limit impacts to streamflow from demand increases including: Mott's Run, Hunting Run, Rocky Pen Run, as well as a proposed reservoir in Greene County. The proposed reservoir (White Run) is expected to be constructed by 2040 and is therefore modeled in the 2040 demand scenario. Including this reservoir results in increases in streamflow when comparing the current and 2040 demand scenarios for the L90 and L30 metrics in the Rapidan River headwaters. This is because the 2040 demand scenario replaces the Rapidan Service Authority's Rapidan River WTP direct withdrawal with the White Run reservoir in 2040 scenario. Increased flows in the Rapidan river segment above Ruckersville in 2030 and 2040 are due to the proposed construction of White Run reservoir, and rules that eliminate pumping from the Rapidan when flow goes below the "drought warning" level. Drought warning flow is calculated to be at or below 10% of historically observed flows in the given month. These results are contingent on the construction of the reservoir. Should that construction not proceed reductions in streamflow may be observed in the headwaters of the Rapidan River as demands increase. Significant decreases downstream of Lake Pelham are observed in the 2030 and 2040 demand scenarios driven by increasing demands from the Town of Culpeper which result in reductions or cessation of downstream releases from the Lake in the simulations. Impacts would be expected between Lake Pelham and the Town of Culpeper Wastewater Treatment Plant discharge, which includes around four miles of Mountain Run Creek. The withdrawal from Lake Pelham is currently exempt from VWP permit requirements and therefore no release or flow by requirements are in place. Unmet demands as a result of increased demands are not simulated for any public water supplier in the 2040 demand scenario.

- **Climate Scenarios:** Current climate modeling suggests Virginia will generally receive more precipitation on average in the future. However, the data also suggests the possibility of more severe droughts despite this overall trend of increasing precipitation. Comparing current climate and demands to the dry climate scenario (which includes 2040 demands) shows reductions in streamflow ranging between 20-40% across the entire basin for both long-term droughts (L90) and short-term droughts (L30). Impacts to public water supply as well as aquatic life and other beneficial uses could occur during these critical periods. These scenarios should be evaluated and considered by localities and users when evaluating existing sources and alternatives, as well as for broader planning and resource management efforts by all stakeholders whether state or local. However, in large part due to available storage, no potential unmet demand was simulated in the dry climate scenario for CWS.

- **Exempt User Scenario:** Most of the large surface water withdrawals within this basin operate under VWP permits with withdrawal limits and operational rules defined in the permit. In the exempt user scenario these facilities are modeled at their permit limit. As with the 2040 demand scenario, the exempt user scenario results in a simulated flow of zero below Lake Pelham during extreme droughts. This would result in impacts to Mountain Run between Lake Pelham and the Town of Culpeper's discharge (approximately 4 miles of stream). However, in this scenario return flows from the Town of Culpeper WTP increase streamflows in the downstream Rappahannock River segment by around 5 cfs in the short-term drought metric (L30). This is driven by withdrawals at the highest exempt user demand amount from Lake Pelham, the non-consumptive portions of which are returned downstream. No other river segments show a reduction in streamflow greater than 10% when comparing the exempt user scenario to current demands during a long-term drought (L90); streamflows in the Robinson River are simulated to fall by more than 10% in a short-term drought (L30) driven by the Town of Madison's

WTP maximum possible exempt user demands. Finally, as observed in the 2040 demand scenario, increased streamflow is simulated in the headwaters of the Rapidan River due to the inclusion of the White Run Reservoir. Should this reservoir not be constructed and future demands are instead met by the Rapidan Service Authority's direct withdrawal from the Rapidan River, reductions in streamflow would be driven by the maximum possible exempt demand for the Rapidan intake and the loss of the releases from the reservoir.

- The Upper Rapphannock Minor Basin is projected to experience an increase in groundwater use for Small SSUs (domestic and private well use) of more than 107%, or 5.75 MGD between 2020 and 2040. This is a significant increase on the local fractured rock aquifer systems which are already estimated to supply 5.33 MGD for domestic use in 2020. Evaluation and investigation of local aquifer systems in areas where growth is concentrated may be necessary to ensure adequate supply. Groundwater supplies in the Piedmont region tend to be limited and capacity can vary significantly over even short distances. Concentrated well development can lead to both well interference andor declines in surface water baseflows. Some localities have already invested significant resources in study of their local hydrogeology in cooperation with DEQ and other State and Federal agencies. This is an area where additional resources will be necessary as demands continue to increase.

- Below the fall-line located in the City of Fredericksburg, the Rappahannock River becomes tidal freshwater. Interest and pursuit of withdrawals in tidal freshwater areas of the state have increased in recent years. However, the ability to answer how increasing demands in combination with sea level rise in non-tidal portions of a river may impact water quality, particularly related to salinity, is still limited. Investment in modeling tools that allow the evaluation of water quality impacts in tidal rivers is increasingly necessary to determine the viability and sustainability of withdrawals in these areas.

A.16 Lower Rappahannock Minor Basin

A.16.1 Watershed Overview

The Rappahannock River is formed at Chester Gap on the eastern slope of the Blue Ridge Mountains. The river runs southeast across the Piedmont province, before crossing the fall-line in the City of Fredericksburg. From there it is tidally influenced as it flows through the Coastal Plain of Virginia before entering the Chesapeake Bay 20 miles south of the Potomac River. The Lower Rappahannock Minor Basin consists of the tidal portions of the Rappahannock River. Portions of the Northern Neck and Middle Peninsula are included. As salinity increases towards the Chesapeake Bay, so too does dependence on groundwater as the major source. This basin is part of the Eastern Virginia Groundwater Management Area, although it was only recently added to the existing management area in 2014.

The total spatial area of the basin occupies 1,356 sq. miles and includes all or portions of the localities listed in Table 81. The major population centers located within or near the basin include the City of Fredericksburg as well as suburbs in Stafford and Spotsylvania counties. Population in these areas continues to grow due to proximity to Northern Virginia and Washington D.C.

A.16.2 Existing Water Sources

The major surface water source within the basin is the Rappahannock River. Groundwater within the basin is primarily withdrawn from confined aquifers, primarily the Potomac Aquifer. Withdrawals within the basin are used for public water supply as well as for agriculture, irrigation, commercial, power generation, and industrial/manufacturing.

The location of wells and surface water intakes identified to DEQ within the basin are shown in Figure 327. This figure does not include private or domestic wells. The greatest concentration of surface water intakes is located in the tidal fresh portions of the Rapphannock River, or the first 25 miles or so below the fall-line. Once the river becomes too high in salinity for most uses, surface water withdrawals are generally from impounded non-tidal streams. Groundwater wells are constructed throughout the basin.

Table 81: Population Trend by Locality in Lower Rappahannock Basin

Localities	20 Year % Change
Caroline	24.83
Essex	4.16
King and Queen	1.02
King George	33.11
Lancaster	-9.58
Middlesex	5.67
Northumberland	-5.42
Richmond County	0.18
Spotsylvania	30.24
Stafford	35.79
Westmoreland	3.34
Fredericksburg	29.56

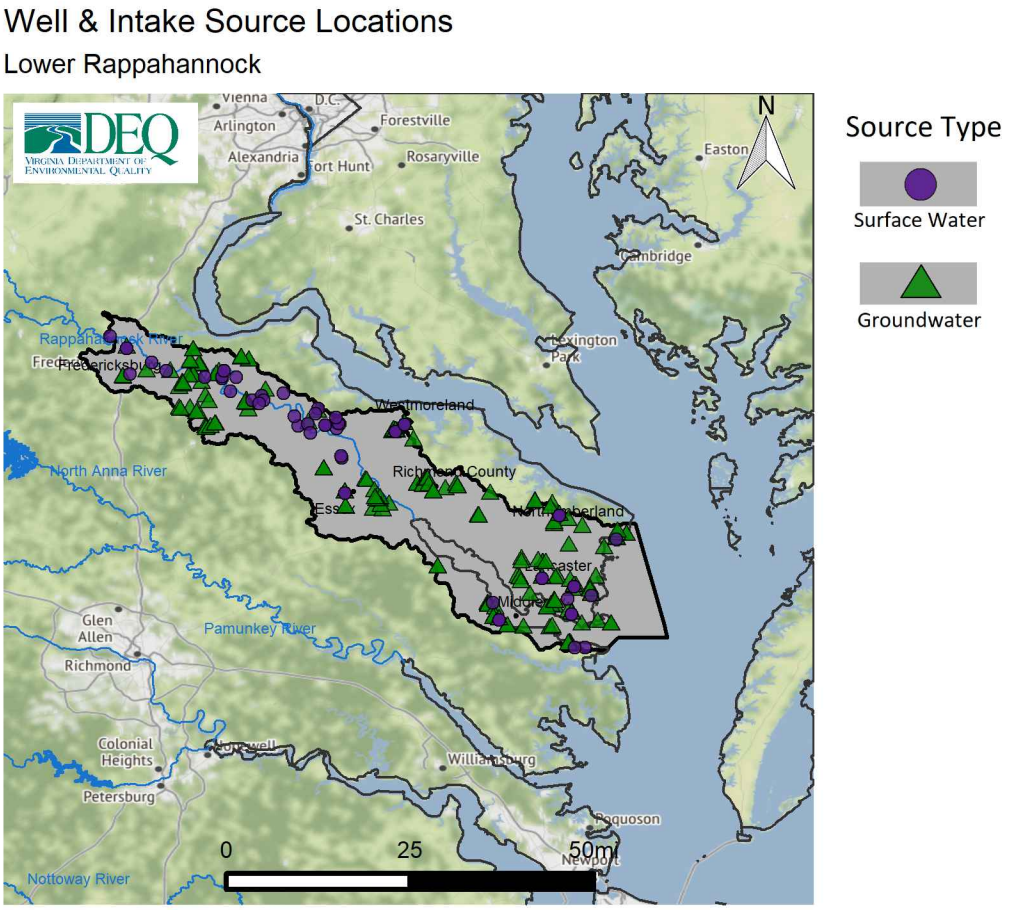

Figure 327: Spatial distribution of groundwater wells and intakes in the Lower Rappahannock Minor Basin

A.16.3 Existing Water Use

The following section discusses existing (current) water use within the basin, which is based on existing demand information submitted to DEQ in the water supply plans. Table 82 provides a summary of all demands within the basin by system type and source type including power generation. It also provides a count of surface water or groundwater sources associated with each system type.

Table 82: Summary of Lower Rappahannock Minor Basin Water Demand by Source Type and System Type (including Power Generation)

System Type	Source Count	2020 Demand (MGD)	2030 Demand (MGD)	2040 Demand (MGD)	20 Year Percent Change
Surface Water					
Agriculture	31	1.89	2.03	2.18	15.22
CWS	0	0.06	0.07	0.07	9.44
Large SSU	10	3.27	3.29	3.30	0.96
Small SSU	N/A	0.00	0.00	0.00	0.00
Total SW	**41**	**5.22**	**5.39**	**5.55**	**6.32**
Groundwater					
Agriculture	11	0.29	0.31	0.33	12.33
CWS	137	1.86	2.74	3.63	95.62
Large SSU	29	0.27	0.27	0.28	5.21
Small SSU	N/A	3.29	3.59	3.89	18.28
Total GW	**177**	**5.71**	**6.91**	**8.13**	**42.38**
Total (SW + GW)					
Agriculture	42	2.18	2.35	2.51	14.84
CWS	137	1.92	2.81	3.70	92.81
Large SSU	39	3.54	3.56	3.58	1.28
Small SSU	N/A	3.29	3.59	3.89	18.28
Minor Basin Total	**218**	**10.93**	**12.31**	**13.68**	**25.16**

* Small SSU demands are county-wide estimates of private well usage below 300,000 gallons a month. The number of private wells is not known.

The total existing demand from all surface and groundwater sources is approximately 10.93 MGD, with groundwater supplying approximately 5.71 MGD or 52% of total water demands. Surface water demand within the basin totals approximately 5.22 MGD, or 48% of current demands.

The five largest facility demands for each source type are provided in Table 83. The largest groundwater demands include CWS facilities for the Town of Tappahannock, the Town of Kilmarnock, and Caroline County Utility System. The largest surface water demands include Omega Protein, Birchwood Power Facility (which is in the process of shutting down), and Ingleside Plantation.

Table 83: Top 5 Users in 2040 by Source Type in the Lower Rappahannock Minor Basin (including Power Generation)

Facility Name	System Type	Locality	2020 Demand (MGD)	2030 Demand (MGD)	2040 Demand (MGD)	20 Year Percent Change	% of Total Surface Water
Surface Water							
Omega Protein	Large SSU	Northumberland	1.46	1.46	1.46	0.00	26.31
Birchwood Power Facility	Large SSU	King George	1.16	1.16	1.16	0.00	20.9
Ingleside Plantation And Liberty Farm	AG	Westmoreland	0.54	0.54	0.54	0.00	9.73
Black Marsh Farm	AG	Caroline	0.38	0.45	0.51	34.21	9.19
Davis And Pratt Farms	AG	Caroline	0.36	0.42	0.48	33.33	8.65
Total SW			3.9	4.03	4.15	6.41	74.77
Groundwater							**% of Total Groundwater**
Caroline County Utility System	CWS	Caroline	0.19	0.78	1.36	615.79	16.73
Town Of Tappahannock	CWS	Essex	0.37	0.43	0.5	35.14	6.15
Milford Sanitary District Water System	CWS	Caroline	0.05	0.19	0.34	580	4.18
Town Of Kilmarnock	CWS	Lancaster	0.21	0.22	0.22	4.76	2.71
Fort A. P. Hill Water System	CWS	Caroline	0.12	0.16	0.2	66.67	2.46
Total GW			0.94	1.78	2.62	178.72	32.23

Table 82 also provides the proportion of each use category that is supplied by either surface water or groundwater. Use categories include Community Water Systems (CWS), Large Self-Supplied User (Large SSU), Small Self-Supplied User (Small SSU), and Agricultural Self-Supplied User (AG). These categories are defined below. Surface water demand is primarily comprised of Large SSU and AG demands. Groundwater demand is primarily comprised of CWS and Small SSU demands.

The CWS category includes any public and private waterworks that serve at least 15 service connections used by year-round residents or regularly serve at least 25 year-round residents, and are regulated under the Virginia Department of Health's Waterworks Regulation (12VAC5-590). In the Lower Rappahannock Minor Basin, approximately 5.71 MGD of groundwater demand and 0.06 MGD of surface water demand is from CWS facilities. Significant groundwater users within this category include the CWS facilities noted above. There are no large surface water demands associated with CWS facilities.

Large SSUs include any non-CWS or AG who withdraw more than 300,000 gallons per month from a well or surface water intake. In the Lower Rappahannock Minor Basin, approximately 0.27 MGD of groundwater demand and 3.27 MGD of surface water demand is from Large SSUs. Significant groundwater users within this category include Omega Protein and Birchwood Power. Note that Birchwood Power is expected to close in 2021. These are also the most significant surface water users from this category as well.

Small SSUs include any users who withdraw less than 300,000 gallons per month from wells. Small SSUs generally consist of residential or domestic use for those who live outside service areas and provide their own water. Small SSU demand is generally met with groundwater. In the Lower Rappahannock Minor

Basin, approximately 3.29 MGD of groundwater demand is from Small SSUs. The localities with the highest estimated Small SSU demand include Middlesex, Essex, and Northumberland counties.

The AG category includes crop farms, livestock operations, aquaculture and other agricultural facilities. In the Lower Rappahannock Minor Basin, approximately 0.29 MGD of groundwater demand and 1.89 MGD of surface water demand is from AG. Significant groundwater users within this category include Ingleside Plantation Nurseries, Broaddus Farms, and Greenhost Incorporated. Significant surface water users from this category include Inglesie Plantation Nurseries, Davis and Pratt Farms, and Cloverfield Farm.

A.16.4 Projected Population and Water Use

Projected Population: Trends in water use are generally driven by trends in population change or economic development. Increasing population within an area generally means increased connections for community water systems or additional groundwater demands from homeowners that construct wells. Increasing population in an area also tends to incentivize both new and expanded industrial and commercial water use.

Table 81 shows the projected change in population by percent between 2020 and 2040 for each locality located partly or wholly within this minor basin. The highest increases in population are projected in localities such as Stafford, King George, Spotsylvania, and Caroline counties, and the City of Fredericksburg; all of which continue to grow largely due to proximity to Northern Virginia and Washington D.C.

Projected Water Use: The following section discusses projected water use through 2040 within the Lower Rappahannock Minor Basin, based on projections provided in local and regional water supply plans. Table 82, included in the existing demand section above, is the basis for information discussed in this section.

Total demand within the basin is projected to increase from 10.93 MGD in 2020 to 13.68 MGD in 2040, or approximately 25.1%. Surface water demand is projected to increase by approximately 0.33 MGD, or 6.3%, by 2040. Groundwater demand is projected to increase by 2.42 MGD, or 42%, by 2040. As expected, projected increases in groundwater facilities is the major driver in increasing demands.

Demand from CWS users within the basin is projected to increase by 92% by 2040. CWS use is almost entirely groundwater based. Caroline County, Milford Sanitation District, and the Town of Tappahannock have the highest projected increases in the basin for CWS facilities. With limited surface water sources available, groundwater is currently the most viable water source for CWS.

Demand from Large SSUs within the basin is not projected to change significantly. Facilities with the largest water demand increases include the Fredericksburg Country Club and the Four Winds Campground. Large SSUs within the basin were primarily projected to remain constant in water demands over the planning period.

Demand from Small SSUs within the basin are projected to increase by approximately 18.28% by 2040. As noted previously, Small SSU demand is entirely met with groundwater and represents domestic/residential well use. Middlesex and Northumberland counties projected the highest increases in Small SSU demands. As significant population increases are expected within many localities in the watershed, increase domestic well use will occur.

Demand from AG within the basin are projected to increase by approximately 15% by 2040. This represents only a small increase in demand by volume primarily made up of projected increases in demands from surface water sources. The largest increases in demand are projected by the Davis & Pratt Farms, Black Marsh Farm, and Racefield Farm. Water demands from the majority of AG in the basin are projected to remain constant.

A.16.5 Cumulative Impact Analysis

The Lower Rappahannock Minor Basin does not include significant non-tidal surface water segments and therefore surface water cumulative impact analysis was not completed in this basin. The Trends and Goals sections below discusses results from the Cumulative Impact Analysis (CIA) Groundwater Modeling completed in the Eastern Virginia Groundwater Management Area. The methods and results for the groundwater modeling scenarios are provided in Chapter 4, Section 4.3.3, Virginia Coastal Plain Model Results, which may warrant review prior to reading the following sections.

A.16.6 Spatial Overview of Groundwater Demands

A substantial portion of the demands in this basin are supplied by groundwater. Figure 328 identifies the location and size of projected groundwater demands in the basin for 2040 based on information provided by localities in water supply plans.

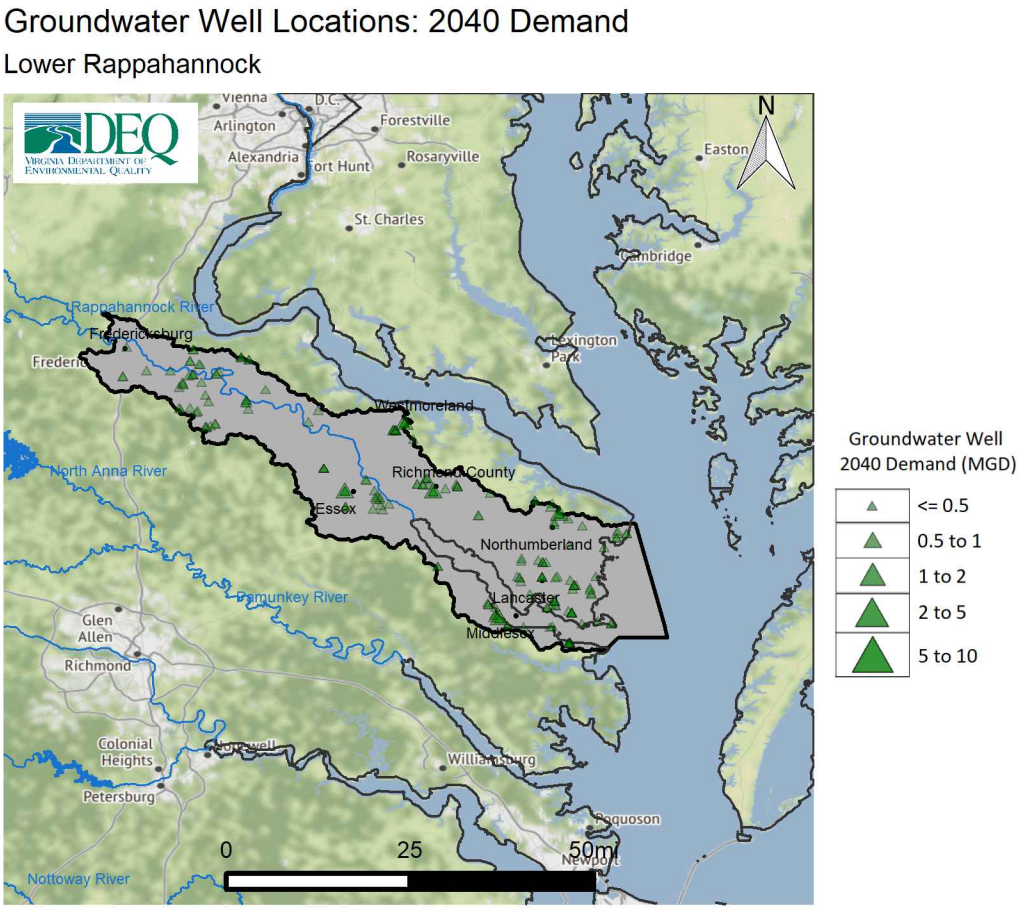

Figure 328: Projected 2040 Groundwater Demands in the Rappahannock Lower Minor Basin

A.16.7 Trends and Goals

The Code of Virginia mandates that the State Water Control Board should take into consideration the principle that "adequate and safe supplies shall be preserved and protected for human consumption, while conserving maximum supplies for other beneficial uses". [114] This principle is the key driver of the challenges in water resource management, which is that all beneficial uses must be adequately considered when evaluating impacts to water resources. The State Water Control Board is tasked with ensuring that water supply quantity needs are met at all times while also protecting Virginia's natural resources, and furthermore, ensuring equitable allocation during a time of shortage.[115]

The primary purpose of this section is to identify where the most significant challenges to long-term sustainability of water supply and other beneficial uses are indicated based on the CIA and information collated from local water supply plans within this basin. Goals for future planning and areas for additional data collection or analysis are also suggested where appropriate.

- **Coastal Plain Groundwater Demand Scenarios:** The Lower Rappahannock Minor Basin is characterized by limited freshwater surface water availability, particularly in the Northern Neck and Middle Peninsula where the Rappahannock is too high in salinity for most uses. Across the basin, almost all demand for CWS facilities is met through groundwater withdrawals from confined aquifers such as the Potomac Aquifer. This includes for counties such as Caroline, King George, Middlesex, Lancaster, Richmond, Westmoreland, and Northumberland. CIA groundwater modeling of the 2020 and 2040 demand scenarios was completed using the VAHydro Virginia Coastal Plain Groundwater Model for the State Plan. The results of these simulations are covered in detail in a number of figures provided in Chapter 4, section 4.3.3, and in the discussion in section 4.3.4. Review of these sections of Chapter 4 will be useful for the reader as context for the below results. With respect to this basin, the following are the key trends.

- **Potomac Aquifer:** Statewide, in the 2020 demand scenario water levels in the Potomac Aquifer are simulated to recover gradually from 2020 through 2050, before marginally declining through 2070. This indicates that demands as estimated in the 2020 demand scenario appear to allow for stabilized water levels in most of the Coastal Plain. However, in the 2040 demand scenario, due to both projected increases in domestic (small SSU) and permitted demands, water levels decline continuously from 2020 to 2070. This results in significantly more areas of the Coastal Plain where water levels fall below the critical surface and critical cells are simulated. With regard to this basin, critical cells are simulated in Caroline and Stafford counties, as well as in eastern King George County. While some critical cells are simulated along the fall-line in both the 2020 and 2040 demand scenario, the 2040 demand scenario expands the extent of the critical cells with significantly more cells in Caroline County in particular (see section 4.3.3). These results suggest both new and existing groundwater users in Caroline County that use the Potomac Aquifer, whether large or small, could face challenges in meeting the regulatory criteria for issuance of a a groundwater withdrawal permit. While critical cells are not simulated in either scenario in the Potomac Aquifer (the main aquifer in use in this area) outside of Stafford and King George counties, any large groundwater use could have an area of impact (area in which a withdrawal results in a one-foot drawdown) large enough that it would result in permitting challenges nonetheless.

- **Other Aquifers:** The results for the Aquia and Piney Point aquifers are more similar when comparing the 2020 and 2040 demand scenario. The Aquia Aquifer is simulated to have a considerable number of critical cells in Caroline, King George, and Stafford counties in both the 2020 and 2040 demand scenario. The 2040 demand scenario results in more critical cells. These critical cells are in large part due to the hydrogeology of the Aquia Aquifer which is increasingly thin and shallow along the fall-line. Similarly in the Piney Point Aquifer, the 2020 and 2040 demand scenarios result in a comparable number of critical cells. In this case the cells are primarily located in Essex and Westmoreland counties.

[114] § 62.1-44.36 of the Code of Virginia
[115] 9VAC25-390-20.1

The Piney Point and Aquia Aquifers are not as commonly used as the Potomac Aquifer in this area and these simulations indicate that increasing demands are not expected to have as significant an impact on these aquifers in this area.

- The results suggest the potential for challenges in permitting groundwater withdrawals in the eastern portions of this basin even in the 2020 demand scenario, particularly in portions of Caroline County. The 2040 demand scenario simulation expands the areal extent of where such challenges may occur, and in so doing increases the likelihood that existing or proposed permits for larger withdrawals in the Northern Neck or Middle Peninsula could also be impacted by critical cells. Several of the localities in this region are aware of these challenges and are actively pursuing alternatives, including tidal fresh surface water withdrawals. In general, these results underscore the importance of continuing efforts to invest in regional planning, alternatives, interconnection opportunities, and more robust conservation for groundwater users in this area.
- **Tidal Fresh Surface Water Withdrawals:** Several tidal freshwater withdrawals are in operation or are proposed in the Rappahannock River. Withdrawals in both the non-tidal headwaters and in the tidal fresh portions of a river can reduce freshwater inflow and can impact salinity. Evaluating the extent of these potential water quality changes will need to be an area of increasing focus as withdrawals in and upstream of freshwater tidal rivers becomes more common.

A.17 Upper Tennessee Minor Basin

A.17.1 Watershed Overview

The Upper Tennessee Minor Basin is located along the furthermost western extent of Virginia. The watershed drains southwest into Tennessee through steep mountainous terrain. The total spatial area of the basin occupies 3,235.06 sq. miles and includes all or portions of the localities listed in Table 84. The major population centers within the basin include the Cities of Bristol and Norton along with Tazewell, Washington, and Wise counties. Land use and cover in the basin is widely forested mountains, with limited impervious surface.

A.17.2 Existing Water Sources

Major surface water sources within the basin include the Clinch, Holston, and Powell rivers. The watershed also relies on several reservoirs for supply including the Norton, South Holston, Upper Banner Mine, Tom Creek, and Appalachian reservoirs. Groundwater within the basin is primarily withdrawn from fractured bedrock aquifers. Surface water is the primary water source in the basin, as groundwater supplies are less productive.

Withdrawals within the basin are used for public water supply agriculture, irrigation, commercial, industrial/manufacturing, and power generation. Surface water is the primary water source in the watershed with forty-nine intakes identified to DEQ as currently active. Groundwater wells are widespread in the basin with thirty-one wells identified to DEQ as currently active in the basin. This number does not include private or domestic wells.

The location of wells and surface water intakes identified to DEQ within the basin are shown in Figure 329. This figure does not include private or domestic wells. Withdrawal locations are focused adjacent to major surface water sources and areas of highest population. Limited withdrawals are located away from major surface water sources, as major population centers are located along the primary rivers in the basin.

Table 84: Population Trend by Locality in Upper Tennessee Basin

Localities	20 Year % Change
Bland	-11.20
Buchanan	-31.30
Dickenson	-17.95
Grayson	-21.95
Lee	-1.94
Russell	-16.86
Scott	-10.06
Smyth	-13.07
Tazewell	-10.60
Washington	1.99
Wise	-8.72
Wythe	0.18
Bristol	-6.93
Norton	-3.67

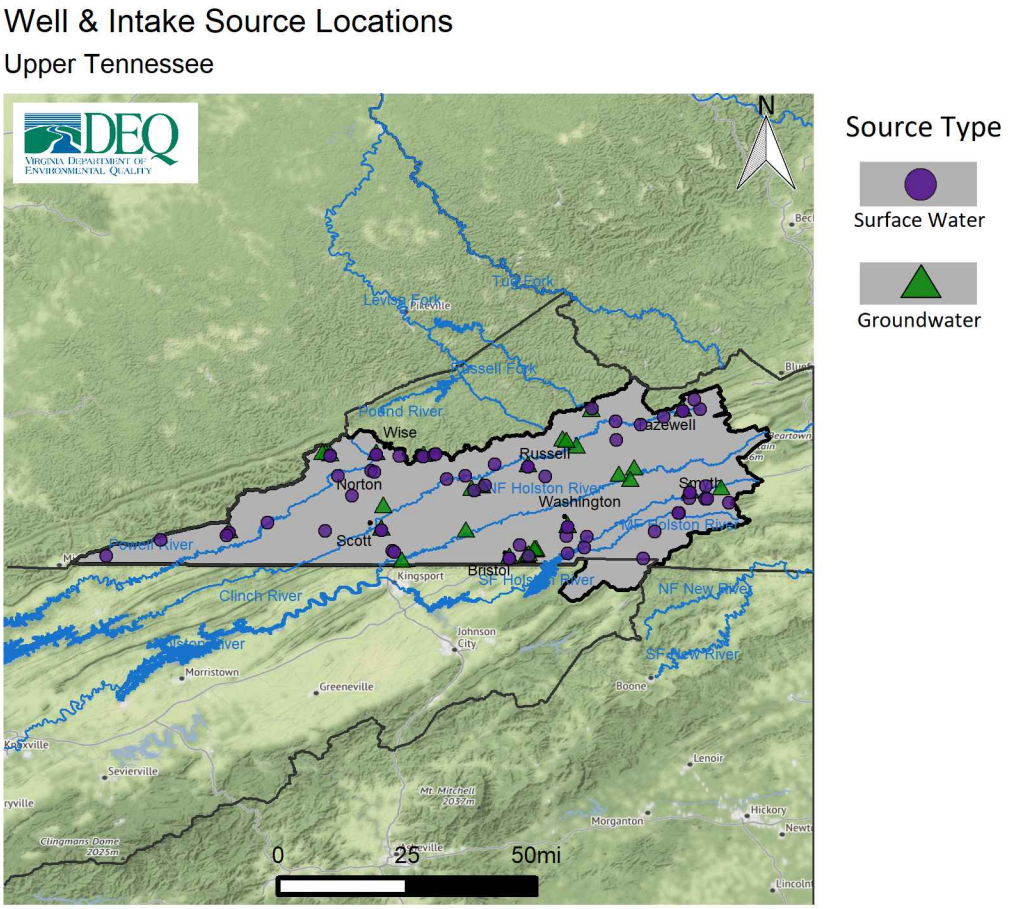

Figure 329: Spatial distribution of groundwater wells and intakes in the Upper Tennessee Minor Basin

A.17.3 Existing Water Use

The following section discusses existing (current) water use within the basin, which is based on existing demand information submitted to DEQ in the water supply plans. Table 85 provides a summary of all demands within the basin by system type and source type including power generation. It also provides a count of surface water or groundwater sources associated with each system type.

Table 85: Summary of Upper Tennessee Minor Basin Water Demand by Source Type and System Type (including Power Generation)

System Type	Source Count	2020 Demand (MGD)	2030 Demand (MGD)	2040 Demand (MGD)	20 Year Percent Change
Surface Water					
Agriculture	1	5.58	5.58	5.58	0.00
CWS	34	24.86	25.44	26.02	4.69
Large SSU	14	0.08	0.09	0.10	13.71
Small SSU	N/A	0.00	0.00	0.00	0.00
Total SW	**49**	**30.52**	**31.11**	**31.70**	**3.87**
Groundwater					
Agriculture	0	0.13	0.13	0.13	0.00
CWS	18	1.47	1.63	1.79	22.01
Large SSU	13	0.22	0.26	0.30	37.62
Small SSU	N/A	3.35	2.71	2.08	-37.92
Total GW	**31**	**5.17**	**4.73**	**4.30**	**-16.83**
Total (SW + GW)					
Agriculture	1	5.71	5.71	5.71	0.00
CWS	52	26.32	27.07	27.81	5.65
Large SSU	27	0.30	0.35	0.40	30.98
Small SSU	N/A	3.35	2.71	2.08	-37.92
Minor Basin Total	**80**	**35.68**	**35.84**	**36.00**	**0.90**

* Small SSU demands are county-wide estimates of private well usage below 300,000 gallons a month. The number of private wells is not known.

The total existing demand from all surface and groundwater sources is approximately 35.68 MGD, with groundwater supplying approximately 5.17 MGD or 14.5% of total water demands. Surface water demand within the basin totals approximately 30.52 MGD, or 85.5% of current demands. Surface water demands dominate in the basin, primarily supplying community water systems and agricultural users. Groundwater demand is significantly less in the basin, and primarily supports small self-supplied users and community water systems in the basin.

The five largest demands for each source type including power generation are provided in Table 86. The largest groundwater demands in the basin primarily supply Community Water System (CWS) facilities in the basin including the Town of Saltville and Russell and Smyth counties. The largest surface water demands include the Washington County Service Authority, Town of Marion, City of Bristol, and Town of Big Stone Gap. The Marion Fish Cultural Station is also a significant demand of surface water in the basin with the third largest surface water demand in the watershed. Note that the Marion Fish Cultural Station is largely non-consumptive as water is returned to the source of withdrawal after the facility.

Table 86: Top 5 Users in 2040 by Source Type in the Upper Tennessee Minor Basin (including Power Generation)

Facility Name	System Type	Locality	2020 Demand (MGD)	2030 Demand (MGD)	2040 Demand (MGD)	20 Year Percent Change	% of Total Surface Water
Surface Water							
Wcsa Middle Fork Holston WTP	CWS	Washington	5.19	5.41	5.62	8.29	17.73
Marion WTP And Service Area	CWS	Smyth	2.22	2.61	2.99	34.68	9.43
Marion Fish Cultural Station	AG	Smyth	2.71	2.71	2.71	0.00	8.55
Bristol (Va) WTP	CWS	Washington	2.3	2.3	2.3	0.00	7.26
Big Stone Gap WTP	CWS	Wise	2.12	1.86	1.6	-24.53	5.05
Total SW			14.54	14.89	15.22	4.68	48.01
Groundwater							**% of Total Groundwater**
Saltville Service Area	CWS	Smyth	0.87	1.02	1.17	34.48	27.21
Castlewood Service Area	CWS	Russell	0.19	0.19	0.2	5.26	4.65
Olde Farm Golf Course	Large SSU	Washington	0.13	0.16	0.19	46.15	4.42
Honaker Service Area	CWS	Russell	0.14	0.15	0.16	14.29	3.72
Watson Gap Service Area	CWS	Smyth	0.11	0.11	0.11	0.00	2.56
Total GW			1.44	1.63	1.83	27.08	42.56

Table 85 also provides the proportion of each use category that is supplied by either surface water or groundwater. Use categories include Community Water System (CWS), Large Self-Supplied User (Large SSU), Small Self-Supplied User (Small SSU), and Agricultural Self-Supplied User (AG). These categories are defined below. Surface water demand in the basin is primarily comprised of CWS and AG. Groundwater demand is primarily from Small SSUs and CWS facilities. Groundwater demands from AG and Large SSUs are limited compared to Small SSUs and CWS facilities. The basin is consistent with the majority of the state as surface water is the primary source for CWS, while demand from domestic/residential wells is the greatest groundwater use category in the watershed.
The CWS category includes any public and private waterworks that serve at least 15 service connections used by year-round residents or regularly serve at least 25 year-round residents, and are regulated under the Virginia Department of Health's Waterworks Regulation (12VAC5-590). In the Upper Tennessee Basin, approximately 1.47 MGD of groundwater demand and 24.86 MGD of surface water demand is from CWS. Significant groundwater users within this category include the Washington and Wise County Service Authorities, the Cities of Bristol and Norton, and the Town of Marion. Significant surface water users in the category include the Washington County Service Authority, Russell County, and the Town of Saltville. CWS is the greatest category of demand in the basin representing more than 73% of current total demands.

Large SSUs include any non-CWS or AG who withdraw more than 300,000 gallons per month from a well or surface water intake. In the Upper Tennessee Minor Basin, approximately 0.22 MGD of groundwater demand and 0.08 MGD of surface water demand is from Large SSUs. Significant surface water users in the category are limited to golf courses and mining operations including the Virginia Golf Club and the Coal Creek Preparation Plant. Significant groundwater users within this category are limited with the Olde Farm and Virginian Golf Courses reporting the majority of demands in the category. Limited groundwater

withdrawals are associated with mining operations in the basin with the Coal Creek Prep Plant the only mining operation reporting a groundwater demand. Large SSU demands are minimal compared to other use categories.

Small SSUs include any users who withdraw less than 300,000 gallons per month from wells. Small SSUs generally consist of residential or domestic use for those who live outside service areas and provide their own water. In the Upper Tennessee Basin, approximately 3.35 MGD of groundwater demand is from Small SSUs. Localities with the greatest estimated county-wide demands from residential groundwater wells include Russell, Tazewell, Scott, Wise, and Smyth counties. Other localities with more extensive public water supply systems or smaller population centers such as the City of Bristol, and Lee and Washington counties have significantly less domestic groundwater demands.

The AG category includes crop farms, livestock operations, aquaculture and other agricultural facilities. In the Upper Tennessee Minor Basin, approximately 0.13 MGD of groundwater demand and 5.58 MGD of surface water demand is from agricultural users. Significant groundwater users within this category include countywide agricultural demand estimates in Smyth and Washington counties. Significant surface water users from this category include the Marion Fish Culture Station located in Smyth County, and countywide surface water demand estimates for Smyth and Washington counties. With limited reporting of withdrawals from facilities in the basin, the Southwest Virginia Regional Water Supply Plan provided countywide estimates of agricultural withdrawals in the basin.

A.17.4 Projected Population and Water Use

Projected Population: Trends in water use are generally driven by trends in population change or economic development. Increasing population within an area generally means increased connections for community water systems or additional demands from homeowners that construct wells. Increasing population in an area also tends to incentivize both new and expanded industrial and commercial water use. Alternatively, the addition of new economic opportunities such as a large employer may include additional water withdrawals for operational needs. Reviewing short and long term population projections can inform water supply planning efforts.

Table 84 shows the projected change in population by percent between 2020 and 2040 for each locality located partly or wholly within this minor basin. The population projections within the basin show only two localities with expected increases over the planning period. Washington County is projected to have a 1.99% increase in population by 2040 and is the fastest growing locality in the basin. Wythe County is the only other locality projecting an increase in population by 2040, with 0.18% projected. All other localities in the watershed are projecting significant decreases over the planning period. Buchanan County is projected to have the greatest reduction in population over the planning period with more than 31% expected. As a very rural portion of Virginia with limited economic opportunities available to retain and attract individuals, individuals will likely continue to migrate out of the region. The projections in the basin are consistent with the statewide trend of outward migration from rural areas in Virginia towards more urban areas.

Projected Water Use: The following section discusses projected water use through 2040 within the Upper Tennessee basin, based on projections provided in local and regional water supply plans. Table 85, included in the existing demand section above, is the basis for information discussed in this section.

Total water demands within the basin are projected to increase from 35.68 MGD to 36.00 MGD by 2040. The major demand trend in the basin is the projected decline (37.92%) in Small SSU demands. As populations decline throughout the basin, demands from residential homeowners are expected to continue to decline throughout the planning period. Additionally, projected increases in population in Washington County align with the projected increases in CWS demands for the Washington County Public Service Authority. Surface water demand is projected to increase by 1.18 MGD, or 3.87 %, by 2040. Groundwater demand is projected to decrease by 0.87 MGD, or 16.83%, by 2040.

The largest contributors to increases in total projected demand include the Washington County Service Authority, Town of Marion, Town of Saltville, and the Thomas Bridge Water Company that serves a wide portion of the basin. The greatest projected declines are expected as a result of outward migrations with significant reductions in groundwater demands from private well owners in Tazewell, Russell, and Wise counties. Additionally, reduced demands from the Town of Big Stone Gap,the City of Norton, and Scott County WTPs are projected.

Demands from CWS users within the basin is projected to increase in demand by 5.65% by 2040. Within this category, surface water use is projected to increase by 4.69%, while groundwater use is projected to increase by 22.01%. The greatest contributors to projected increases in surface water demand are the Town of Marion, Washington, Saltville, and Tazewell counties public water supply systems. The Town of Marion WTP is projecting the greatest increase in demand within the basin increasing from 720 MGY to approximately 970 MGY. The Washington County Service Authority is also projecting significant increases in demands; this aligns with the projected increases in population for the county and the number of localities the authority serves. Groundwater demands within the category are projected to increase from 1.47 MGD in 2020 to 1.79 MGD in 2040, or approximately 22.01%. The projected increases in groundwater demands are almost entirely from projections for the Town of Saltville service area. The Town of Saltville provides water throughout the basin via interconnections including to Smyth and Washington counties.

Demands from Large SSUs users within the basin is projected to increase by 30.98% by 2040. Within this category, surface water use is projected to increase by 13.71%, while groundwater use is projected to increase by 37.62%. While more than 30% increases are projected the total increase in water demand is less than .02MGD of total water demand from surface and groundwater sources. With limited economic development or growth projected to occur over the planning period, Large SSU demands are largely expected to remain constant over the planning period.

Demands from Small SSUs within the basin is projected to decrease 37.92% by 2040, which means a decrease in demand from private or domestic wells. Within the basin population is projected to decline throughout the planning period, which drives the locality estimates for domestic well use. As individuals migrate out of the watershed, domestic well use will continue to drop over the planning period.

Demands from agriculture users within the basin are projected to remain constant throughout 2040. Within this category, surface water use is the primary water source with 5.58 MGD of demand expected throughout the planning period. Groundwater use is significantly less with 0.13 MGD of demand expected through the planning period. As a largely rural basin, agricultural demand estimates for the basin are significant compared to other minor basins in Virginia.

A.17.5 Cumulative Impact Analysis

The following section provides a brief summary of the Cumulative Impact Analysis (CIA) modeling results in the Upper Tennessee Minor Basin. Discussion of these results will primarily be found in the Trends and Goals section of this appendix. However a brief overview of the VAHydro model and the scenarios and metrics is provided below.

The VAHydro surface water model simulates streamflow using inputs such as precipitation, climate, land use, and topography, combined with data on all known withdrawals and discharges, and operational rules of major hydrologic features such as reservoirs. Each minor basin is broken into smaller hydrologic subsections, or river segments. The model simulates the water balance on a daily basis for each individual river segment, with each downstream segment being affected by the cumulative impact of streamflow changes occurring in upstream segments. The following figures help analyze this cumulative impact within the Upper Tennessee Minor Basin (model results summarized by river segment). Note that this section is not intended to document in detail the methods and assumptions for the VAHydro model or for the scenarios and metrics discussed. More documentation of the model and assumptions can be found in Chapter 4.

The VAHydro surface water model was used to simulate streamflow under a variety of scenarios. Demand scenarios examine how streamflow is impacted under 2030 or 2040 demands as compared to current (2020) demands. Demands were calculated based on current and future demand information submitted through local and regional water supply plans. Climate change scenarios examine how streamflow is impacted when 2040 demands are simulated in conjunction with a range of precipitation and temperature conditions that may occur in the future due to changing climate (Dry, Median, Wet scenarios). Finally, the exempt user scenario examines impacts from users excluded, or exempt, from VWP permit requirements per Va. Code § 62.1-44.15:22 B. Exempt users were simulated at the maximum possible demand identified through a review of demand justification values commonly asserted by exempt users, including but not limited to VDH pump capacity, maximum pre-1989 withdrawal, and maximum intake capacity. In order to effectively manage surface water resources and address the uncertainty related to these demands, DEQ determined the most conservative, or maximum possible, demand should be evaluated in this scenario. However, DEQ does not agree that the maximum values used in this scenario represent an allocation for, or the expectation of, a future withdrawal of that volume; nor does DEQ concede that any particular exempt user is necessarily entitled to withdraw any particular maximum value used in this scenario. The methods and assumptions for each of these modeling scenarios are discussed in more detail in Chapter 4.

For each scenario described above, different metrics can be used to evaluate the simulated streamflow. A metric is a method for measuring or evaluating a given set of data; different metrics can be evaluated to answer different questions. Within this section the following metrics will be discussed: the lowest 30 day flow (L30), the lowest 90 day flow (L90), 7Q10, and overall change in flow. The L30 describes the lowest consecutive 30 day average daily streamflow over the simulation period. This metric is a representation of a short-term, or acute drought, and is a good metric for evaluating impacts to direct withdrawals without storage. Similarly the lowest 90 day flow represents the lowest consecutive 90 day average daily streamflow over the simulation period. This would represent a prolonged drought and is often used to evaluate impacts to reservoirs. The 7Q10 is the lowest 7-day average flow that occurs (on average) once every 10 years. 7Q10 is generally used in the evaluations of in-stream beneficial uses such as waste assimilative capacity. Overall change in flow describes the net loss of water from the riverine system as a result of off-stream use not otherwise returned through point source discharges, or losses due to evapotranspiration. This metric is useful for evaluating impacts to aquatic life and is discussed in more detail in Chapter 4.

Demand Scenarios: 2020 demand or current demand, 2030 demand, and 2040 demand scenarios were simulated. The following series of figures compares the 2030 and 2040 demand scenarios to the current demand scenario. The change in flow depicted on each map is the change expected when comparing two scenarios - in this case future demands compared to current demands. Each page includes two figures comparing either the 2030 or 2040 demand scenario to current demand using the L30, L90, and 7Q10 metrics. This allows for comparisons of simulated impacts between the 2030 and 2040 demand scenarios. The scenarios and metrics are identified in the paragraph below and in the figure captions.

Figures 330 and 331 compare the lowest 30 day flow simulated with the current demand scenario with the lowest 30 day flow simulated in the 2030 and 2040 demand scenarios respectively. Figures 332 and 333 compare the lowest 90 day low flow simulated with the current demand scenario with the lowest 90 day flow simulated in the 2030 and 2040 demand scenarios respectively. Figures 334 and 335 compare the 7Q10 simulated with the current demand scenario with the 7Q10 simulated in the 2030 and 2040 demand scenarios respectively.

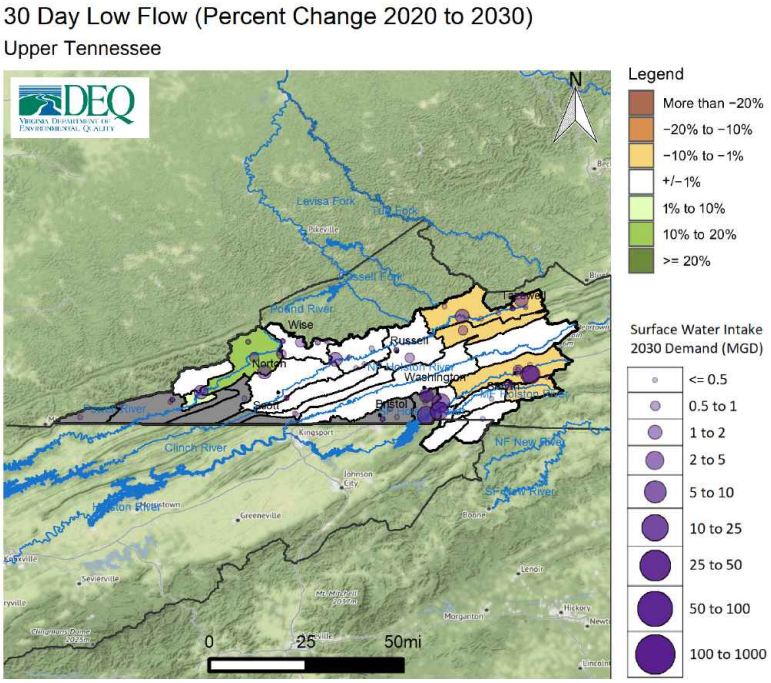

Figure 330: Change in 30 day low flow between 2020 and 2030 demand scenarios within the Upper Tennessee Minor Basin

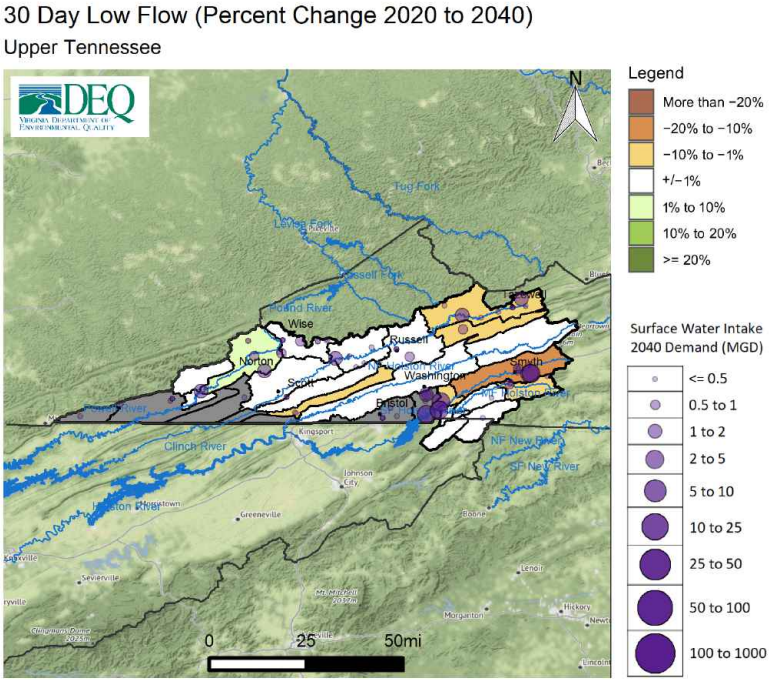

Figure 331: Change in 30 day low flow between 2020 and 2040 demand scenarios within the Upper Tennessee Minor Basin

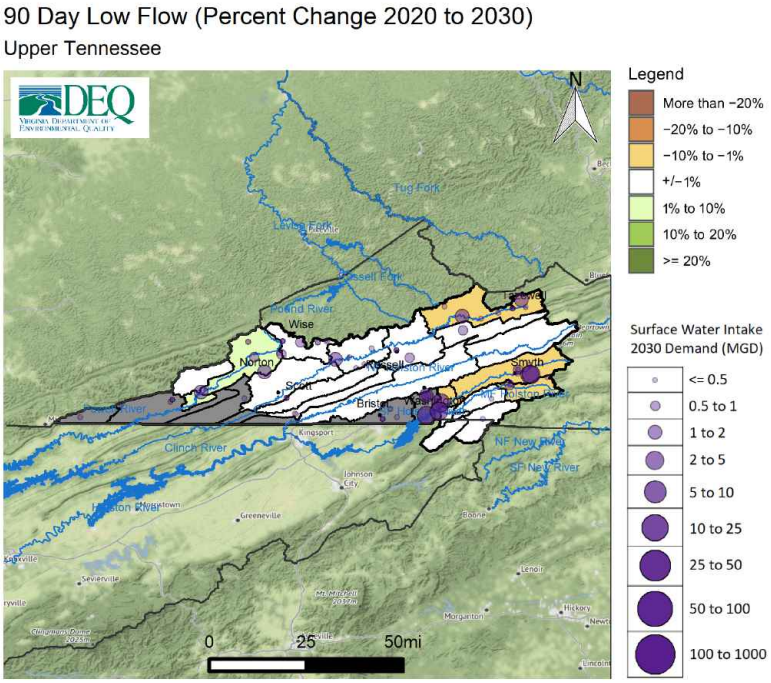

Figure 332: Change in 90 day low flow between 2020 and 2030 demand scenarios within the Upper Tennessee Minor Basin

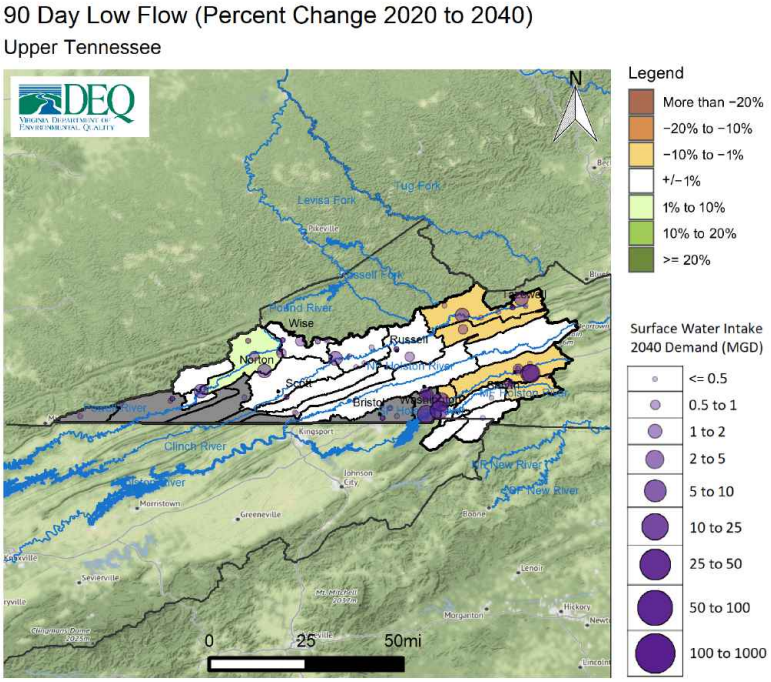

Figure 333: Change in 90 day low flow between 2020 and 2040 demand scenarios within the Upper Tennessee Minor Basin

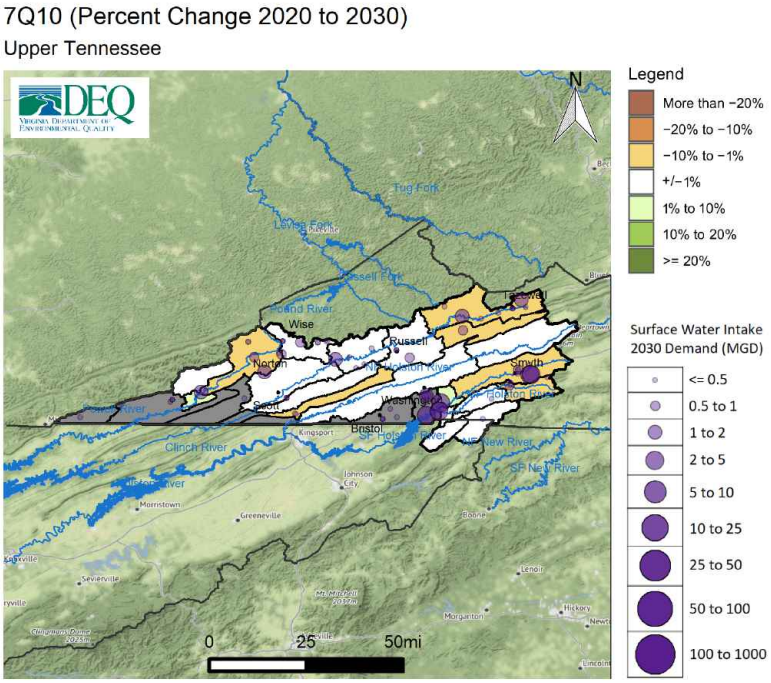

Figure 334: Change in 7Q10 between 2020 and 2030 demand scenarios within the Upper Tennessee Minor Basin

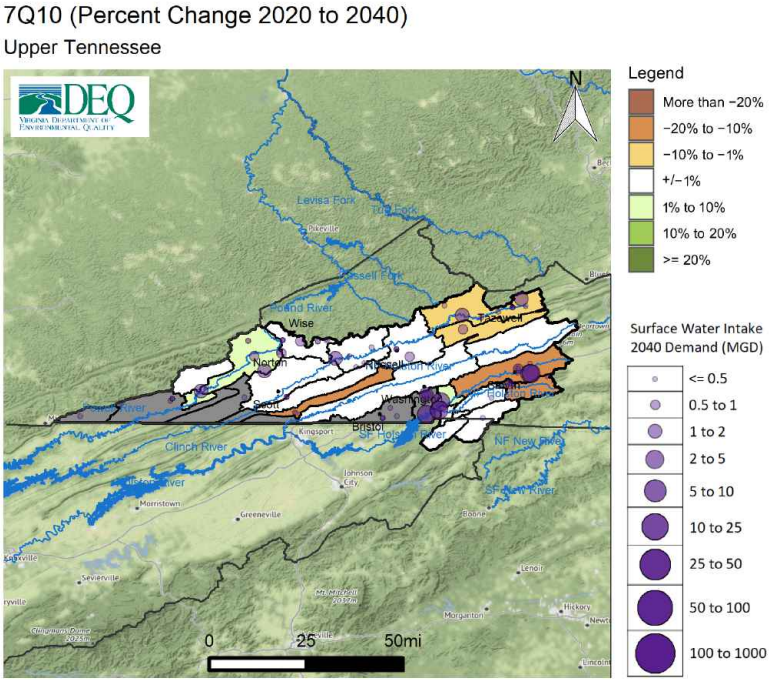

Figure 335: Change in 7Q10 between 2020 and 2040 demand scenarios within the Upper Tennessee Minor Basin

The figures above show a comparison between two scenarios. An additional way to evaluate impacts to streamflow is to examine the total reduction in streamflow resulting from all withdrawals within a river segment, as well as losses due to evapotranspiration, while taking into consideration any discharges back to the source. To use a common industry term, the overall change in flow metric evaluates "consumptive use", or the amount of water removed from the river that is not returned through discharges. This can help describe potential impacts to downstream withdrawals, while also providing a basis for evaluating impacts to aquatic life. In general, total reductions in streamflow can result in a proportional reduction in aquatic biodiversity [116]. The relationship between streamflow and aquatic biodiversity is discussed in more detail in Chapter 4. Figure 336 shows the overall change in streamflow for the 2030 Demand Scenario, while figure 337 shows the overall change in streamflow for the 2040 Demand Scenario.

[116] Rapp, J.L., R. Burgholzer, J. Kleiner, D. Scott, and E. Passero. 2020. "Application of a New Species-Richness Based Flow Ecology Framework for Assessing Flow Reduction Effects on Aquatic Communities." Journal of the American Water Resources Association 1–14.https://doi.org/10.1111/1752-1688.12877.

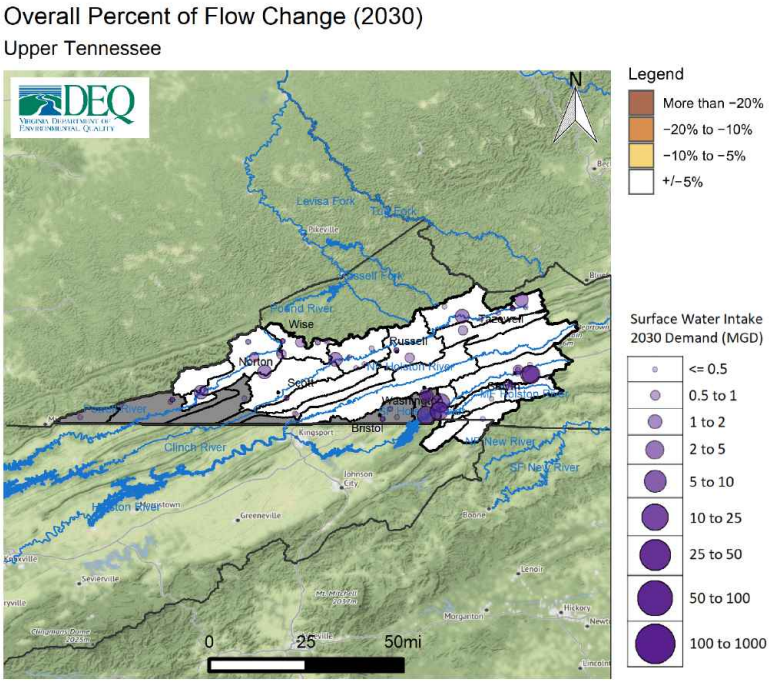

Figure 336: Overall change in flow in percent for 2030 demand scenario within the Upper Tennessee Minor Basin

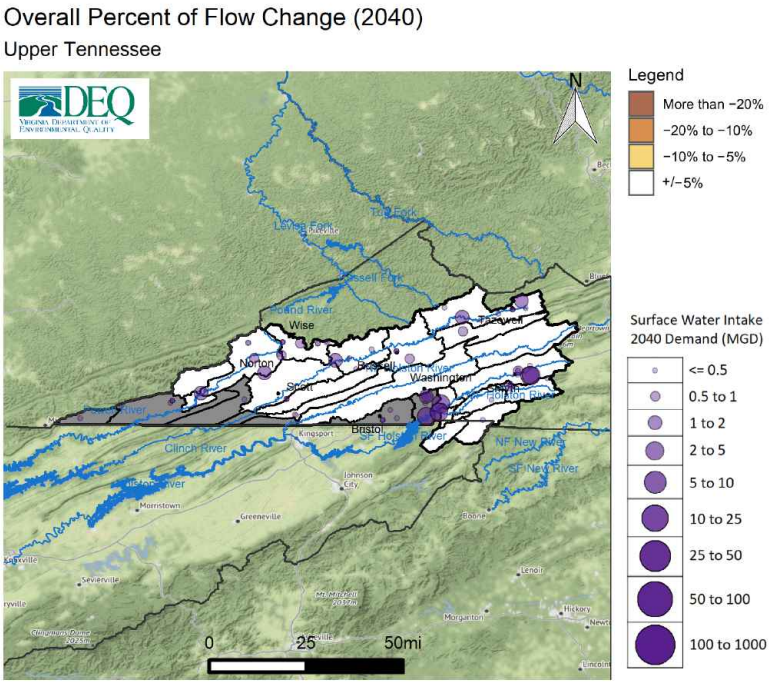

Figure 337: Overall change in flow in percent for 2040 demand scenario within the Upper Tennessee Minor Basin

Climate Scenarios:Three scenarios that simulate impacts to streamflow in response to changes in temperature and climate were completed for areas in the state where climate data was available, which includes the portions of the Commonwealth located in the Chesapeake Bay watershed. Details on the methods and assumptions employed for these scenarios can be found in Appendix B. The three scenarios can be described as dry, median, and wet scenarios. Virginia is expected to experience a range of precipitation and temperature changes that may vary spatially and from year to year. The potential for both more severe and prolonged droughts as well as for higher intensity and more frequent rain events must be considered. These three scenarios are not intended as predictions of future climate conditions, but as representations of several possibilities that climate change models indicate could occur. Should they occur, these results provide an evaluation of how streamflows may be impacted. Their purpose is to build upon existing climate modeling to provide a foundation for state and local government, as well as other stakeholders, to better evaluate what practical water resource challenges may be associated with the range of climate conditions Virginia could experience. Note that the Upper Tennessee Minor Basin is located outside of the Chesapeake Bay watershed and therefore climate scenarios were not completed at this time. DEQ is working to expand these climate scenarios to cover the entire state for future planning efforts.

Exempt User Scenario: The exempt user scenario simulates the maximum possible exempt demand by users excluded from Virginia Water Protection permitting requirements per Va. Code § 62.1-44.15:22 B., in combination with the permitted withdrawal limits for those users that are permitted. A more detailed discussion of the data and assumptions used in this scenario can be found in Chapter 4 and Appendix B. Note that this scenario uses current climate conditions. Figure 338 depicts the percent change in the Lowest 30 Day Flow between the exempt user scenario and current (2020) demand. Figure 339 depicts the percent change in the Lowest 90 Day Flow between the exempt user scenario and current (2020) demand. Figure 340 depicts the percent change in the 7Q10 between the exempt user scenario and current (2020) demand. Finally, figure 341 depicts the overall change in flow in percent (consumptive use) for the exempt user scenario.

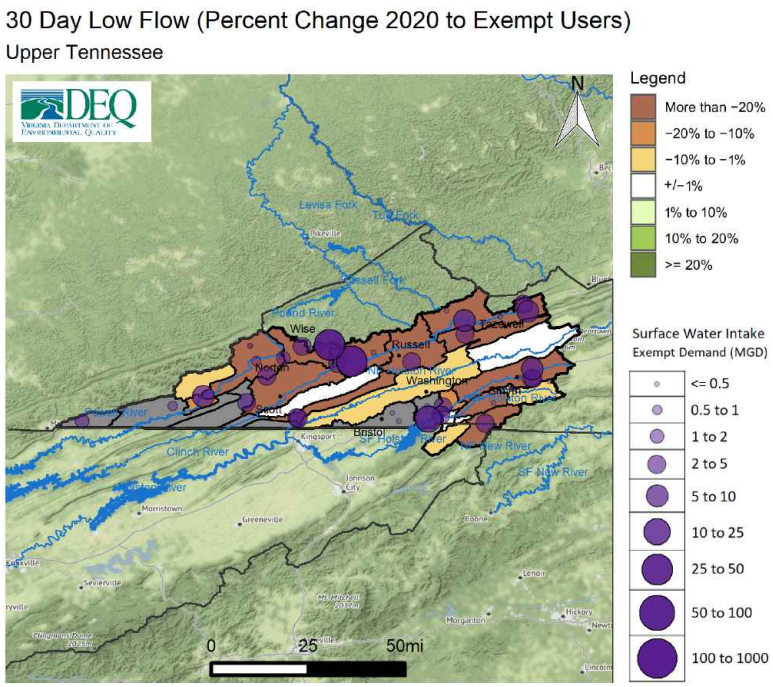

Figure 338: Change in 30 day low flow between current demand scenario and exempt user scenario within the Upper Tennessee Minor Basin

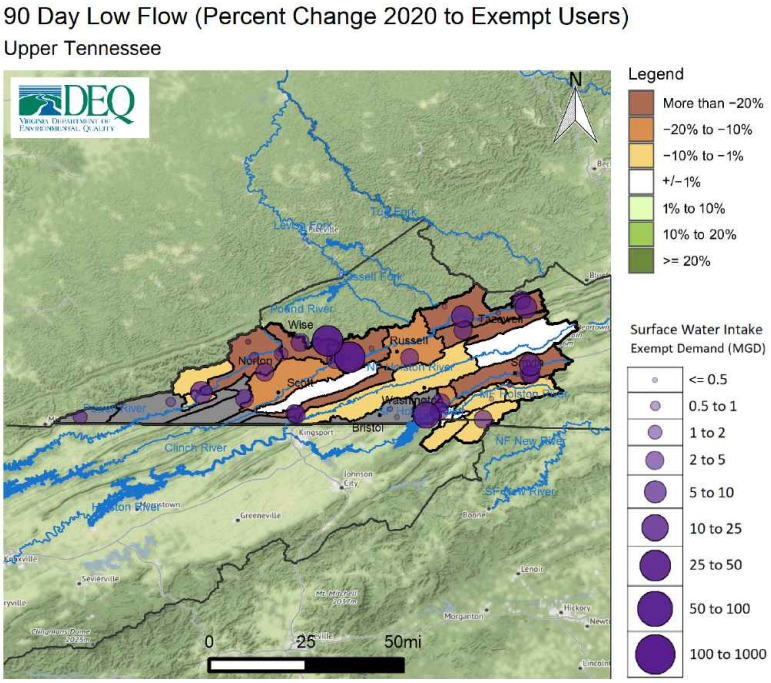

Figure 339: Change in 90 day low flow between current demand scenario and exempt user scenario within the Upper Tennessee Minor Basin

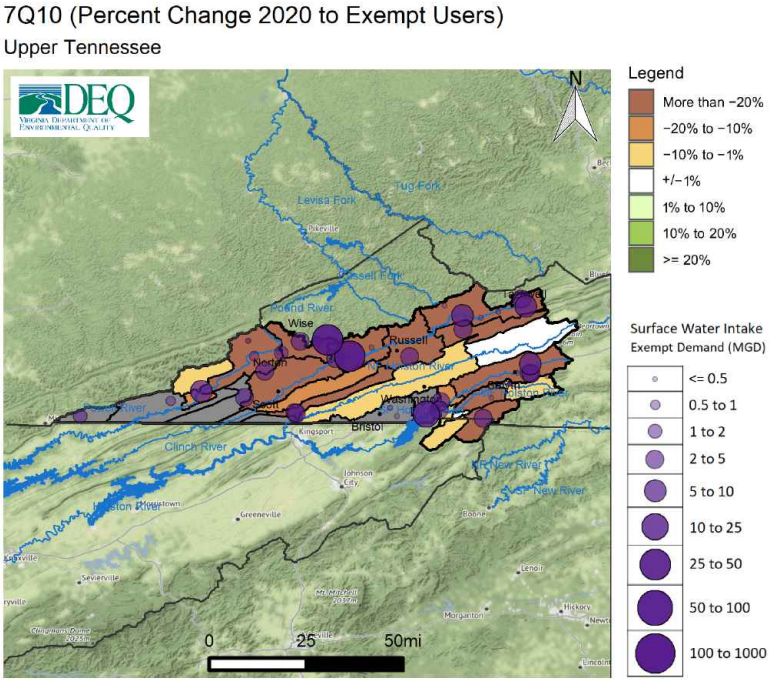

Figure 340: Change in 7Q10 between current demand scenario and exempt User scenario within the Upper Tennessee Minor Basin

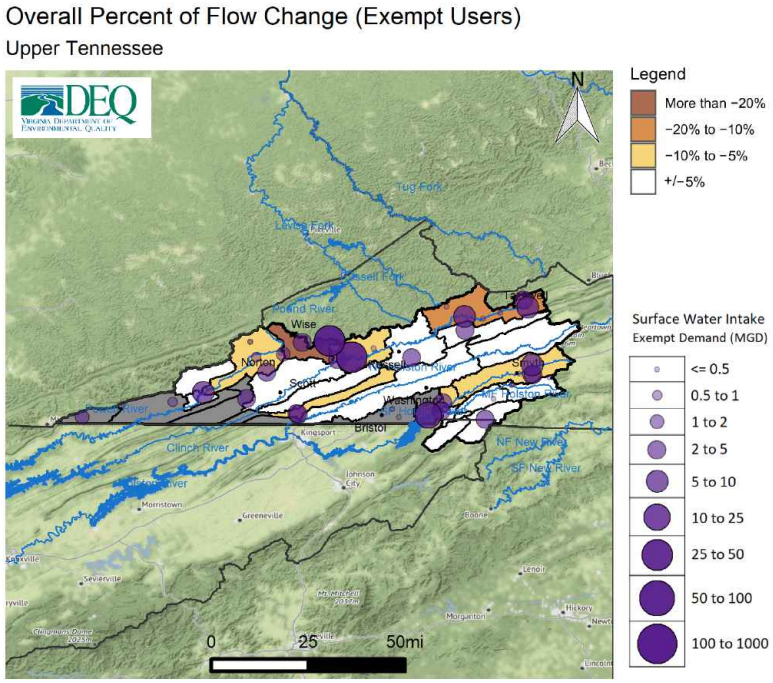

Figure 341: Overall change in flow in percent for exempt user scenario within the Upper Tennessee Minor Basin

Potential Unmet Demand: Potential unmet demand was evaluated for all facilities within the basin for each scenario. Potential unmet demand is the portion of surface water demand for a specific facility that is limited by available streamflow as simulated in a given model scenario, including any known operational limits such as flow-by requirements. This unmet demand, if realized, could be managed through water conservation, through alternative sources, operational changes, or from available storage. Absent of these or other options, this portion of demand could remain unmet. As with all scenarios, demand requirements were determined using demand projections provided in the water supply plans. In the case of the exempt user scenario, the highest possible withdrawal amount was used for users exempt from VWP permitting requirements.

This metric is useful for evaluating where the results seen in the above figures may result in challenges in meeting future demands under a variety of conditions including increasing demands in the basin, changing climate, or withdrawals from users exempt from permitting requirements. Table 87 provides for each facility the highest average daily potential unmet demand over a 30 day period over the course of the simulation for the following scenarios: 2020 demand, 2030 demand, 2040 demand, and exempt User. Only facilities showing potential unmet demand in at least one scenario appear on this table. Additional information on the potential unmet demand metric can be found in B.

Table 87: Change in Highest 30 Day Potential Unmet Demand (MGD) in Upper Tennessee Minor Basin

Facility	2020 Demand	2030 Demand	2040 Demand	Dry Climate	Exempt User
Coeburn WTP	0.00	0.00	0.00	-	30.13
St. Paul WTP	0.00	0.00	0.00	-	19.53
Clinch River Plant	0.00	0.00	0.00	-	8.99
Greater Tazwell Regional WTP	0.05	0.07	0.09	-	7.31
Wcsa Middle Fork Holston WTP	0.81	1.02	1.24	-	6.05
Marion WTP And Service Area	0.01	0.08	0.21	-	5.4
Pennington Gap WTP	0.06	0.04	0.04	-	5.28
Richlands Service Area	0.05	0.07	0.08	-	4.7
Raven-Doran WTP	0.00	0.00	0.00	-	3.71
Wise (Town) WTP	0.00	0.00	0.00	-	2.47
Claypool Hill WTP	0.00	0.00	0.00	-	1.79
Gate City WTP	0.00	0.00	0.00	-	1.36
Moccasin Gap WTP	0.00	0.00	0.00	-	1.36
Big Stone Gap WTP	0.18	0.08	0.04	-	1.22
Marion Fish Cultural Station	0.01	0.02	0.03	-	0.6
Moss No. 3 Preparation Plant	0.00	0.00	0.00	-	0.32
Norton WTP	0.02	0.02	0.01	-	0.3
Washington County Service Area	0.00	0.00	0.00	-	0.2
Toms Creek Preparation Plant	0.00	0.00	0.00	-	0.17
Ramsey Preparation Plant	0.00	0.00	0.00	-	0.04
Genisis Prep Plant	0.00	0.00	0.00	-	0.02
Bullitt Complex	0.00	0.00	0.00	-	0.02
Pounding Mill Plant	0.00	0.00	0.00	-	0.01
Jewell Ridge WTP	0.00	0.00	0.00	-	0.01
Coal Creek No. 3 Prep Plant	0.00	0.00	0.00	-	0.01
Appalachia WTP	0.01	0.01	0.01	-	0.01
Crcc Roaring Fork Water Withdrawal	0.00	0.00	0.00	-	0.01
Thomas Br Water Co Servce Area	0.00	0.00	0.01	-	0.00

* Climate scenarios were not completed in areas located outside of the Chesapeake Bay Basin

Note: Potential unmet demand is the portion of surface water demand for a specific facility that is limited by available streamflow as simulated in a given model scenario, including any known operational limits such as flow-by requirements. This unmet demand, if realized, could be managed through water conservation, alternative sources, operational changes, or from available storage.

A.17.6 Trends and Goals

The Code of Virginia mandates that the State Water Control Board should take into consideration the principle that "adequate and safe supplies shall be preserved and protected for human consumption, while conserving maximum supplies for other beneficial uses". [117] This principle is the key driver of the challenges in water resource management, which is that all beneficial uses must be adequately considered when evaluating impacts to surface water resources. The State Water Control Board is tasked with ensuring that water supply quantity needs are met at all times while also protecting Virginia's natural resources, and furthermore, ensuring equitable allocation during a time of shortage.[118] While evaluating and planning for the long-term sustainability of water supply for Virginia is the primary goal for the State Plan, evaluating and limiting impacts to in-stream beneficial uses such as aquatic habitat life is also part of DEQ's responsibility.

The primary purpose of this section is to identify where the most significant challenges to long-term sustainability of water supply and other beneficial uses are indicated based on the CIA and information collated from local water supply plans within this basin. Goals for future planning and areas for additional data collection or analysis are also suggested where appropriate.

The CIAs were completed using the best available data and methods known to DEQ. This discussion focuses on the evaluation of trends - in other words the prevailing tendency or inclination. This means evaluating whether streamflow is simulated to increase or decrease in a given scenario, and by how much. A relative trend indicating reductions of greater than or equal to 10% in streamflow, whether driven by demand increases, changing climate conditions, or exempt user demands was considered a threshold for potential impacts to beneficial uses. The following summarize the key trends or goals for this basin:

- **Demand Scenarios:** Surface water demands in the Upper Tennessee Minor Basin are projected to increase by approximately 3.8% over the planning period, primarily to meet increasing CWS demands in population centers. Growth in surface water demands are focused within the Town of Marion, Washington County Service Authority, and the Greater Tazewell Regional WTP. However, overall demands are not projected to increase significantly within the basin and this results in fewer impacts in demand scenarios than in other parts of Virginia. When comparing the 2040 demand scenario to the 2020 demand scenario, no reductions greater than 10% were simulated for most metrics, although a more than 10% reduction in the short-term drought flow (L30) was simulated within the Middle Fork of the Holston River near Marion; this is the only river segment with a greater than 10% reduction in L30. These reductions are driven by increased surface water demands from the Marion WTP Holston River intake. The Upper Tennessee watershed is an area of high aquatic biodiversity in Virginia and potential impacts to sensitive species may occur as a result of reduced streamflow. Additionally, potential unmet demand is simulated in the 2040 scenario for Washington County, Tazewell County, the Town of Marion, and several smaller CWS systems across the basin. The Southwest Virginia Water Supply Plan, provides information on alternative water sources available to mitigate potential unmet demands. For example, the Washington County Service Authority primarily relies on an interconnection with the City of Bristol to offset unmet demands. Although the overall trend in demands is not indicating the potential for significant demand increase driven impacts to streamflow, such interconnections provide a critical tool to address unmet demand that could still occur even under current demands.

- **Climate Scenario:** As climate change data was not available in this basin, climate change scenarios were not completed for this basin. The overall trend in climate change simulations statewide suggests the potential for higher average temperatures and higher average precipitation totals. However, the simulations also suggest the potential for more significant droughts than have been historically experienced in Virginia. Simulations completed elsewhere in the Commonwealth show short-term and

[117] § 62.1-44.36 of the Code of Virginia
[118] 9VAC25-390-20.1

long-term droughts with 20-50% reductions in streamflow compared to previous droughts. The potential for more severe droughts must be considered by localities and users when evaluating existing sources and alternatives, as well as for broader planning and resource management efforts by all stakeholders whether state or local.

- **Exempt User Scenario:** The exempt user scenario, which models the cumulative maximum possible exempt demands from all users exempt from VWP permitting requirements, shows widespread reductions in streamflow reductions of more than 10% in thirteen river segments during a short term drought (L30), and ten river segments during long term drought (L90), when comparing the exempt user scenario to 2020 demands. The most significant impacts occur within the Clinch, Powell, and Holston Rivers with potential reductions of more than 60% compared to the 2020 demand scenario for L30 and L90. A more than 10% reduction in overall flow (consumptive use) is simulated within two river segments with the greatest impacts to the Clinch and Guest rivers. These trends in the exempt user scenario are driven by the maximum possible exempt demands from several municipal and Large SSUs. The greatest impact to overall stream flows are a result of demands from major public water supply and industrial intakes in the Toms Creek Reservoir, Clinch River, South Holston Lake, and the Holston River. Reductions in the Clinch River segments are driven by the maximum possible exempt demands for three primary users: the Town of St. Paul, Tazewell Regional WTP, and the Clinch River Appalachian Power Company generation facility. Reductions of overall flow (consumptive use) suggest potential impacts to the significant biodiversity in this region should facilities operate at these demands. Potential unmet demands are also simulated in the exempt user scenario including for CWS facilities such as Greater Tazewell WTP, Washington County, and the town of Marion, Coeburn and St. Paul WTPs. These results indicate that the cumulative maximum possible exempt user demands in the basin may exceed the water budget in many river segments within the basin. Preserving water supply and other beneficial uses may require managing these demands with respect to their cumulative impacts and in the context of the available resources in the basin.

A.18 York Mattaponi Minor Basin

A.18.1 Watershed Overview

The York River is formed at the confluence of the Pamunkey and Mattaponi rivers. The Mattaponi's major tributaries are the Matta, Po, and Ni rivers. Both the Pamunkey and Mattaponi rivers flow through the Piedmont and Coastal Plain provinces, and are characterized by slight rolling hills at the headwaters and flatter areas dominated by farmland moving into the tidal portions. Cropland/pasture and forest make up the majority of land-use across the York Mattaponi Minor Basin with increasing urban development nearing urban centers such as the City of Richmond and the City of Fredericksburg.
The total spatial area of the basin occupies 910 sq. miles and includes all or portions of the localities listed in Table 88. The major population centers within the basin include the suburban areas around the City of Fredericksburg and Spotsylvania County.

A.18.2 Existing Water Sources

Major surface water sources within the basin include the Mattaponi River and the Ni River Reservoir. Groundwater within the basin is primarily withdrawn from fractured rock aquifers west of interstate 95, and from Coastal Plain Aquifer system east of interstate 95, specifically the Potomac Aquifer.

Withdrawals within the basin are used for public water supply as well as for agriculture, irrigation, commercial, and industrial/manufacturing.

The location of wells and surface water intakes identified to DEQ within the basin are shown in figure 342. This figure does not include private or domestic wells.

Table 88: Population Trend by Locality in York Mattaponi Basin

Localities	20 Year % Change
Caroline	24.83
Essex	4.16
Gloucester	3.18
King and Queen	1.02
King William	19.85
Orange	25.12
Spotsylvania	30.24

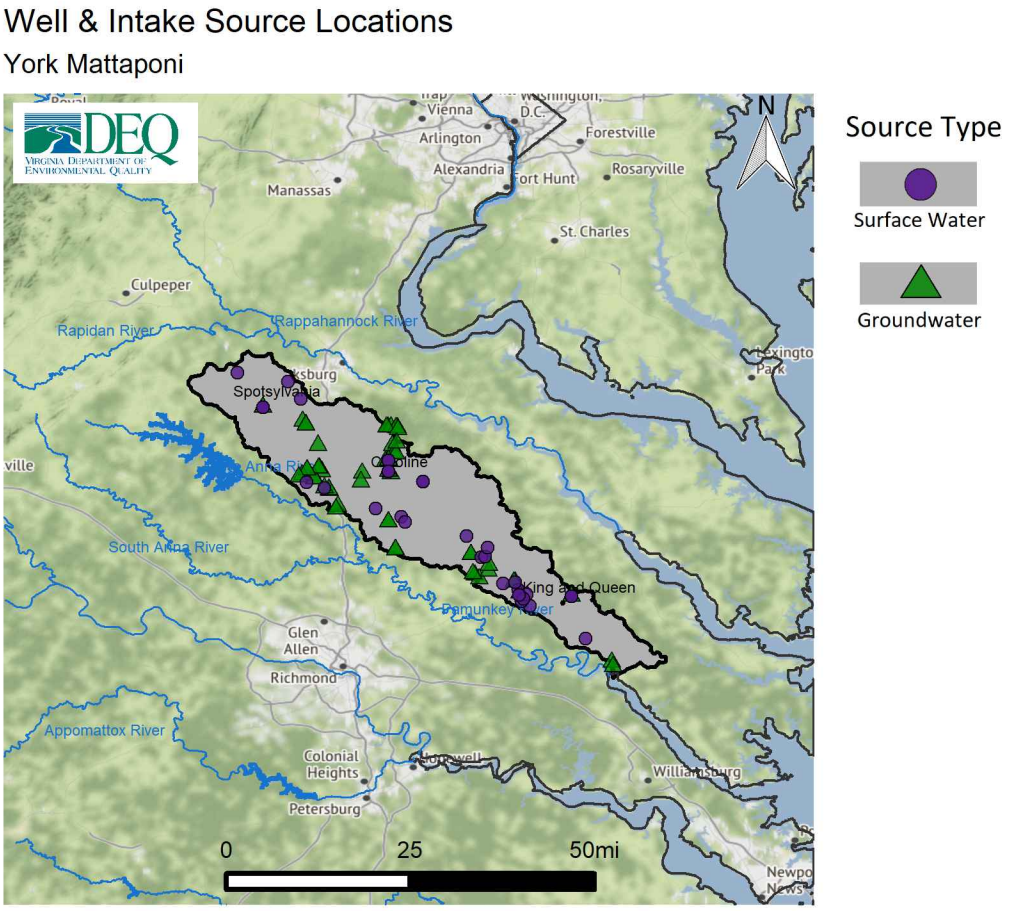

Figure 342: Spatial distribution of groundwater wells and intakes in the York Mattaponi Minor Basin

A.18.3 Existing Water Use

The following section discusses existing or current water use within the basin, which is based on existing demand information submitted to DEQ in the water supply plans. Table 89 provides a summary of all demands within the basin by system type and source type including power generation. It also provides a count of surface water or groundwater sources associated with each system type.

Table 89: Summary of York Mattaponi Minor Basin Water Demand by Source Type and System Type (including Power Generation)

System Type	Source Count	2020 Demand (MGD)	2030 Demand (MGD)	2040 Demand (MGD)	20 Year Percent Change
Surface Water					
Agriculture	23	1.53	1.59	1.65	8.31
CWS	2	3.76	5.35	6.93	84.03
Large SSU	3	0.17	0.13	0.09	-49.01
Small SSU	N/A	0.00	0.00	0.00	0.00
Total SW	**28**	**5.46**	**7.07**	**8.67**	**58.79**
Groundwater					
Agriculture	2	0.02	0.02	0.02	0.00
CWS	69	1.90	5.18	8.45	343.65
Large SSU	8	0.03	0.04	0.05	39.73
Small SSU	N/A	6.02	7.50	8.97	49.16
Total GW	**79**	**7.97**	**12.74**	**17.49**	**119.45**
Total (SW + GW)					
Agriculture	25	1.54	1.61	1.67	8.23
CWS	71	5.67	10.52	15.37	171.24
Large SSU	11	0.21	0.17	0.14	-34.24
Small SSU	N/A	6.02	7.50	8.97	49.16
Minor Basin Total	**107**	**13.44**	**19.80**	**26.15**	**94.57**

* Small SSU demands are county-wide estimates of private well usage below 300,000 gallons a month. The number of private wells is not known.

The total existing demand from all surface and groundwater sources is approximately 13.42 MGD, with groundwater supplying approximately 7.96 MGD or 59% of total water demands. Surface water demand within the basin totals approximately 5.46 MGD, or 41% of current demands. The York Mattaponi Minor Basin is one of the few minor basins where total groundwater demands are higher than surface water demands.

The five largest facility demands for each source type including power generation are provided in table 90. The largest groundwater demands are all CWS facilities including Caroline County's system and the Town of Bowling Green's system. The largest surface water demand by far is the Spotysylvania County's Ni River WTP, followed by several agricultural operations.

Table 90: Top 5 Users in 2040 by Source Type in the York Mattaponi Minor Basin (including Power Generation)

Facility Name	System Type	Locality	2020 Demand (MGD)	2030 Demand (MGD)	2040 Demand (MGD)	20 Year Percent Change	% of Total Surface Water
Surface Water							
Ni River WTP	CWS	Spotsylvania	3.7	5.27	6.85	85.14	79.01
Enfield Sod - Enfield Farm	AG	King William	0.54	0.54	0.54	0.00	6.23
Broaddus Farms	AG	Caroline	0.37	0.43	0.49	32.43	5.65
Glenwood	AG	King and Queen	0.42	0.42	0.42	0.00	4.84
Endfield Nursery	AG	King and Queen	0.11	0.11	0.11	0.00	1.27
Total SW			5.14	6.77	8.41	63.62	97
Groundwater							**% of Total Groundwater**
Caroline County Utility System	CWS	Caroline	0.38	1.52	2.66	600	15.21
Sydnor - Braxton's Landing	CWS	King William	0.06	0.57	1.09	1716.67	6.23
Town Of Bowling Green Water System	CWS	Caroline	0.15	0.58	1.02	580	5.83
Oak Springs Subdivision	CWS	King William	0.05	0.53	1.01	1920	5.77
King William County - Central Garage Water System	CWS	King William	0.05	0.47	0.88	1660	5.03
Total GW			0.69	3.67	6.66	865.22	38.08

Table 89 also provides the proportion of each use category that is supplied by either surface water or groundwater. Use categories include Community Water System (CWS), Large Self-Supplied User (Large SSU), Small Self-Supplied User (Small SSU), and Agricultural Self-Supplied User (AG). These categories are defined below. Surface water demand is primarily comprised of CWS and AG demands. Groundwater demand is primarily comprised of CWS and Small SSU demands. Small SSU demands alone make up 45% of current demands in the basin.

The CWS category includes any public and private waterworks that serve at least 15 service connections used by year-round residents or regularly serve at least 25 year-round residents, and are regulated under the Virginia Department of Health's Waterworks Regulation (12VAC5-590). In the York Mattaponi Minor Basin, approximately 1.90 MGD of groundwater demand and 3.76 MGD of surface water demand is from CWS. Significant groundwater users within this category include the West Point Public Water System and the Caroline County Utility System the primary users in the category. Significant surface water users include the Ni River WTP and Lake Caroline WTP.

Large SSUs include any non-CWS or AG who withdraw more than 300,000 gallons per month from a well or surface water intake. In the York Mattoponi Basin, approximately 0.03 MGD of groundwater demand and 0.17 MGD of surface water demand is from large SSUs. Significant groundwater users within this category include the Dominion Ladysmith power generation facility. Significant surface water demands include the

Fawn Lake Country Club as the primary user in the category. Minimal Large SSUs are present in the basin compared to other watersheds.

Small SSUs include any users who withdraw less than 300,000 gallons per month from wells. Small SSUs generally consist of residential or domestic use for those who live outside service areas and provide their own water. Small SSU demand is generally met with groundwater. In the York Mattaponi Minor Basin, approximately 6.02 MGD of groundwater demand is from Small SSUs. Domestic well demands are the largest use category in the basin including both surface and groundwater sources. The greatest demands are primarily focused within Spotsylvania County. As population increases over the planning period, demands from domestic well users are also projected to increase in the highest populated localities.

The AG category includes crop farms, livestock operations, aquaculture and other agricultural facilities. In the York Mattaponi Minor Basin, approximately 0.02 MGD of groundwater demand and 1.53 MGD of surface water demand is from AG users. Significant groundwater users within this category include the Endfield Nursery and cumulative withdrawals from small users in spotsylvania County. Surface water is the primary water source for the category. Significant surface water users include the Enfield Sod Farm, Broaddus Farms, and Glenwood Farm.

A.18.4 Projected Population and Water Use

Projected Population: Trends in water use are generally driven by trends in population change or economic development. Increasing population within an area generally means increased connections for community water systems or additional demands from homeowners that construct wells. Increasing population in an area also tends to incentivize both new and expanded industrial and commercial water use.

Table 88 shows the projected change in population by percent between 2020 and 2040 for each locality located partly or wholly within this minor basin. All localities within the watershed are projected to increase with Spotsylvania, Orange, Caroline, and King George Counties all projected to increase by 20-30% over the planning period. Proximity of these localities to Washington D.C., Richmond, and Fredericksburg continue to drive population increases. More rural localities in the basin such as Essex, Gloucester, and King and Queen Counties show significantly slower population increases over the planning period.

Projected Water Use: The following section discusses projected water use through 2040 within the York Mattaponi basin, based on projections provided in local and regional water supply plans. Table 89, included in the existing demand section above, is the basis for information discussed in this section.

Total demand within the basin is projected to increase from 13.44 MGD in 2020 to 26.15 MGD, or 94.5% by 2040. Increased demands are driven by rapid increases in CWS demands from groundwater sources, and increased domestic well use as populations increase throughout the basin. Surface water demand is projected to increase by 3.21 MGD, or 28.7% by 2040. Groundwater demand is projected to increase by 9.52 MGD, or 119.4% by 2040. Demand increases in the basin are primarily driven by increased demands from the Ni River WTP and Small SSU demands within Spotsylvania County.

Demand from CWS users within the basin is projected to increase in demand 171.24% by 2040. Within this category, surface water use is projected to increase by 84.0%, while groundwater use is projected to increase by 343.6%. The primary driver of the increase in surface water demands in the category are from increased demands from the Ni River Reservoir WTP to meet growing public water supply demands. Groundwater demands in the category are projected to increase significantly over the planning period primarily driven by the Sydnor Braxton Landing and King William County Central Garage, and Caroline County Utilities systems.

Demand from Large SSUs within the basin is projected to decrease in demand by 34.2% by 2040. Within this category, surface water use is projected to decrease by 49.0%, while groundwater use is projected to increase by 39.7%. Surface water demands are primarily driven by decreases in demand by the Fawn Lake Country

Club. Groundwater demands are primarily driven by increased demands from the Dominion Ladysmith Power Generation facility.

Demand from Small SSUs within the basin is projected to increase 49.1% by 2040. As noted previously, Small SSU demand is entirely met with groundwater and represents domestic or residential well users. Demand increases in the category are primarily driven by significant projected increases in county-wide estimates within Spotsylvania County. Increases in demand align with projected increases in population over the planning period.

Demand from AG within the basin are projected to increase 8.2% by 2040. Within this category, surface water use is projected to increase by 8.3%, while groundwater use is projected to remain constant over the planning period. Demands in the category are primarily driven by increases from Broaddus Farms, Glenwood Farm, and the Enfield Sod Farm.

A.18.5 Cumulative Impact Analysis

The following section provides a brief summary of the Cumulative Impact Analysis (CIA) modeling results in the York Mattoponi Minor Basin. Discussion of these results will primarily be found in the Trends and Goals section of this appendix. However a brief overview of the VAHydro model and the scenarios and metrics is provided below.

The VAHydro surface water model simulates streamflow using inputs such as precipitation, climate, land use, and topography, combined with data on all known withdrawals and discharges, and operational rules of major hydrologic features such as reservoirs. Each minor basin is broken into smaller hydrologic subsections, or river segments. The model simulates the water balance on a daily basis for each individual river segment, with each downstream segment being affected by the cumulative impact of streamflow changes occurring in upstream segments. The following figures help analyze this cumulative impact within the York Mattoponi Minor Basin model results summarized by river segment. Note that this section is not intended to document in detail the methods and assumptions for the VAHydro model or for the scenarios and metrics discussed. More documentation of the model and assumptions can be found in Chapter 4.

The VAHydro surface water model was used to simulate streamflow under a variety of scenarios. Demand scenarios examine how streamflow is impacted under 2030 or 2040 demands as compared to current (2020) demands. Demands were calculated based on current and future demand information submitted through local and regional water supply plans. Climate change scenarios examine how streamflow is impacted when 2040 demands are simulated in conjunction with a range of precipitation and temperature conditions that may occur in the future due to changing climate (Dry, Median, Wet scenarios). Finally, the exempt user scenario examines impacts from users excluded, or exempt, from VWP permit requirements per Va. Code § 62.1-44.15:22 B. Exempt users were simulated at the maximum possible demand identified through a review of demand justification values commonly asserted by exempt users, including but not limited to VDH pump capacity, maximum pre-1989 withdrawal, and maximum intake capacity. In order to effectively manage surface water resources and address the uncertainty related to these demands, DEQ determined the most conservative, or maximum possible, demand should be evaluated in this scenario. However, DEQ does not agree that the maximum values used in this scenario represent an allocation for, or the expectation of, a future withdrawal of that volume; nor does DEQ concede that any particular exempt user is necessarily entitled to withdraw any particular maximum value used in this scenario. The methods and assumptions for each of these modeling scenarios are discussed in more detail in Chapter 4.

For each scenario described above, different metrics can be used to evaluate the simulated streamflow. A metric is a method for measuring or evaluating a given set of data; different metrics can be evaluated to answer different questions. Within this section the following metrics will be discussed: the lowest 30 day flow (L30), the lowest 90 day flow (L90), 7Q10, and overall change in flow. The L30 describes the lowest consecutive 30 day average daily streamflow over the simulation period. This metric is a representation of a short-term, or acute drought, and is a good metric for evaluating impacts to direct withdrawals without storage. Similarly the lowest 90 day flow represents the lowest consecutive 90 day average daily streamflow

over the simulation period. This would represent a prolonged drought and is often used to evaluate impacts to reservoirs. The 7Q10 is the lowest 7-day average flow that occurs (on average) once every 10 years. 7Q10 is generally used in the evaluations of in-stream beneficial uses such as waste assimilative capacity. Overall change in flow describes the net loss of water from the riverine system as a result of off-stream use not otherwise returned through point source discharges, or losses due to evapotranspiration. This metric is useful for evaluating impacts to aquatic life and is discussed in more detail in Chapter 4.

Demand Scenarios: 2020 demand or current demand, 2030 demand, and 2040 demand scenarios were simulated. The following series of figures compares the 2030 and 2040 demand scenarios to the current demand scenario. The change in flow depicted on each map is the change expected when comparing two scenarios - in this case future demands compared to current demands. Each page includes two figures comparing either the 2030 or 2040 demand scenario to current demand using the L30, L90, and 7Q10 metrics. This allows for comparisons of simulated impacts between the 2030 and 2040 demand scenarios. The scenarios and metrics are identified in the paragraph below and in the figure captions.

Figures 343 and 344 compare the lowest 30 day flow simulated with the current demand scenario with the lowest 30 day flow simulated in the 2030 and 2040 demand scenarios respectively. Figures 345 and 346 compare the lowest 90 day low flow simulated with the current demand scenario with the lowest 90 day flow simulated in the 2030 and 2040 demand scenarios respectively. Figures 347 and 348 compare the 7Q10 simulated with the current demand scenario with the 7Q10 simulated in the 2030 and 2040 demand scenarios respectively.

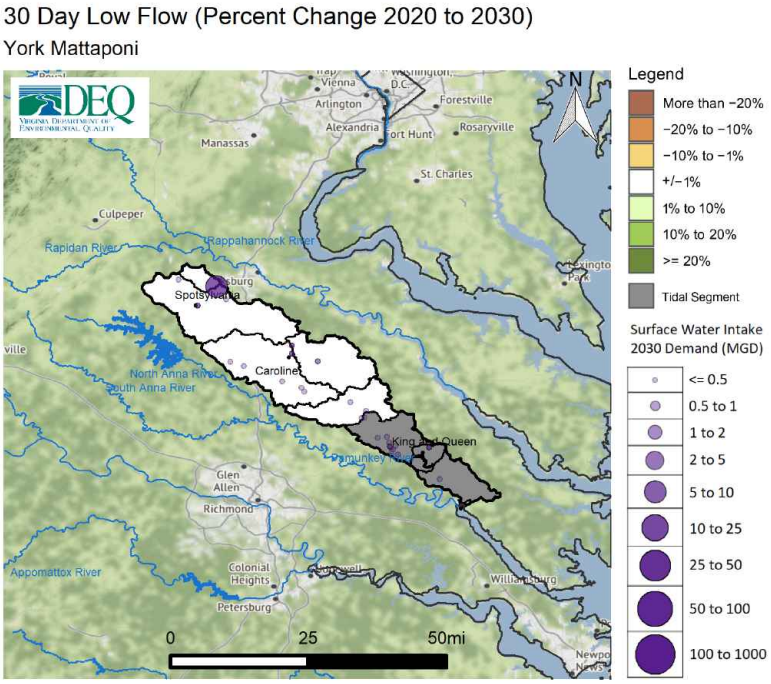

Figure 343: Change in 30 day low flow between 2020 and 2030 demand scenarios within the York Mattaponi Minor Basin

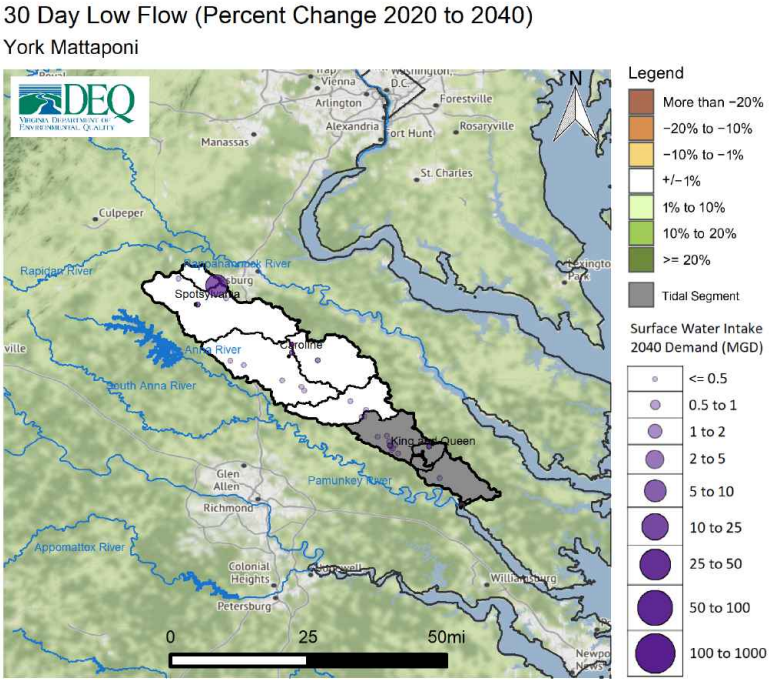

Figure 344: Change in 30 day low flow between 2020 and 2040 demand scenarios within the York Mattaponi Minor Basin

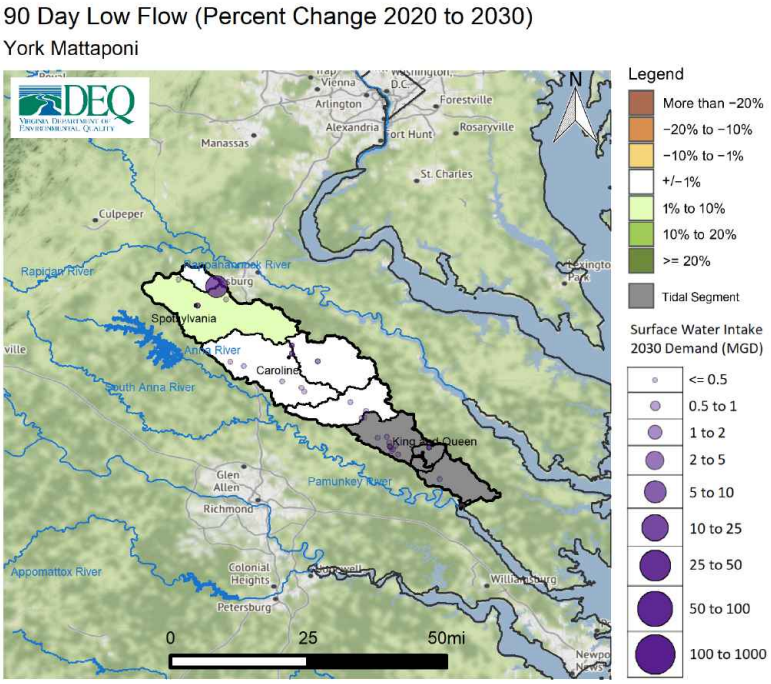

Figure 345: Change in 90 day low flow between 2020 and 2030 demand scenarios within the York Mattaponi Minor Basin

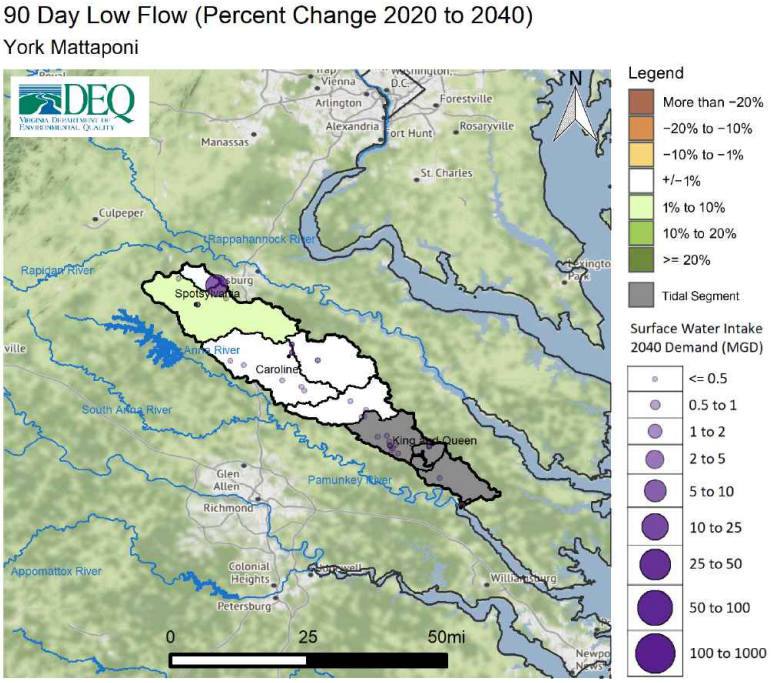

Figure 346: Change in 90 day low flow between 2020 and 2040 demand scenarios within the York Mattaponi Minor Basin

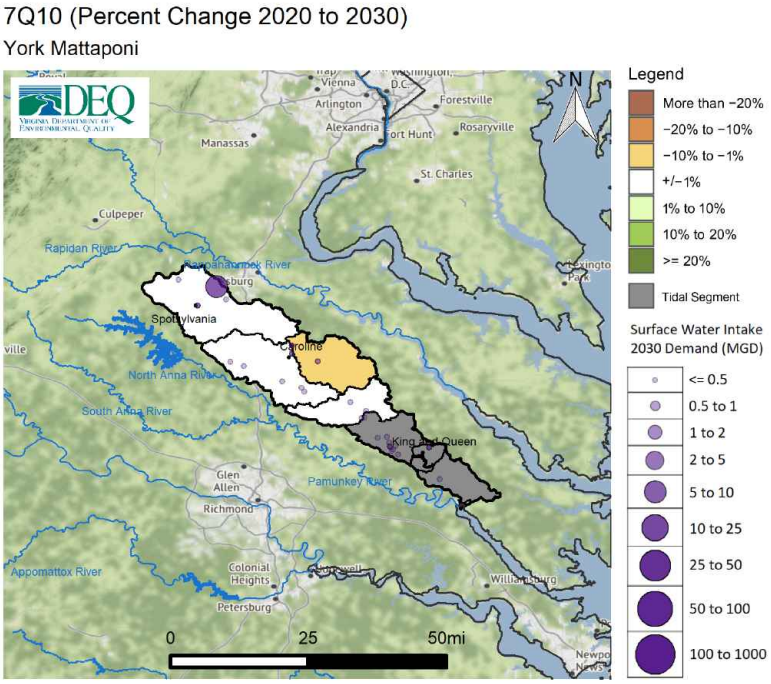

Figure 347: Change in 7Q10 between 2020 and 2030 demand scenarios within the York Mattaponi Minor Basin

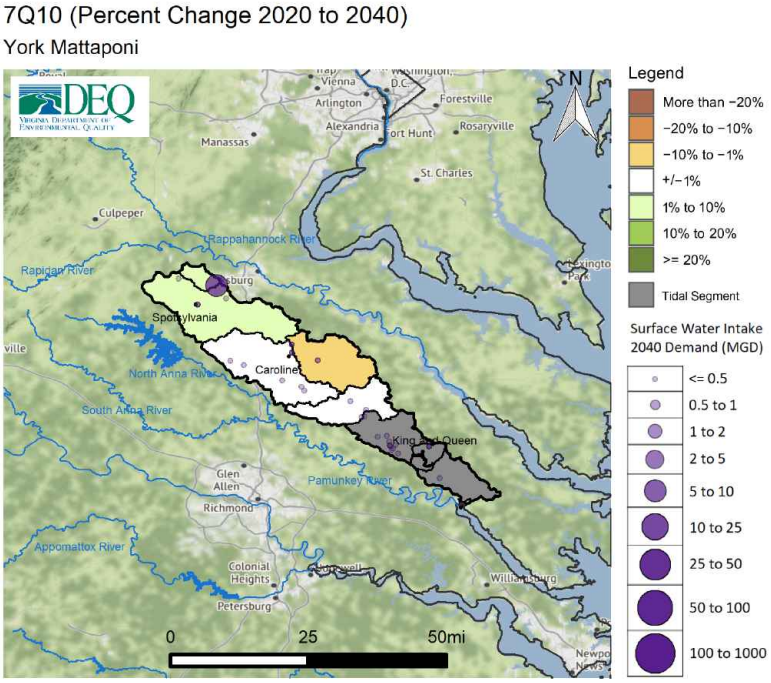

Figure 348: Change in 7Q10 between 2020 and 2040 demand scenarios within the York Mattaponi Minor Basin

The figures above show a comparison between two scenarios. An additional way to evaluate impacts to streamflow is to examine the total reduction in streamflow resulting from all withdrawals within a river segment, as well as losses due to evapotranspiration, while taking into consideration any discharges back to the source. To use a common industry term, the overall change in flow metric evaluates "consumptive use", or the amount of water removed from the river that is not returned through discharges. This can help describe potential impacts to downstream withdrawals, while also providing a basis for evaluating impacts to aquatic life. In general, total reductions in streamflow can result in a reduction in aquatic biodiversity [119]. The relationship between streamflow and aquatic biodiversity is discussed in more detail in Chapter 4. Figure 349 shows the overall change in streamflow for the 2030 Demand Scenario, while figure 350 shows the overall change in streamflow for the 2040 Demand Scenario.

[119] Rapp, J.L., R. Burgholzer, J. Kleiner, D. Scott, and E. Passero. 2020. "Application of a New Species-Richness Based Flow Ecology Framework for Assessing Flow Reduction Effects on Aquatic Communities." Journal of the American Water Resources Association 1–14.https://doi.org/10.1111/1752-1688.12877.

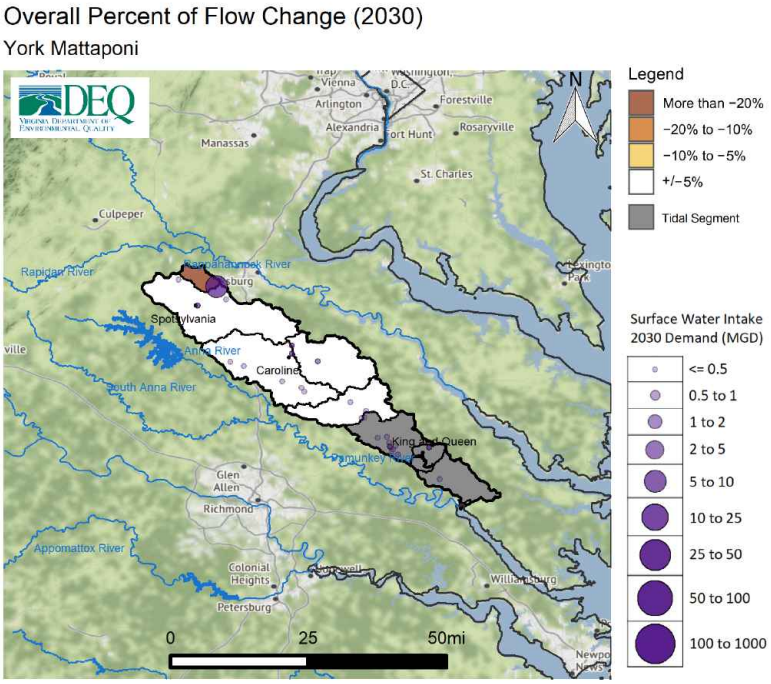

Figure 349: Overall change in flow in percent for 2030 demand scenario within the York Mattaponi Minor Basin

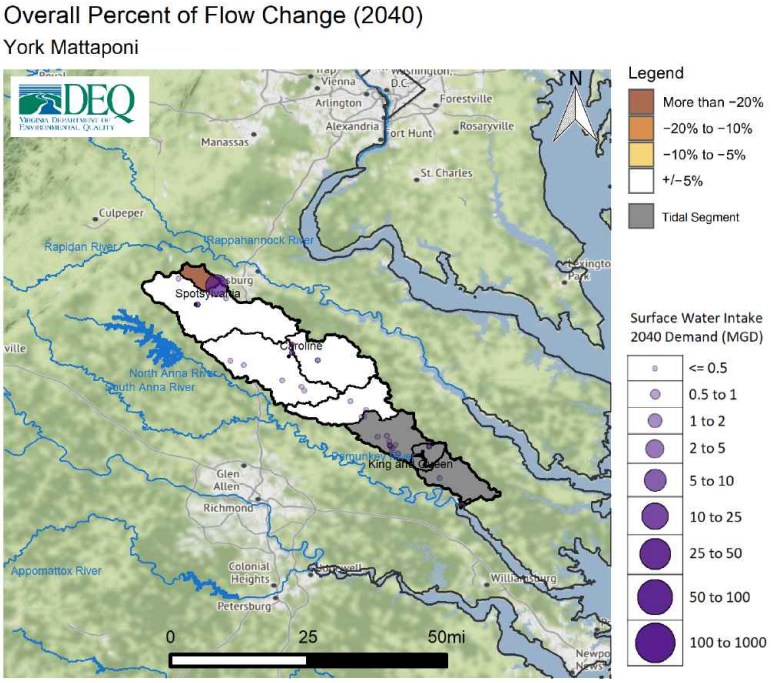

Figure 350: Overall change in flow in percent for 2040 demand scenario within the York Mattaponi Minor Basin

Climate Scenarios:Three scenarios that simulate impacts to streamflow in response to changes in temperature and climate were completed for areas in the state where climate data was available, which includes the portions of the Commonwealth located in the Chesapeake Bay watershed. Details on the methods and assumptions employed for these scenarios can be found in Appendix B. In short, the three scenarios can be described as dry, median, and wet scenarios. Virginia is expected to experience a range of precipitation and temperature changes that may vary spatially and from year to year. The potential for both more severe and prolonged droughts as well as for higher intensity and more frequent rain events must be considered. These three scenarios are not intended as predictions of future climate conditions, but as representations of several possibilities that climate change models indicate could occur. Should they occur, these results provide an evaluation of how streamflows may be impacted. Their purpose is to build upon existing climate modeling to provide a foundation for state and local government, as well as other stakeholders, to better evaluate what practical water resource challenges may be associated with the range of climate conditions Virginia could experience.

Figure 351 depicts the percent change in the L30 for the dry climate scenario in conjunction with 2040 demands, as compared to the current climate and demand scenario. Reductions in streamflow in this scenario may be caused by reduced precipitation, increased demand, or as is generally the case, a combination of both. Figures 352 and 353 depict the L30 for the median and wet climate scenarios (in conjunction with 2040 demands) as compared to the current climate and demand scenario.

Figure 354 depicts the percent change in the L90 for the dry climate scenario in conjunction with 2040 demands, as compared to the current climate and demand scenario. Figures 355 and 356 depict the L30 for the median and wet climate scenarios (in conjunction with 2040 demands) as compared to the current climate and demand scenario.

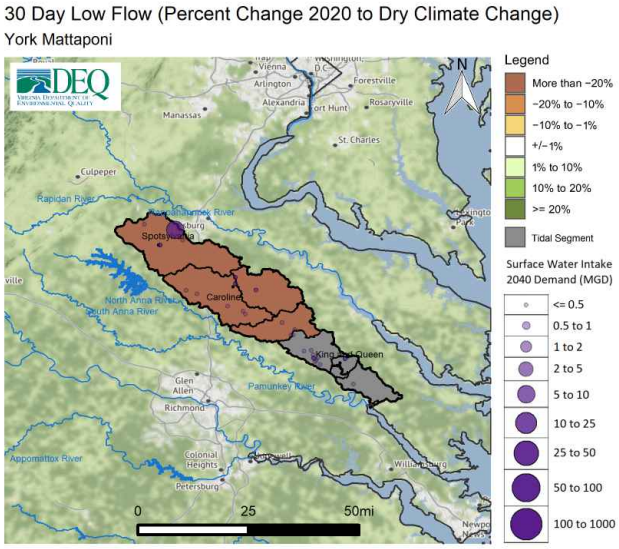

Figure 351: Change in 30 day low flow between current climate/demand scenario and the dry climate/2040 demand scenario within the York Mattaponi Minor Basin

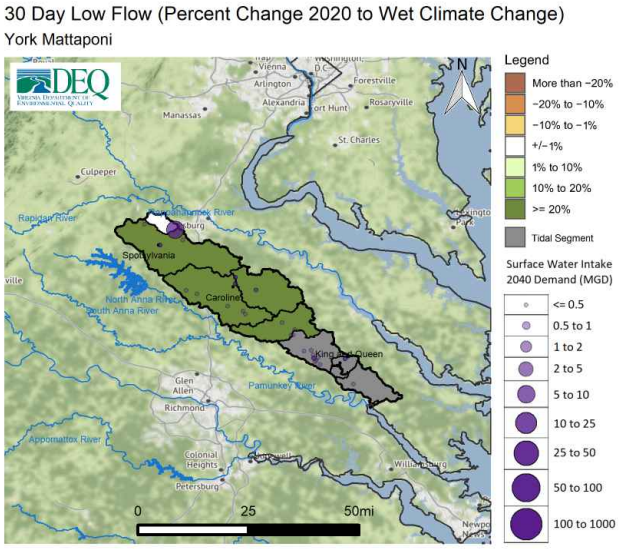

Figure 353: Change in 30 day low flow between current climate/demand scenario and the wet climate/2040 demand scenario within the York Mattaponi Minor Basin

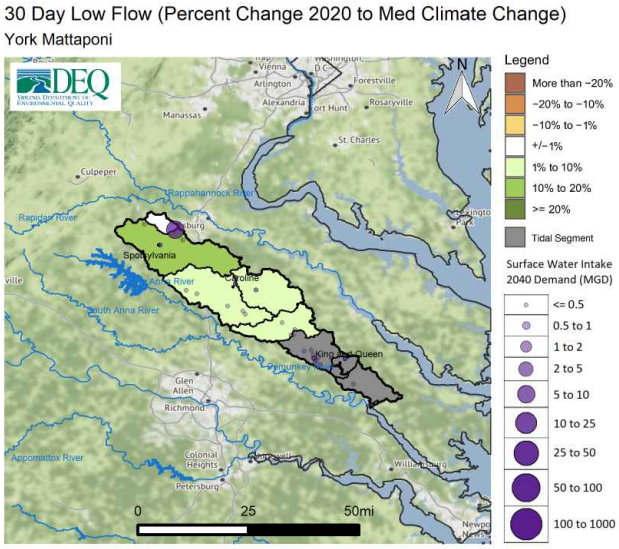

Figure 352: Change in 30 day low flow between current climate/demand scenario and the median climate/2040 demand scenario within the York Mattaponi Minor Basin

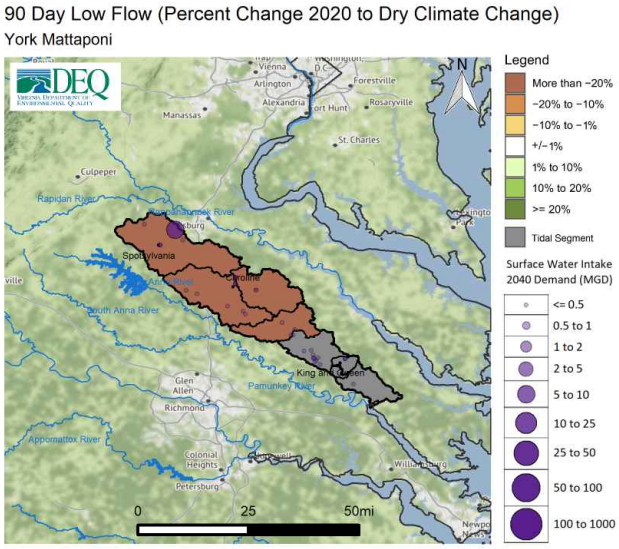

Figure 354: Change in 90 day low flow between current climate/demand scenario and the dry climate/2040 demand scenario within the York Mattaponi Minor Basin

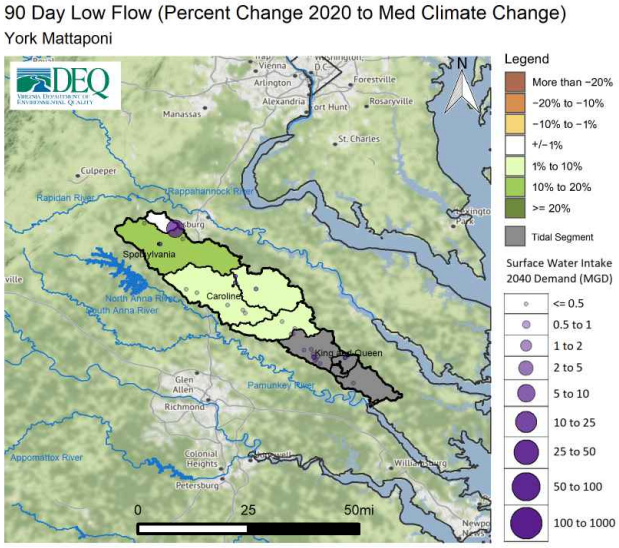

Figure 355: Change in 90 day low flow between current climate/demand scenario and median climate/2040 demand scenario within the York Mattaponi Minor Basin

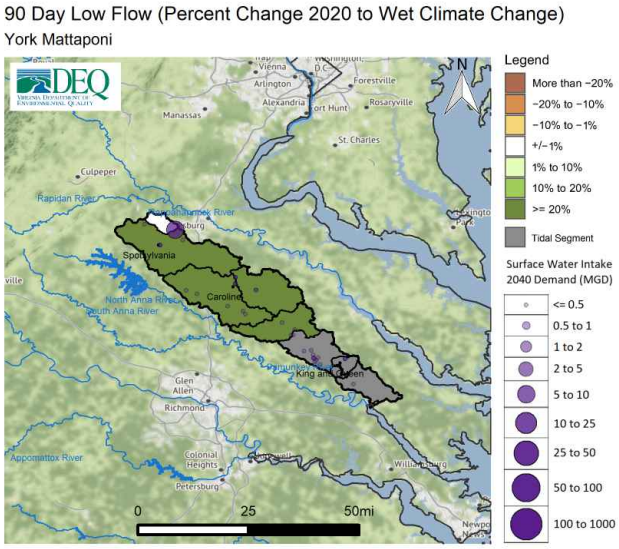

Figure 356: Change in 90 day low flow between current climate/demand scenario and wet climate/2040 demand scenario within the York Mattaponi Minor Basin

Exempt User Scenario: The exempt user scenario simulates the maximum possible exempt demand by users excluded from Virginia Water Protection permitting requirements per Va. Code § 62.1-44.15:22 B., in combination with the permitted withdrawal limits for those users that are permitted. A more detailed discussion of the data and assumptions used in this scenario can be found in Appendix B. Note that this scenario uses current climate conditions. Figure 357 depicts the percent change in the Lowest 30 Day Flow between the exempt user scenario and current (2020) demand. Figure 358 depicts the percent change in the Lowest 90 Day Flow between the exempt user scenario and current (2020) demand. Figure 359 depicts the percent change in the 7Q10 between the exempt user scenario and current (2020) demand. Finally, figure 360 depicts the overall change in flow in percent (consumptive use) for the exempt user scenario.

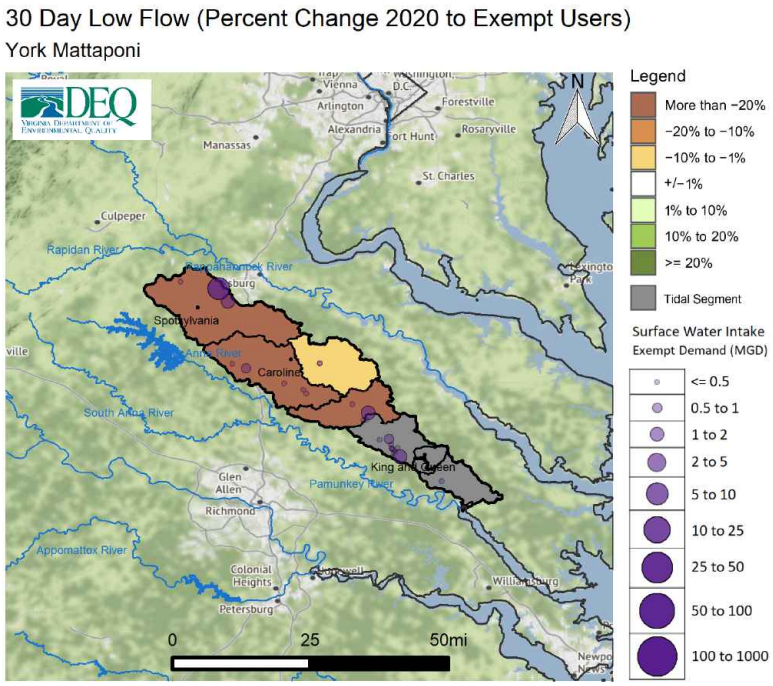

Figure 357: Change in 30 day low flow between current demand scenario and exempt user scenario within the York Mattaponi Minor Basin

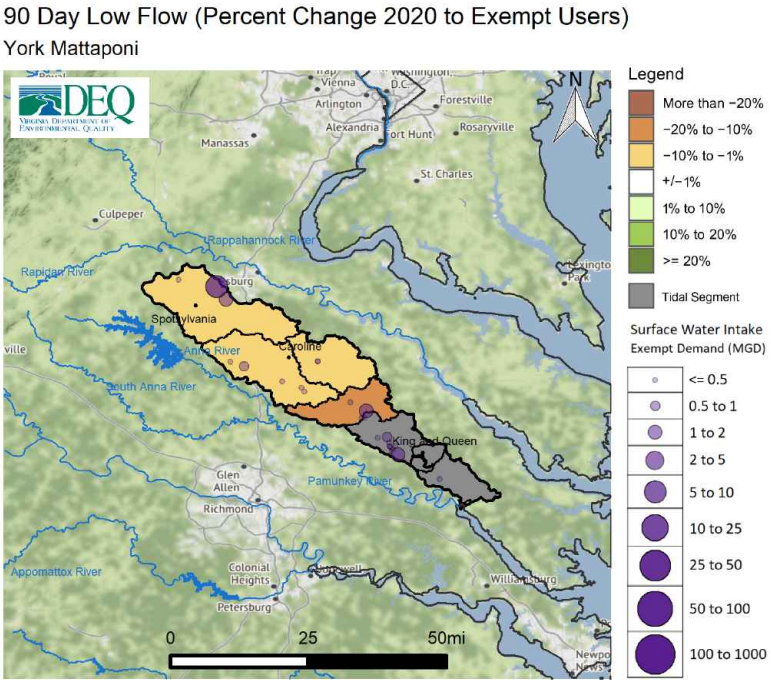

Figure 358: Change in 90 day low flow between current demand scenario and exempt user scenario within the York Mattaponi Minor Basin

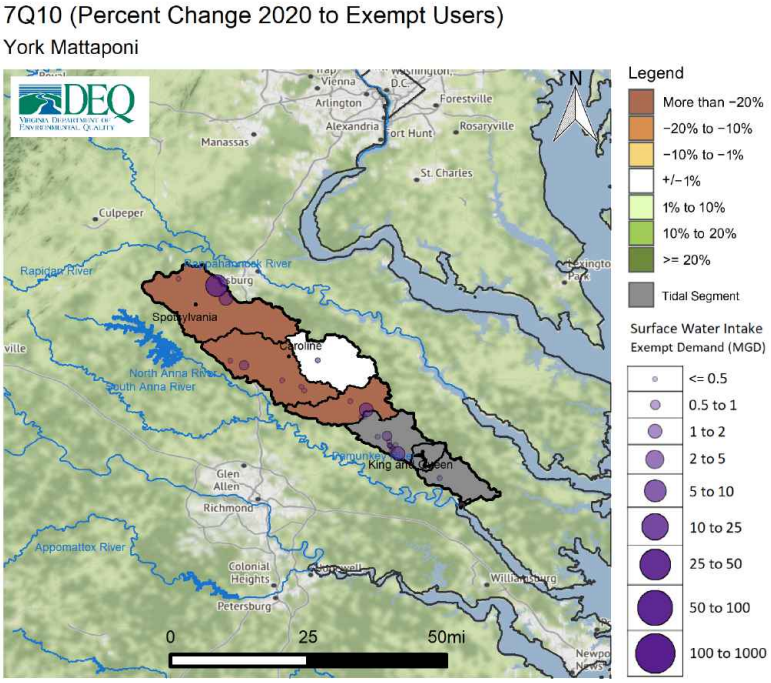

Figure 359: Change in 7Q10 between current demand scenario and exempt user scenario within the York Mattaponi Minor Basin

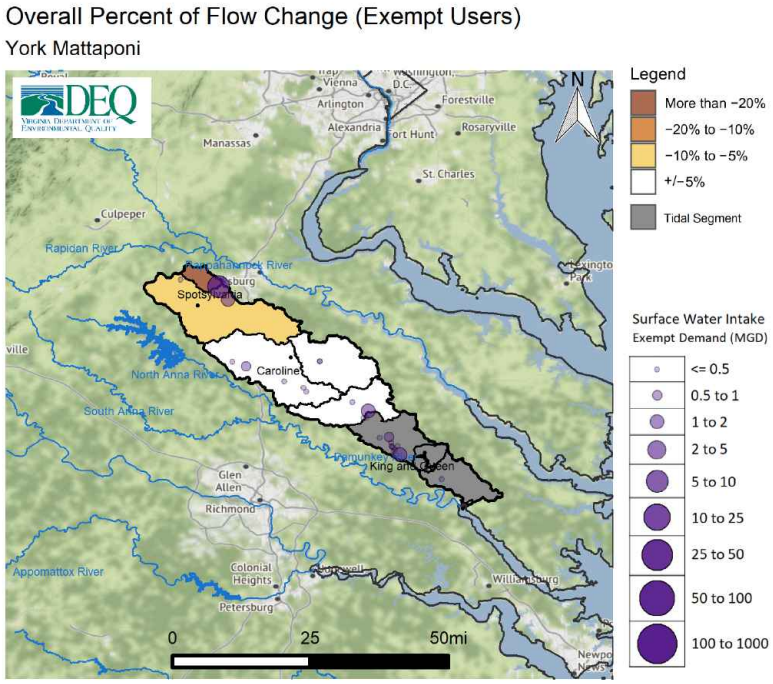

Figure 360: Overall change in flow in percent for exempt user scenario within the York Mattaponi Minor Basin

Potential Unmet Demand: Potential unmet demand was evaluated for all facilities within the basin for each scenario. Potential unmet demand is the portion of surface water demand for a specific facility that is limited by available streamflow as simulated in a given model scenario, including any known operational limits such as flow-by requirements. This unmet demand, if realized, could be managed through water conservation, through alternative sources, operational changes, or from available storage. Absent of these or other options, this portion of demand could remain unmet. As with all scenarios, demand requirements were determined using demand projections provided in the water supply plans. In the case of the exempt user scenario, the highest possible withdrawal amount was used for users exempt from VWP permitting requirements.

This metric is useful for evaluating where the results seen in the above figures may result in challenges in meeting future demands under a variety of conditions including increasing demands in the basin, changing climate, or withdrawals from users exempt from permitting requirements. Table 91 provides for each facility the highest average daily potential unmet demand over a 30 day period over the course of the simulation for the following scenarios: 2020 demand, 2030 demand, 2040 demand, dry climate, and exempt User. Only facilities showing potential unmet demand in at least one scenario appear on this table. The dry climate scenario is selected among the climate scenarios as the dry scenario represents the potential for increased drought intensity and frequency, and therefore poses the greatest challenge for water supply. Additional information on the potential unmet demand metric can be found in Appendix B.

Table 91: Change in Highest 30 Day Potential Unmet Demand (MGD) in York Mattaponi Minor Basin

Facility	**2020 Demand**	**2030 Demand**	**2040 Demand**	**Dry Climate**	**Exempt User**
Ni River WTP	0.00	5.93	7.76	7.87	8.05
Lake Caroline	0.00	0.00	0.00	0.00	0.58
Spotsylvania Quarry	0.00	0.00	0.00	0.00	0.01
Broaddus Farms	0.00	0.01	0.02	0.00	0.00

* Climate scenarios were not completed in areas located outside of the Chesapeake Bay Basin

Note: Potential unmet demand is the portion of surface water demand for a specific facility that is limited by available streamflow as simulated in a given model scenario, including any known operational limits such as flow-by requirements. This unmet demand, if realized, could be managed through water conservation, alternative sources, operational changes, or from available storage.

A.18.6 Spatial Overview of Groundwater Demands

The cumulative impact analysis figures above provide an overview of surface water demands in the basin but did not include groundwater demands. Figure 361 identifies the location and size of projected groundwater demands in the basin for 2040 based on information provided by localities in water supply plans.

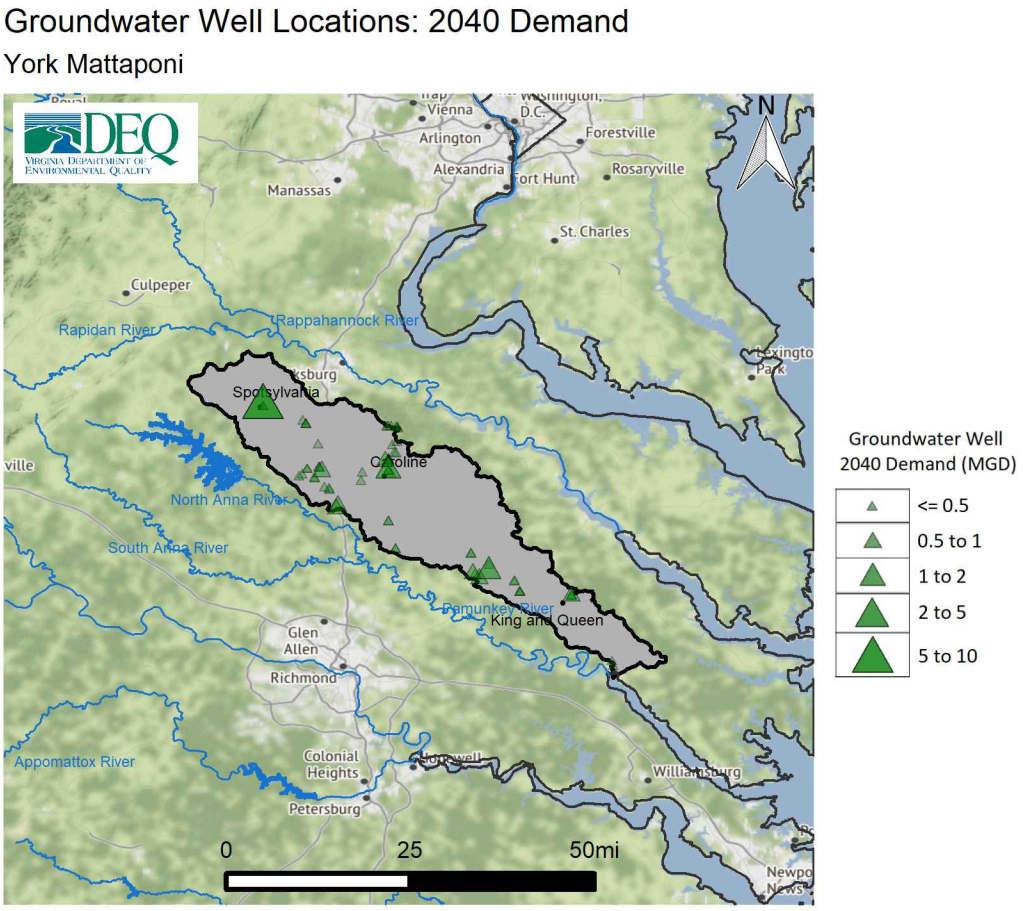

Figure 361: Projected 2040 Groundwater Demands in the York Mattaponi Minor Basin

A.18.7 Trends and Goals

The Code of Virginia mandates that the State Water Control Board should take into consideration the principle that "adequate and safe supplies shall be preserved and protected for human consumption, while conserving maximum supplies for other beneficial uses".[120] This principle is the key driver of the challenges in water resource management, which is that all beneficial uses must be adequately considered when evaluating impacts to surface water resources. The State Water Control Board is tasked with ensuring that water supply quantity needs are met at all times while also protecting Virginia's natural resources, and furthermore, ensuring equitable allocation during a time of shortage.[121] While evaluating and planning for the long-term sustainability of water supply for Virginia is the primary goal for the State Plan, evaluating and limiting impacts to in-stream beneficial uses such as aquatic habitat life is also part of DEQ's responsibility.

The primary purpose of this section is to identify where the most significant challenges to long-term sustainability of water supply and other beneficial uses are indicated based on the CIA and information collated from local water supply plans within this basin. Goals for future planning and areas for additional data collection or analysis are also suggested where appropriate.

The CIAs were completed using the best available data and methods known to DEQ. This discussion focuses on the evaluation of trends - in other words the prevailing tendency or inclination. This means evaluating whether streamflow is simulated to increase or decrease in a given scenario, and by how much. A relative trend indicating reductions of greater than or equal to 10% in streamflow, whether driven by demand increases, changing climate conditions, or exempt user demands was considered a threshold for potential impacts to beneficial uses. The following summarize the key trends or goals for this basin:

- **Demand Scenario:** Demands within the York Mattaponi are projected to increase by approximately 94% through the planning period. Demand increases are driven by CWS and private individual well owners reliant on groundwater. The majority of demand increases are projected to occur from increases from the Ni River WTP and cumulative withdrawals from increased development of individual homeowner wells in Spotsylvania County. When comparing the 2020 and 2040 demand scenarios, no streamflow reductions of more than 10% were simulated within the basin for the long-term drought (L90), short-term drought (L30), or 7Q10 metrics. While none of the drought metrics show reductions of 10% or greater, overall percent of flow change or consumptive use impacts of more than 20% occur within one river segment. Withdrawals from the Ni River Reservoir in Spotsylvania County show consumptive use over 40% in the 2040 demand scenario. Current withdrawals from the Ni Reservoir by Spotsylvania County are not regulated through a VWP permit, with no regulated release downstream of the reservoir. Unmet demands are projected to occur for the Ni River WTP as a result of significant demand increases with more than 7 MGD of unmet demands projected to occur by 2040 due to reservoir draw down in the simulations.

- **Climate Change Scenario:** Current climate modeling suggests Virginia will generally receive more precipitation on average in the future. However, the data also suggests the possibility of more severe droughts despite this overall trend of increasing precipitation. The dry climate scenario simulates significant reductions in streamflow of more than 20% for more than half the basin for both the short-term (L30) and long-term drought (L90) metrics. This would result in broad impacts to aquatic life and other beneficial uses including public water supplies. The potential for more severe droughts must be considered by localities and users when evaluating existing sources and alternatives, as well as for broader planning and resource management efforts by all stakeholders whether state or local.

- **Exempt User Scenario:** The exempt user scenario, which models the maximum exempt demand from all users exempt from VWP permitting requirements, shows reductions in streamflow during for

[120] § 62.1-44.36 of the Code of Virginia
[121] 9VAC25-390-20.1

the short-term drought (L30), long-term drought (L90), and 7Q10 for several segments including the Mattaponi River and tributaries. The maximum exempt demands from the Ni River Reservoir are the primary driver in simulated streamflow reductions in the basin. The maximum exempt demand from irrigation, mining, and commercial facilities in the basin also contribute to streamflow reductions and the potential for unmet demands to occur. In the exempt scenario, the greatest unmet demands were simulated for the Ni River Reservoir and Lake Caroline, which are simulated to have unmet demands of 8.05 MGD and 0.58 MGD respectively. These results indicate that the cumulative maximum exempt demands in the basin may exceed the water budget in many river segments within the basin. Preserving water supply and other beneficial uses will require managing these demands with respect to their cumulative impacts and in the context of the available resources in the basin.

- **Coastal Plain Groundwater Demand Scenarios:** Much of the York Mattaponi Minor Basin is characterized by limited fresh surface water availability from tidal streams and rivers in the basin. In these areas of the basin much of the water demands are met through groundwater withdrawals from confined aquifers in Caroline, Essex, Gloucester, King and Queen, and King William counties. The VA Hydro Virginia Coastal Plain Groundwater Model was used for cumulative impact analysis of 2020 and 2040 demand scenarios. The results of these simulations are covered in detail in a number of figures provided in subsection 4.3.3. These results inform this discussion. With respect to the York Mattaponi Minor Basin, the following are the key trends. In the 2020 demand scenario, water levels in the Potomac Aquifer are expected to recover gradually from 2020 to 2050 before declining marginally through 2070. However, in the 2040 demand scenario, due to significant increases in domestic (Small SSU) combined with permitted demands, water levels continue to fall from 2020 through 2070. In the 2040 scenario, critical cells are simulated in the Potomac Aquifer in Caroline County along the fall-line, and in the eastern edge of King William County. A significant number of critical cells are simulated in the Aquia Aquifer in Caroline County and King William County in both the 2020 and 2040 demand scenarios; however the Aquia Aquifer is not generally a major source in this area. Critical cells are also simulated in the Piney Point Aquifer in King William, Caroline, and King and Queen counties in the 2020 and 2040 demand scenarios results. The 2040 scenario results, when compared to the 2020 scenarios, indicates increases in the number and extent of critical cells with impacts expanding further from the fall-line. These results suggest that for each of the three aquifers discussed, the potential for challenges in permitting withdrawals exists even in the 2020 demand scenario as simulated, particularly in portions of Caroline County. The 2040 demand scenario simulation expands the areal extent of where such challenges may occur. The greatest groundwater demands in the basin are from cumulative withdrawals of domestic wells and CWS and Large SSU systems in Caroline and King and Queen counties. Major municipal suppliers including Caroline County's Central Garage, Town of Bowling Green, and the Town of West Point Water System, all of which depend on groundwater from confined aquifers as their primary water supply source. Westrock's West Point Paper Mill also relies on groundwater for its production water. While reductions in permitted withdrawals have been made in recent years, impacts from private domestic wells (Small SSUs) continue to show rapid demand increases over the planning period. These simulations indicate that even as permitted demands from large facilities have decreased, projected domestic increases as estimated could off-set those reductions. This underscores the importance of continuing to evaluate and pursue alternative sources, interconnection opportunities, and more robust conservation for groundwater users in this basin.

A.19 York Pamunkey Minor Basin

A.19.1 Watershed Overview

The York River is formed at the confluence of the Pamunkey and Mattaponi rivers. The Pamunkey River's major tributaries are the North and South Anna rivers and the Little River. Both the Pamunkey and Mattaponi rivers flow through the Piedmont and Coastal Plain provinces, and are characterized by slight rolling hills at the headwaters and flatter areas dominated by farmland moving into the tidal portions. Cropland/pasture and forest make up the majority of land-use in the basin, with increasing urban development nearing urban centers such as the cities of Richmond and Fredericksburg. The total spatial area of this minor basin occupies 1,444.86 sq. miles and includes all or portions of the localities listed in Table 92. This basin is primarily rural but does include suburban areas of the cities of Richmond, Charlottesville, and Fredericksburg.

A.19.2 Existing Water Sources

Major surface water sources within the basin include Lake Anna, the North Anna River, the South Anna River, and the Pamunkey River. Groundwater within the basin is primarily withdrawn from bedrock aquifers in areas west of the fall-line and from confined aquifers in the coastal plain portion east of the fall-line. The Potomac, Aquia, and Piney Point aquifers are all present in this basin in the area east of the fall-line, although the Potomac Aquifer remains the major source for groundwater withdrawals.

Withdrawals within the basin are used for public water supply as well as for power generation, agriculture, irrigation, commercial, and industrial/manufacturing

The location of wells and surface water intakes identified to DEQ within the basin are shown in Figure 362. This figure does not include private or domestic wells. This map also shows locations of any Instream Flow Incremental Method (IFIM) studies completed in the basin. Surface water withdrawals in this basin are primarily located above the fall line while the distribution of groundwater withdrawals increases below the fall line.

Table 92: Population Trend by Locality in York Pamunkey Basin

Localities	20 Year % Change
Albemarle	24.72
Caroline	24.83
Fluvanna	22.74
Goochland	25.07
Hanover	16.94
King and Queen	1.02
King William	19.85
Louisa	26.67
New Kent	37.48
Orange	25.12
Spotsylvania	30.24

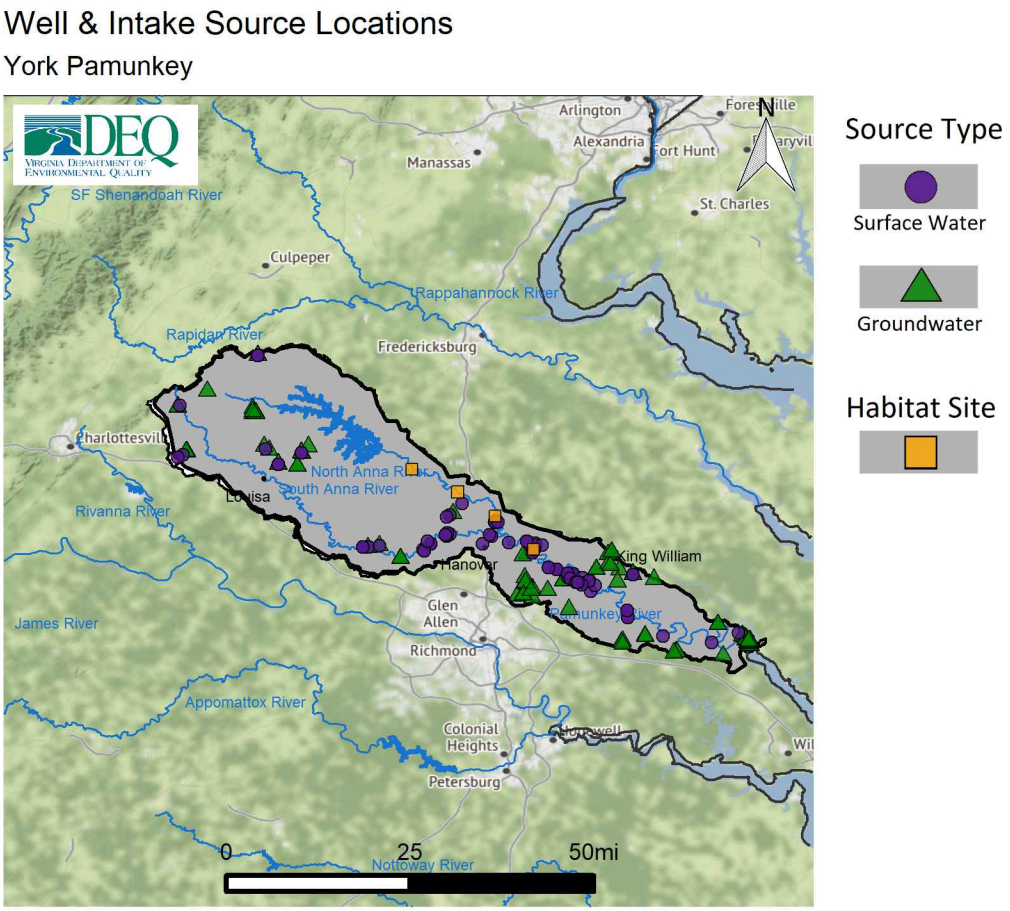

Figure 362: Spatial distribution of groundwater wells and intakes in the York Pamunkey Minor Basin

A.19.3 Existing Water Use

The following section discusses existing (current) water use within the basin, which is based on existing demand information submitted to DEQ in the water supply plans. Table 93 provides a summary of all demands within the basin by system type and source type including power generation. It also provides a count of surface water or groundwater sources associated with each system type. Note that withdrawals related to power generation generally greatly exceed other demand categories and can therefore make evaluating trends for other categories more challenging. Most power generation withdrawals are also largely non-consumptive; water is withdrawn for cooling purposes and then discharged back into the source stream with any loss typically due to evaporation. In this basin demands associated with the North Anna Nuclear Power Plant are significantly higher than the total of all other demands, but the majority of those withdrawals outside of those lost to evaporation are returned to Lake Anna. To ensure other categories of use are adequately represented, Table 94 excludes power generation and will be referenced throughout the following section.

Table 93: Summary of York Pamunkey Minor Basin Water Demand by Source Type and System Type (including Power Generation)

System Type	Source Count	2020 Demand (MGD)	2030 Demand (MGD)	2040 Demand (MGD)	20 Year Percent Change
Surface Water					
Agriculture	73	3.01	3.14	3.26	8.45
CWS	1	3.65	5.74	7.84	114.80
Large SSU	23	1834.61	2209.35	2584.10	40.85
Small SSU	N/A	0.00	0.00	0.00	0.00
Total SW	**97**	**1841.27**	**2218.23**	**2595.20**	**40.95**
Groundwater					
Agriculture	4	0.11	0.11	0.11	-2.69
CWS	101	0.57	1.54	2.52	345.32
Large SSU	32	14.69	14.75	14.81	0.84
Small SSU	N/A	4.57	6.00	7.43	62.39
Total GW	**137**	**19.94**	**22.40**	**24.87**	**24.72**
Total (SW + GW)					
Agriculture	77	3.12	3.25	3.37	8.05
CWS	102	4.21	7.29	10.36	145.79
Large SSU	55	1849.30	2224.10	2598.91	40.54
Small SSU	N/A	4.57	6.00	7.43	62.39
Minor Basin Total	**234**	**1861.20**	**2240.64**	**2620.07**	**40.77**

* Small SSU demands are county-wide estimates of private well usage below 300,000 gallons a month. The number of private wells is not known.

Table 94: Summary of York Pamunkey Minor Basin Water Demand by Source Type and System Type (excluding Power Generation)

System Type	Source Count	2020 Demand (MGD)	2030 Demand (MGD)	2040 Demand (MGD)	20 Year Percent Change
Surface Water					
Agriculture	73	3.01	3.14	3.26	8.45
CWS	1	3.65	5.74	7.84	114.80
Large SSU	18	2.46	2.47	2.47	0.53
Small SSU	N/A	0.00	0.00	0.00	0.00
Total SW	**92**	**9.12**	**11.35**	**13.57**	**48.79**
Groundwater					
Agriculture	4	0.11	0.11	0.11	-2.69
CWS	101	0.57	1.54	2.52	345.32
Large SSU	27	14.68	14.74	14.80	0.81
Small SSU	N/A	4.57	6.00	7.43	62.39
Total GW	**132**	**19.93**	**22.39**	**24.86**	**24.74**
Total (SW + GW)					
Agriculture	77	3.12	3.25	3.37	8.05
CWS	102	4.21	7.29	10.36	145.79
Large SSU	45	17.14	17.20	17.27	0.77
Small SSU	N/A	4.57	6.00	7.43	62.39
Minor Basin Total	**224**	**29.04**	**33.74**	**38.43**	**32.33**

* Small SSU demands are county-wide estimates of private well usage below 300,000 gallons a month. The number of private wells is not known.

The total existing demand from all surface and groundwater sources excluding power generation is approximately 29.04 MGD, with groundwater supplying approximately 19.93 MGD or 69% of total water demands. Surface water demand within the basin totals approximately 9.12 MGD, or 31% of current demands. When excluding withdrawals from the North Anna Nuclear Power Plant, groundwater supplies the majority of the demands in this basin because much of the basin is located where the majority of surface water is tidal and high in salinity.

The five largest facility demands for each source type including power generation are provided in Table 95. The five largest facility demands for each source type excluding power generation are provided in Table 96. The largest groundwater demands include Westrock's West Point Mill Water System, which is one of the largest permitted groundwater withdrawals in the state, as well as Avondale Robin Ridge, New Kent County's Route 33 Corridor Water System, Sydnor's Braxton's Landing WTP, and King William County's Central Garage. West Point's West Point Mill is projected to make up 55% of all estimated 2040 groundwater demands in the basin. The largest surface water demands include the North Anna Nuclear Power Plant as well as Hanover County's Doswell WTP.

Table 95: Top 5 Users in 2040 by Source Type in the York Pamunkey Minor Basin (including Power Generation)

Facility Name	System Type	Locality	2020 Demand (MGD)	2030 Demand (MGD)	2040 Demand (MGD)	20 Year Percent Change	% of Total Surface Water
Surface Water							
North Anna Nuclear Power Plant	Large SSU	Louisa	1832.14	2206.89	2581.63	40.91	99.48
Doswell WTP	CWS	Hanover	3.58	5.64	7.7	115.08	0.3
Doswell Quarry	Large SSU	Hanover	1.01	1.01	1.01	0.00	0.04
Ashland Plant	Large SSU	Caroline	0.82	0.82	0.82	0.00	0.03
Kirby Farms Llc	AG	Hanover	0.42	0.42	0.42	0.00	0.02
Total SW			1837.97	2214.78	2591.58	41	99.86
Groundwater							**% of Total Groundwater**
West Point Mill Water System	Large SSU	King William	14.51	14.51	14.51	0.00	58.34
King William County - Central Garage Water System	CWS	King William	0.02	0.24	0.46	2200	1.85
Venter Heights Water System	CWS	King William	0.02	0.2	0.37	1750	1.49
Route 33 Corridor Water System	CWS	New Kent	0.05	0.16	0.27	440	1.09
Avondale Robin Ridge	Large SSU	Hanover	0.09	0.12	0.16	77.78	0.64
Total GW			14.69	15.23	15.77	7.35	63.41

Table 96: Top 5 Users in 2040 by Source Type in the York Pamunkey Minor Basin (excluding Power Generation)

Facility Name	System Type	Locality	2020 Demand (MGD)	2030 Demand (MGD)	2040 Demand (MGD)	20 Year Percent Change	% of Total Surface Water
Surface Water							
Doswell WTP	CWS	Hanover	3.58	5.64	7.7	115.08	56.74
Doswell Quarry	Large SSU	Hanover	1.01	1.01	1.01	0.00	7.44
Ashland Plant	Large SSU	Caroline	0.82	0.82	0.82	0.00	6.04
Kirby Farms Llc	AG	Hanover	0.42	0.42	0.42	0.00	3.1
North Wales Farm	AG	Caroline	0.3	0.35	0.4	33.33	2.95
Total SW			6.13	8.24	10.35	68.84	76.27
Groundwater							**% of Total Groundwater**
West Point Mill Water System	Large SSU	King William	14.51	14.51	14.51	0.00	58.37
King William County - Central Garage Water System	CWS	King William	0.02	0.24	0.46	2200	1.85
Venter Heights Water System	CWS	King William	0.02	0.2	0.37	1750	1.49
Route 33 Corridor Water System	CWS	New Kent	0.05	0.16	0.27	440	1.09
Avondale Robin Ridge	Large SSU	Hanover	0.09	0.12	0.16	77.78	0.64
Total GW			14.69	15.23	15.77	7.35	63.44

Table 94 also provides the proportion of each use category that is supplied by either surface water or groundwater. Use categories include Community Water System (CWS), Large Self-Supplied User (Large SSU), Small Self-Supplied User (Small SSU), and Agricultural Self-Supplied User (AG). These categories are defined below. Surface water demand is primarily comprised of Large SSUs (the North Anna Nuclear Power Plant), CWS facilities, and AG. Groundwater demand is primarily comprised of Large SSUs such as WestRock's West Point Mill, CWS facilities, and Small SSUs.

The CWS category includes any public and private waterworks that serve at least 15 service connections used by year-round residents or regularly serve at least 25 year-round residents, and are regulated under the Virginia Department of Health Waterworks Regulation (12VAC5-590). In the York Pamunkey Minor Basin, approximately 0.57 MGD of groundwater demand and 3.65 MGD of surface water demand is from CWS. Significant groundwater users within this category include Braxton's Landing, King William County's Central Garage System and Venter Heights Water System, as well as New Kent County's Route 33 Corridor Water System. Significant surface water users from this category include Hanover County's Doswell WTP.

Large SSUs include any non-CWS or AG who withdraw more than 300,000 gallons per month from a well or surface water intake. In the York Pamunkey Minor Basin, approximately 14.69 MGD of groundwater demand and 1834.61 MGD of surface water demand (including North Anna Nuclear Power Plant) is from Large SSUs. Westrock's West Point Mill makes up nearly all Large SSU groundwater demands, while the North Anna Nuclear Power makes up the majority of surface water demands in the category. Other significant surface water users from this category include the Doswell Quarry and Bear Island Ashland Plant.

Small SSUs include any users who withdraw less than 300,000 gallons per month from wells. Small SSU's generally consist of residential or domestic use for those who live outside service areas and provide their

own water. Small SSU demand is generally met with groundwater. In the York Pamunkey Minor Basin, approximately 4.57 MGD of groundwater demand is withdraw from Small SSU, with the greatest estimated demands from Louisa, Orange, and King William counties.

The AG category includes crop farms, livestock operations, aquaculture and other agricultural facilities. In the York Pamunkey Minor Basin, approximately 0.11 MGD of groundwater demand and 3.01 MGD of surface water demand is from AG. Significant groundwater users within this category include Pampatike Hill Farm, Ashland Berry Farm, and Hanover Farms. Significant surface water users from this category include North Wales Farm, Kirby Farms, and Spring Hill Farm.

A.19.4 Projected Population and Water Use

Projected Population: Trends in water use are generally driven by trends in population change or economic development. Increasing population within an area generally means increased connections for community water systems or additional groundwater demand from homeowners that construct wells. Increasing population in an area also tends to incentivize both new and expanded industrial and commercial water use.

Table 92 shows the projected change in population by percent between 2020 and 2040 for each locality located partly or wholly within this minor basin. New Kent, Louisa, Caroline, and Hanover counties are projected to increase in population significantly over the next twenty years. New Kent County is projected to grow at a rate faster than any other locality in the basin. King and Queen County is not projected to increase in population significantly in the next 20 years.

Projected Water Use: The following section discusses projected water use through 2040 within the York Pamunkey Minor Basin basin, based on projections provided in local and regional water supply plans. Table 93 included in the existing demand section above, is the basis for information discussed in this section.

Total demand within the basin is projected to increase by approximately 40.6% by 2040 when including power generation facilities. When excluding power generation, surface water demand is projected to increase by approximately 4.45 MGD, or 48.79% by 2040. Groundwater demand is projected to increase by 4.93 MGD, or approximately 24.7%, by 2040. The North Anna Nuclear Power Plant is the largest water user in the basin, and is responsible for over 700 MGD of the projected increases in water demand in the basin. Increases in total projected demand are primarily driven by increased surface water demands projected by Hanover County's Doswell WTP, and increased groundwater demand from CWS facilities in King William and New Kent counties, and from Small SSU demands.

Demand from CWS users within the basin is projected to increase by over 145.7% by 2040, with the major driver being a significant increase in demand from the Doswell WTP and groundwater demands from a number of CWS facilities. Within this category, surface water use is projected to increase by 114.8%, while groundwater use is projected to increase by over 345.3%. As noted earlier, several CWS facilities are projected to have significant groundwater demand increases between 2020 and 2040.

Demand from Large SSUs within the basin is not projected to increase by 2040, except at the North Anna Nuclear Power Plant, which projects significant demand increases associated with expansion of the plant to include Unit 3. No other significant demand increases are projected in the basin for Large SSU facilities.

Demand from Small SSUs within the basin is projected to increase by 62% by 2040, or approximately 2.86 MGD. As noted previously, Small SSU demand is entirely met with groundwater and represents domestic/private well use. King William, Orange, and Louisa counties are projected to comprise the majority of these demand increases. With significant increases in population throughout the basin expected, the projected increase in demands from Small SSUs align with population projections.

Demand from agriculture users within the basin is projected to increase by approximately 8% by 2040, with both surface water and groundwater demands projected to increase by 8%. Projected increases in AG demands are primarily comprised of county wide estimates for Orange and Louisa counties, as well as by individual farms.

A.19.5 Cumulative Impact Analysis

The following section provides a brief summary of the Cumulative Impact Analysis (CIA) modeling results in the York Pamunkey Minor Basin. Discussion of these results will primarily be found in the Trends and Goals section of this appendix. However a brief overview of the VAHydro model and the scenarios and metrics is provided below.

The VAHydro surface water model simulates streamflow using inputs such as precipitation, climate, land use, and topography, combined with data on all known withdrawals and discharges, and operational rules of major hydrologic features such as reservoirs. Each minor basin is broken into smaller hydrologic subsections, or river segments. The model simulates the water balance on a daily basis for each individual river segment, with each downstream segment being affected by the cumulative impact of streamflow changes occurring in upstream segments. The following figures help analyze this cumulative impact within the York Pamunkey Minor Basin model results summarized by river segment. Note that this section is not intended to document in detail the methods and assumptions for the VAHydro model or for the scenarios and metrics discussed. More documentation of the model and assumptions can be found in Chapter 4.

The VAHydro surface water model was used to simulate streamflow under a variety of scenarios. Demand scenarios examine how streamflow is impacted under 2030 or 2040 demands as compared to current (2020) demands. Demands were calculated based on current and future demand information submitted through local and regional water supply plans. Climate change scenarios examine how streamflow is impacted when 2040 demands are simulated in conjunction with a range of precipitation and temperature conditions that may occur in the future due to changing climate (Dry, Median, Wet scenarios). Finally, the exempt user scenario examines impacts from users excluded, or exempt, from VWP permit requirements per Va. Code § 62.1-44.15:22 B. Exempt users were simulated at the maximum possible demand identified through a review of demand justification values commonly asserted by exempt users, including but not limited to VDH pump capacity, maximum pre-1989 withdrawal, and maximum intake capacity. In order to effectively manage surface water resources and address the uncertainty related to these demands, DEQ determined the most conservative, or maximum possible, demand should be evaluated in this scenario. However, DEQ does not agree that the maximum values used in this scenario represent an allocation for, or the expectation of, a future withdrawal of that volume; nor does DEQ concede that any particular exempt user is necessarily entitled to withdraw any particular maximum value used in this scenario. The methods and assumptions for each of these modeling scenarios are discussed in more detail in Chapter 4.

For each scenario described above, different metrics can be used to evaluate the simulated streamflow. A metric is a method for measuring or evaluating a given set of data; different metrics can be evaluated to answer different questions. Within this section the following metrics will be discussed: the lowest 30 day flow (L30), the lowest 90 day flow (L90), 7Q10, and overall change in flow. The L30 describes the lowest consecutive 30 day average daily streamflow over the simulation period. This metric is a representation of a short-term, or acute drought, and is a good metric for evaluating impacts to direct withdrawals without storage. Similarly, the lowest 90 day flow represents the lowest consecutive 90 day average daily streamflow over the simulation period. This would represent a prolonged drought and is often used to evaluate impacts to reservoirs. The 7Q10 is the lowest 7-day average flow that occurs (on average) once every 10 years. 7Q10 is generally used in the evaluations of in-stream beneficial uses such as waste assimilative capacity. Overall change in flow describes the net loss of water from the riverine system as a result of off-stream use not otherwise returned through point source discharges, or losses due to evapotranspiration. This metric is useful for evaluating impacts to aquatic life and is discussed in more detail in Chapter 4.

Demand Scenarios: 2020 demand or current demand, 2030 demand, and 2040 demand scenarios were simulated. The following series of figures compares the 2030 and 2040 demand scenarios to the current demand scenario. The change in flow depicted on each map is the change expected when comparing two scenarios - in this case future demands compared to current demands. Each page includes two figures comparing either the 2030 or 2040 demand scenario to current demand using the L30, L90, and 7Q10 metrics. This allows for comparisons of simulated impacts between the 2030 and 2040 demand scenarios. The scenarios and metrics are identified in the paragraph below and in the figure captions.

Figures 363 and 364 compare the lowest 30 day flow simulated with the current demand scenario with the lowest 30 day flow simulated in the 2030 and 2040 demand scenarios respectively. Figures 365 and 366 compare the lowest 90 day low flow simulated with the current demand scenario with the lowest 90 day flow simulated in the 2030 and 2040 demand scenarios respectively. Figures 367 and 368 compare the 7Q10 simulated with the current demand scenario with the 7Q10 simulated in the 2030 and 2040 demand scenarios respectively.

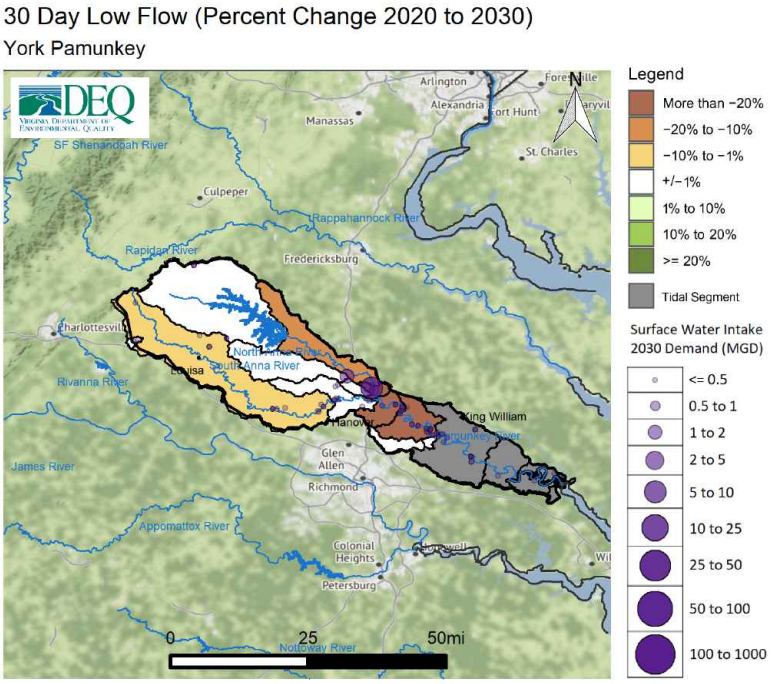

Figure 363: Change in 30 day low flow between 2020 and 2030 demand scenarios within the York Pamunkey Minor Basin

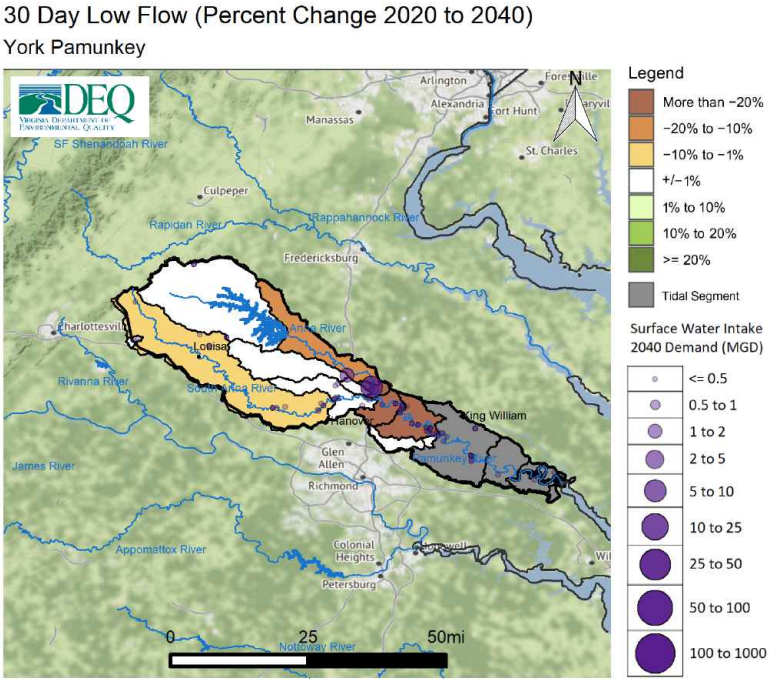

Figure 364: Change in 30 day low flow between 2020 and 2040 demand scenarios within the York Pamunkey Minor Basin

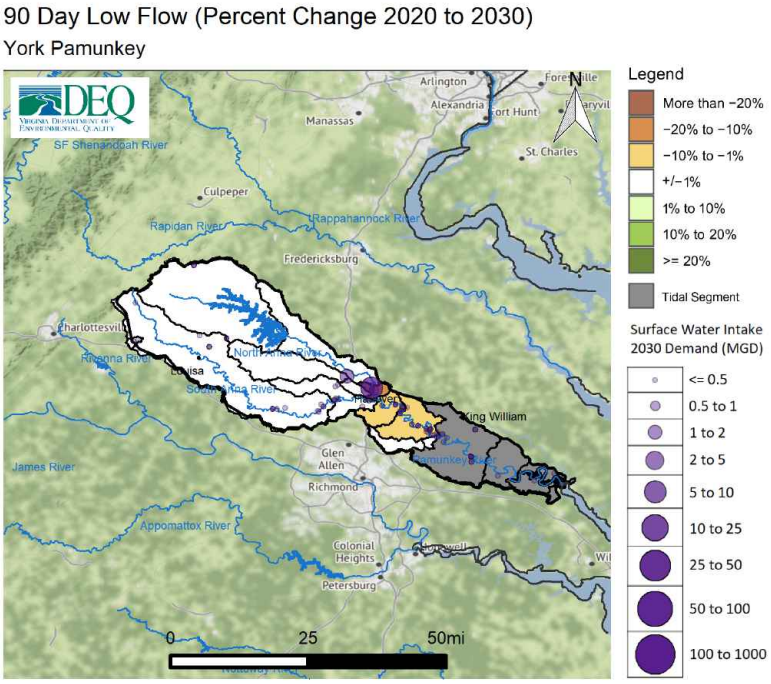

Figure 365: Change in 90 day low flow between 2020 and 2030 demand scenarios within the York Pamunkey Minor Basin

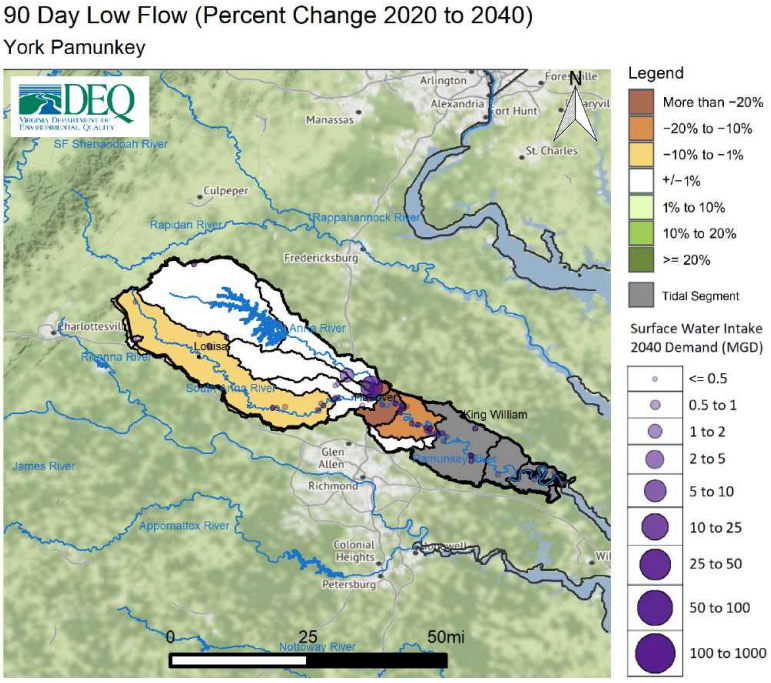

Figure 366: Change in 90 day low flow between 2020 and 2040 demand scenarios within the York Pamunkey Minor Basin

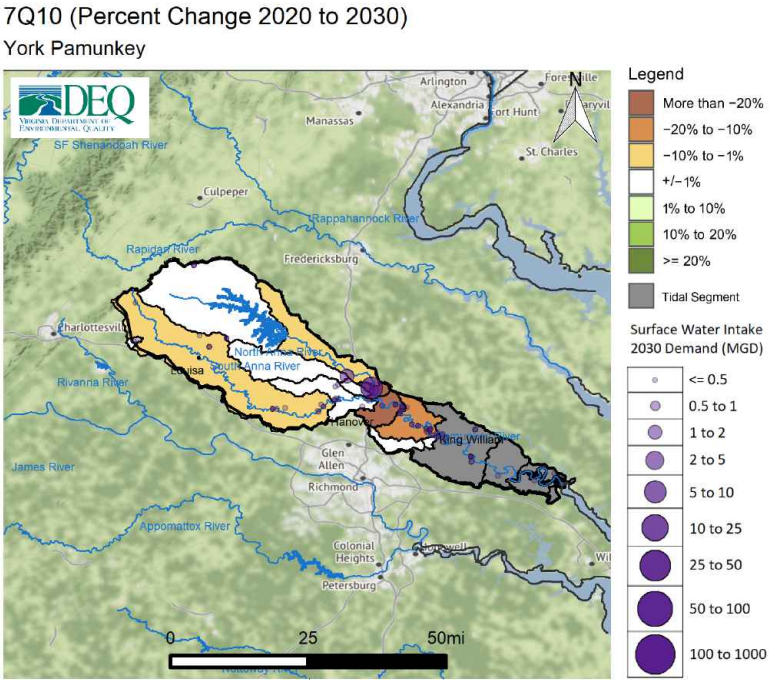

Figure 367: Change in 7Q10 between 2020 and 2030 demand scenarios within the York Pamunkey Minor Basin

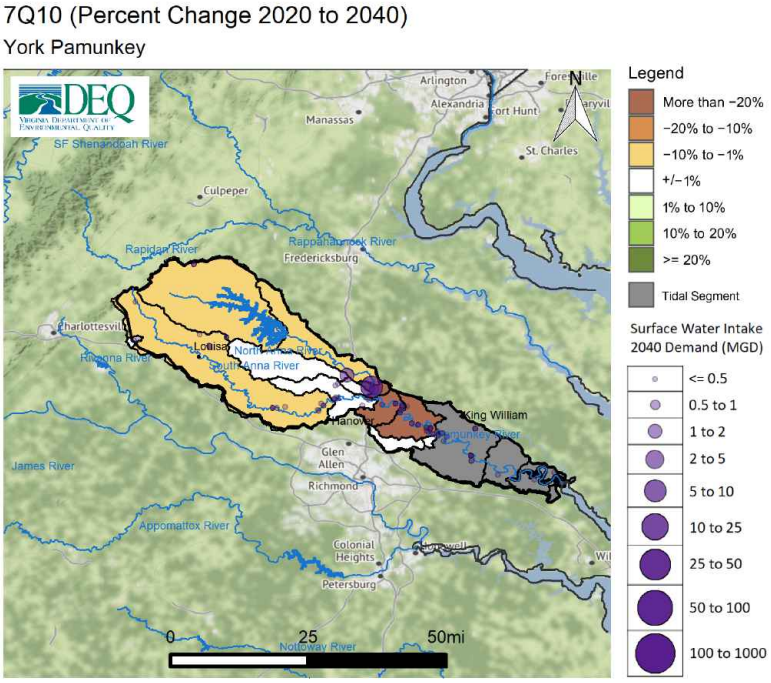

Figure 368: Change in 7Q10 between 2020 and 2040 demand scenarios within the York Pamunkey Minor Basin

The figures above show a comparison between two scenarios. An additional way to evaluate impacts to streamflow is to examine the total reduction in streamflow resulting from all withdrawals within a river segment, as well as losses due to evapotranspiration, while taking into consideration any discharges back to the source. To use a common industry term, the overall change in flow metric evaluates "consumptive use", or the amount of water removed from the river that is not returned through discharges. This can help describe potential impacts to downstream withdrawals, while also providing a basis for evaluating impacts to aquatic life. In general, total reductions in streamflow can result in a reduction in aquatic biodiversity [122]. The relationship between streamflow and aquatic biodiversity is discussed in more detail in Chapter 4. Figure 369 shows the overall change in streamflow for the 2030 Demand Scenario, while figure 370 shows the overall change in streamflow for the 2040 Demand Scenario.

[122] Rapp, J.L., R. Burgholzer, J. Kleiner, D. Scott, and E. Passero. 2020. "Application of a New Species-Richness Based Flow Ecology Framework for Assessing Flow Reduction Effects on Aquatic Communities." Journal of the American Water Resources Association 1–14.https://doi.org/10.1111/1752-1688.12877.

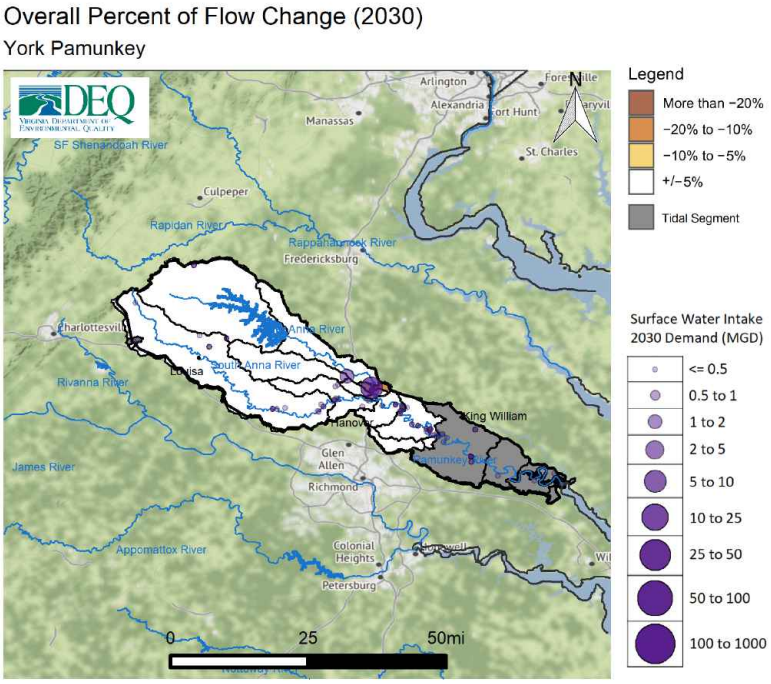

Figure 369: Overall change in flow in percent for 2030 demand scenario within the York Pamunkey Minor Basin

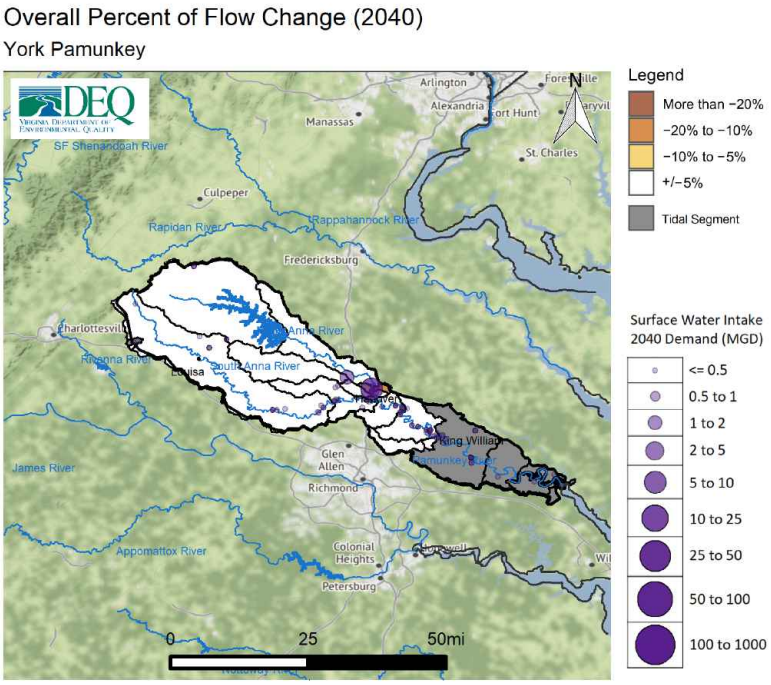

Figure 370: Overall change in flow in percent for 2040 demand scenario within the York Pamunkey Minor Basin

Climate Scenarios:Three scenarios that simulate impacts to streamflow in response to changes in temperature and climate were completed for areas in the state where climate data was available, which includes the portions of the Commonwealth located in the Chesapeake Bay watershed. Details on the methods and assumptions employed for these scenarios can be found in Appendix B. The three scenarios can be described as dry, median, and wet scenarios. Virginia is expected to experience a range of precipitation and temperature changes that may vary spatially and from year to year. The potential for both more severe and prolonged droughts as well as for higher intensity and more frequent rain events must be considered. These three scenarios are not intended as predictions of future climate conditions, but as representations of several possibilities that climate change models indicate could occur. Should they occur, these results provide an evaluation of how streamflows may be impacted. Their purpose is to build upon existing climate modeling to provide a foundation for state and local government, as well as other stakeholders, to better evaluate what practical water resource challenges may be associated with the range of climate conditions Virginia could experience.

Figure 371 depicts the percent change in the L30 for the dry climate scenario in conjunction with 2040 demands, as compared to the current climate and demand scenario. Reductions in streamflow in this scenario may be caused by reduced precipitation, increased demand, or as is generally the case, a combination of both. Figures 372 and 373 depict the L30 for the median and wet climate scenarios (in conjunction with 2040 demands) as compared to the current climate and demand scenario.

Figure 374 depicts the percent change in the L90 for the dry climate scenario in conjunction with 2040 demands, as compared to the current climate and demand scenario. Figures 375 and 376 depict the L30 for the median and wet climate scenarios (in conjunction with 2040 demands) as compared to the current climate and demand scenario.

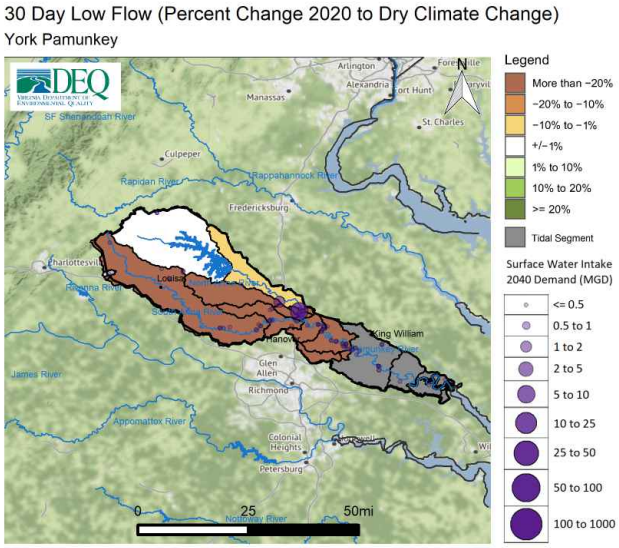

Figure 371: Change in 30 day low flow between current climate/demand scenario and the dry climate/2040 demand scenario within the York Pamunkey Minor Basin

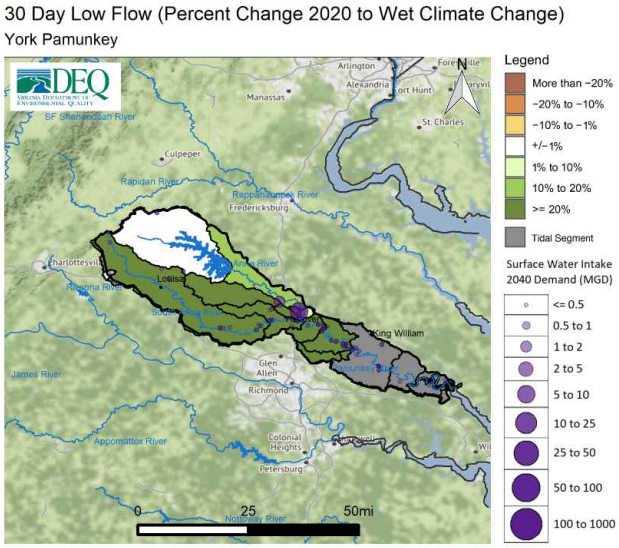

Figure 373: Change in 30 day low flow between current climate/demand scenario and the wet climate/2040 demand scenario within the York Pamunkey Minor Basin

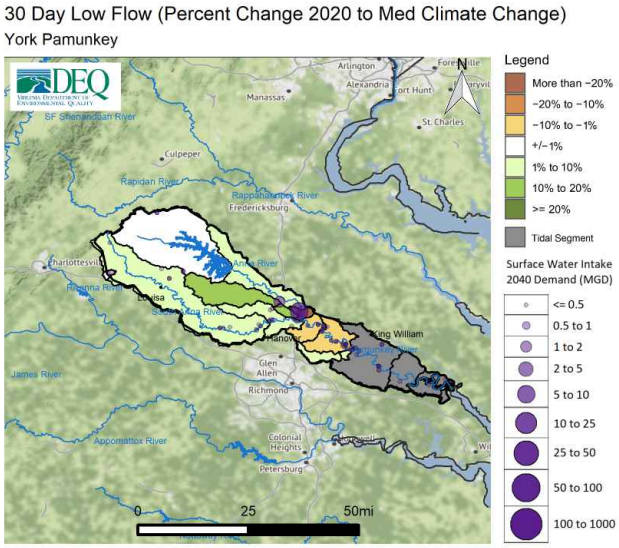

Figure 372: Change in 30 day low flow between current climate/demand scenario and the median climate/2040 demand scenario within the York Pamunkey Minor Basin

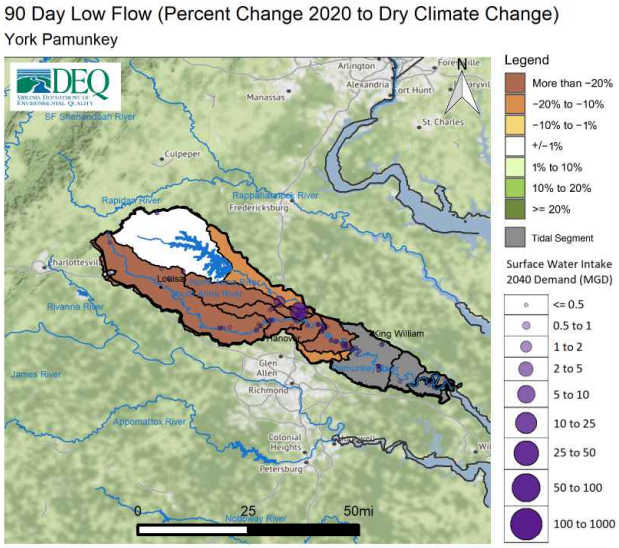

Figure 374: Change in 90 day low flow between current climate/demand scenario and the dry climate/2040 demand scenario within the York Pamunkey Minor Basin

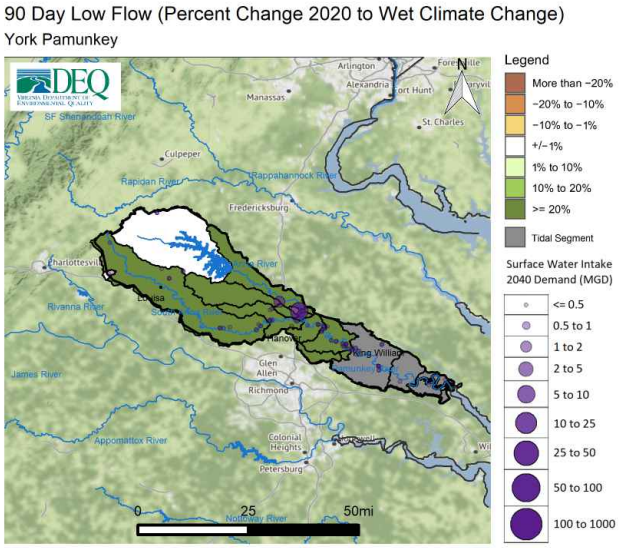

Figure 376: Change in 90 day low flow between current climate/demand scenario and wet climate/2040 demand scenario within the York Pamunkey Minor Basin

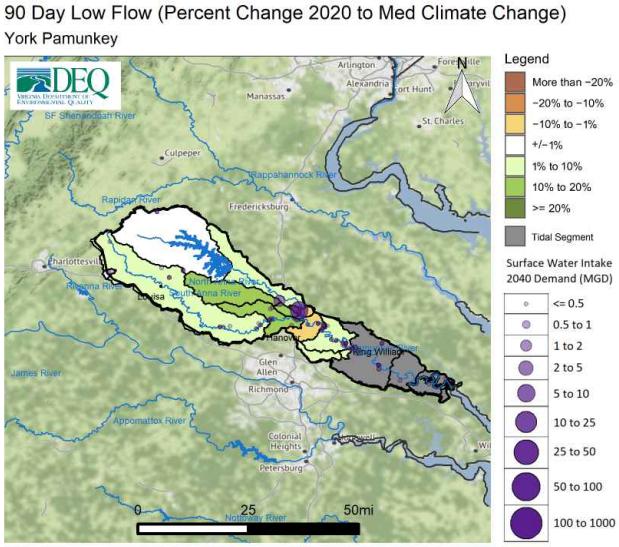

Figure 375: Change in 90 day low flow between current climate/demand scenario and median climate/2040 demand scenario within the York Pamunkey Minor Basin

Exempt User Scenario: The exempt user scenario simulates the maximum possible exempt demand for users excluded from Virginia Water Protection permitting requirements per Va. Code § 62.1-44.15:22 B, in combination with the permitted withdrawal limits for those users that are permitted. A more detailed discussion of the data and assumptions used in this scenario can be found in Appendix B. Note that this scenario uses current climate conditions. Figure 377 depicts the percent change in the lowest 30 day flow between the exempt user scenario and current (2020) demand. Figure 378 depicts the percent change in the Lowest 90 Day Flow between the exempt user scenario and current (2020) demand. Figure 379 depicts the percent change in the 7Q10 between the exempt user scenario and current (2020) demand. Finally, figure 380 depicts the overall change in flow in percent (consumptive use) for the exempt user scenario.

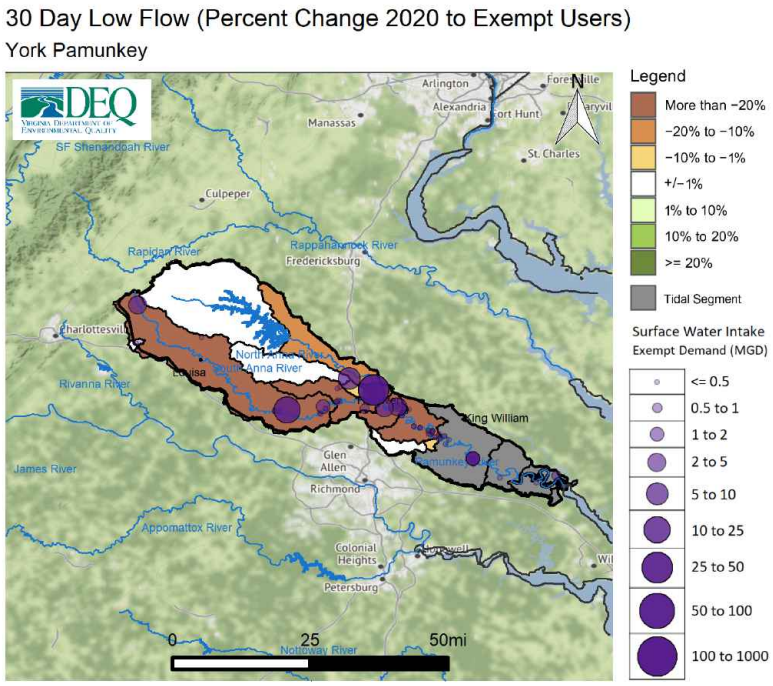

Figure 377: Change in 30 day low flow between current demand scenario and exempt User scenario within the York Pamunkey Minor Basin

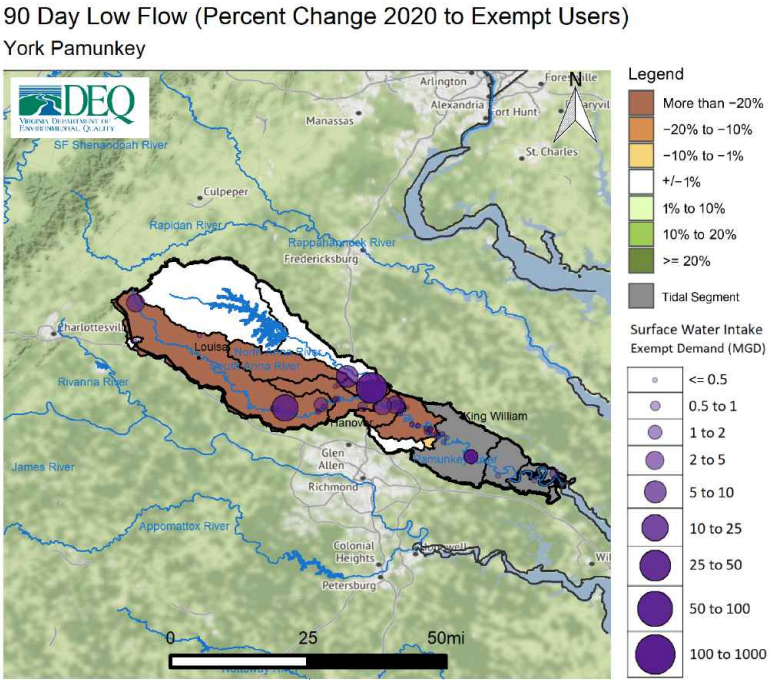

Figure 378: Change in 90 day low flow between current demand scenario and exempt user scenario within the York Pamunkey Minor Basin

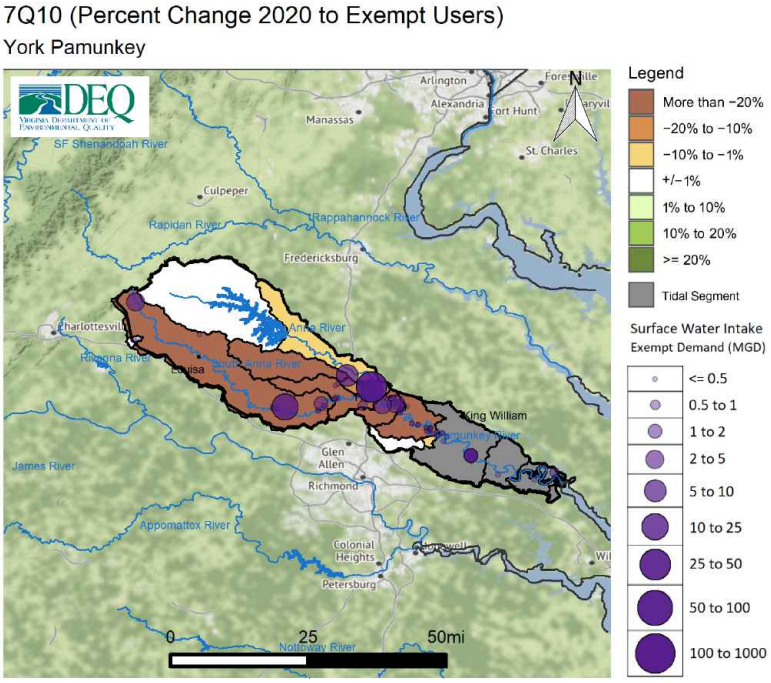

Figure 379: Change in 7Q10 between current demand scenario and exempt user scenario within the York Pamunkey Minor Basin

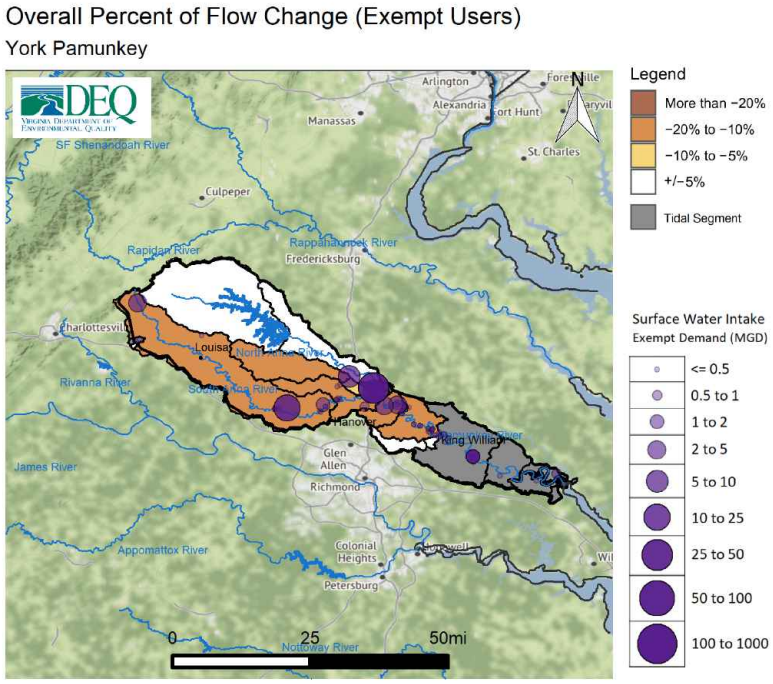

Figure 380: Overall change in flow in percent for exempt user scenario within the York Pamunkey Minor Basin

Potential Unmet Demand: Potential unmet demand was evaluated for all facilities within the basin for each scenario. Potential unmet demand is the portion of surface water demand for a specific facility that is limited by available streamflow as simulated in a given model scenario, including any known operational limits such as flow-by requirements. This unmet demand, if realized, could be managed through water conservation, through alternative sources, operational changes, or from available storage. Absent of these or other options, this portion of demand could remain unmet. As with all scenarios, demand requirements were determined using demand projections provided in the water supply plans. In the case of the exempt user scenario, the highest possible withdrawal amount was used for users exempt from VWP permitting requirements.

This metric is useful for evaluating where the results seen in the above figures may result in challenges in meeting future demands under a variety of conditions including increasing demands in the basin, changing climate, or withdrawals from users exempt from permitting requirements. Table 97 provides for each facility the highest average daily potential unmet demand over a 30 day period over the course of the simulation for the following scenarios: 2020 demand, 2030 demand, 2040 demand, dry climate, and exempt User. Only facilities showing potential unmet demand in at least one scenario appear on this table. The dry climate scenario is selected among the climate scenarios as the dry scenario represents the potential for increased drought intensity and frequency, and therefore poses the greatest challenge for water supply. Additional information on the potential unmet demand metric can be found in Appendix B.

Table 97: Change in Highest 30 Day Potential Unmet Demand (MGD) in York Pamunkey Minor Basin

Facility	**2020 Demand**	**2030 Demand**	**2040 Demand**	**Dry Climate**	**Exempt User**
Doswell WTP	0.00	0.02	0.00	0.00	12.78
Montpelier Plant	0.00	0.00	0.00	0.00	12.39
Lcwa-Northeast Creek Reservoir System	0.00	0.00	0.00	0.00	4.43
Lcwa-Louisa Generation Llc (Odec)	0.00	0.00	0.00	0.00	3.02
Gordonsville Plant	0.00	0.00	0.00	0.00	2.00
Meadow Stud Farm	0.00	0.00	0.00	0.00	1.96
Spring Creek Golf Club	0.19	0.00	0.18	0.18	0.06
Gordonsville Service Area	0.00	0.00	0.00	0.00	0.05

* Climate scenarios were not completed in areas located outside of the Chesapeake Bay Basin

Note: Potential unmet demand is the portion of surface water demand for a specific facility that is limited by available streamflow as simulated in a given model scenario, including any known operational limits such as flow-by requirements. This unmet demand, if realized, could be managed through water conservation, alternative sources, operational changes, or from available storage.

A.19.6 Spatial Overview of Groundwater Demands

The cumulative impact analysis figures above provide an overview of surface water demands in the basin but did not include groundwater demands. Figure 381 identifies the location and size of projected groundwater demands in the basin for 2040 based on information provided by localities in water supply plans.

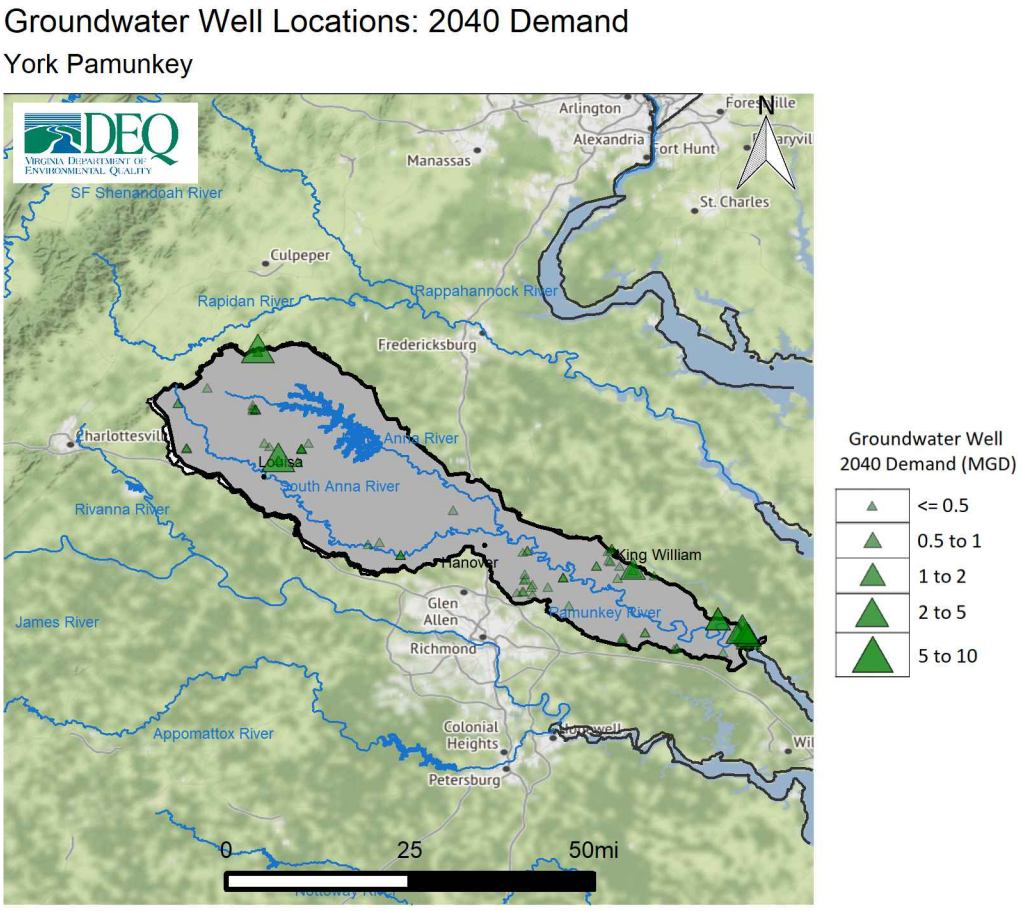

Figure 381: Projected 2040 Groundwater Demands in the York Pamunkey Minor Basin

A.19.7 Trends and Goals

The Code of Virginia mandates that the State Water Control Board should take into consideration the principle that "adequate and safe supplies shall be preserved and protected for human consumption, while conserving maximum supplies for other beneficial uses".[123] This principle is the key driver of the challenges in water resource management, which is that all beneficial uses must be adequately considered when evaluating impacts to surface water resources. The State Water Control Board is tasked with ensuring that water supply quantity needs are met at all times while also protecting Virginia's natural resources, and furthermore, ensuring equitable allocation during a time of shortage.[124] While evaluating and planning for the long-term sustainability of water supply for Virginia is the primary goal for the State Plan, evaluating and limiting impacts to in-stream beneficial uses such as aquatic habitat life is also part of DEQ's responsibility.

The primary purpose of this section is to identify where the most significant challenges to long-term sustainability of water supply and other beneficial uses are indicated based on the CIA and information collated from local water supply plans within this basin. Goals for future planning and areas for additional data collection or analysis are also suggested where appropriate.

The CIAs were completed using the best available data and methods known to DEQ. This discussion focuses on the evaluation of trends - in other words the prevailing tendency or inclination. This means evaluating whether streamflow is simulated to increase or decrease in a given scenario, and by how much. A relative trend indicating reductions of greater than or equal to 10% in streamflow, whether driven by demand increases, changing climate conditions, or exempt user demands was considered a threshold for potential impacts to beneficial uses. The following summarize the key trends or goals for this basin:

- **Demand Scenarios:** Surface water demands in the York Pamunkey minor basin, excluding the Lake Anna Nuclear Power Plant, are projected to increase by around 48.79%, or approximately 4.45 MGD, between 2020 and 2040 with the majority of surface water demand increases coming from CWS facilities, primarily Hanover County's Doswell WTP. When comparing the 2040 demand scenario to the 2020 demand scenario, reductions of more than 10% are simulated in four river segments for the short-term drought (L30) and three segments for the long-term drought (L90). The greatest reductions in terms of both short-term and long-term drought are simulated in the North Anna River at the confluence of the South Anna River, driven largely by projected demand increases for Hanover County's Doswell WTP, and these reductions continue into the Pamunkey River down through the fall-line. In the mainstem of the Pamunkey River, multiple small agriculture withdrawals in total combine to further reduce streamflows prior to the fall-line. Compared to the 2020 demand scenario, simulated streamflows during a long-term drought are at least 30% lower in the 2040 scenario in these areas. Lake Anna is the major driver of streamflows in this basin overall. Lake Anna has a minimum flow-by of 20 cfs during drought conditions; as the metrics in use for this analysis are generally centered around drought conditions, Lake Anna is simulated with a 20 cfs release in all scenarios. Outside of this significant modulation of flows from Lake Anna, a review of the Overall Percent of Flow Change (consumptive use) metric in the 2040 demand scenario shows only moderate reductions in overall flow in this basin as much of the large demands are ultimately returned. The greatest reduction in overall flow is simulated in Mill Creek below Meadows Pond, the withdrawal source for Bear Island Ashland Plant. Meadows Pond does not have a release rule because it is an exempt withdrawal. A reduction in overall flow of around 6% is also simulated in the North Anna River near Doswell, driven primarily by withdrawals from Hanover County's Doswell WTP.
- **Climate Scenarios:** Current climate modeling suggests Virginia will generally receive more precipitation on average in the future. However, the data also suggests the possibility of more severe droughts despite this overall trend of increasing precipitation. The dry climate scenario simulates potential reductions in streamflow that range from 10-90% in both short-term drought (L30) and long-term drought (L90) compared to current climate in most of the non-tidal portion of the York Pamunkey

[123] § 62.1-44.36 of the Code of Virginia
[124] 9VAC25-390-20.1

Basin. Minimum releases from Lake Anna act to buffer streamflows in the dry climate scenario such that reductions immediately below the lake are lesser than simulated elsewhere. Potential unmet demand is not simulated in the dry climate scenario for any CWS facilities, although releases from Lake Anna likely work to limit impacts to the largest CWS facility downstream (Hanover County's Doswell WTP). While impacts to existing facilities were not significant in the dry climate scenario, the potential for more severe droughts must be evaluated and considered by localities and users when evaluating new sources or alternatives, as well as for broader planning and resource management efforts by all stakeholders whether state or local.

- **Exempt User Scenario:** The exempt user scenario, compared to the 2020 demand scenario, shows simulated reductions in short-term drought (L30) and long-term drought (L90) streamflows of more than 20% across most of the non-tidal portions of the basin including the North Anna River, the South Anna River, and in the Pamunkey River down through the fall-line. The most significant reductions (more than 90%) in the short-term and long-term drought metrics are simulated in the North Anna River near Doswell. Simulated streamflow in the exempt user scenario is reduced to less than one cfs during short-term and long-term drought driven primarily by Hanover County's Doswell WTP maximum possible exempt demand, which is seven times greater than the facility's 2020 demands. The maximum possible exempt demand for Bear Island Ashland Plant contribute to further reductions downstream in the North Anna River at the confluence with the South Anna River and down into the Pamunkey River. Streamflow reductions in the L30 and L90 in the South Anna River in the exempt user scenario are driven primarily by the maximum possible exempt demands from the US Silica's Montpelier Plant, Lewa-Louisa Generation Plant, and Louisa Service Authority's Northeast Creek Reservoir. Potential unmet demand in the exempt user scenario is simulated for several facilities including US Silica's Montpelier Plant North Anna River intake, Louisa Service Authority's Northeast Creek Reservoir, the Lewa-Louisa Generation Plant, as well as Meadow Stud Farm. The exempt user scenario also results in a 25% reduction in overall flow (consumptive use) in the North Anna River around Doswell, and a more than 10% reduction throughout the Pamunkey River and the South Anna River. These simulated reductions are well above the threshold where impacts to aquatic life and habitat would be expected. These results indicate that the cumulative maximum possible exempt demands in the basin may exceed the water budget in many river segments within the basin. Preserving water supply and other beneficial uses will require managing these demands with respect to their cumulative impacts and in the context of the available resources in the basin.

- **Coastal Plain Groundwater Demand Scenarios:** The lower portion of the York Pamunkey Minor Basin is characterized by limited freshwater surface water availability from tidal streams and rivers. In these areas, most demand is met through groundwater withdrawals from confined aquifers such as the Potomac Aquifer. This includes parts of Hanover, New Kent, and King William counties. Cumulative impact analysis groundwater modeling of the 2020 and 2040 demand scenarios was completed using the VAHydro Virginia Coastal Plain Groundwater Model for the State Plan. The results of these simulations are covered in detail in a number of figures provided in Chapter 4, section 4.3.3. These results inform this discussion. With respect to this basin, the following are the key trends. In the 2020 demand scenario water levels in the Potomac Aquifer are simulated to recover gradually from 2020 through 2050, before marginally declining through 2070. However, in the 2040 demand scenario, due to the increased domestic (Small SSU) and permitted demands, water levels continue to decline from 2020 to 2070. This results in portions of this basin where water levels fall below the critical surface and critical cells are simulated. This is most prevalent in the area along the fall-line, where the aquifers become shallower and thinner, and these impacts generally decrease with distance from the fall-line.

- This basin includes or is near a number of large groundwater withdrawals, and significant increases in groundwater demands are projected. Cumulative pumping from these facilities combined with domestic/unpermitted use results in a substantial cone of depression in both demand scenarios in the Potomac, Aquia, and Piney Point aquifers. In the 2020 scenario, Potomac Aquifer critical cells are simulated in Hanover County, while in the 2040 scenario the number of critical cells greatly increases and expands into New Kent County. For the Aquia and Piney Point Aquifers, the 2020 demand scenario results in critical cells in King William, New Kent, and Hanover counties, with significant increases

in the number and extent of critical cells in the 2040 demand scenario (see section 4.3.3). These results suggest that for each of the three aquifers discussed, the potential for challenges in permitting withdrawals exists even in the 2020 demand scenario as simulated, particularly in portions of Hanover County. The 2040 demand scenario simulation expands the areal extent of where such challenges may occur, as portions of King William and New Kent County are simulated to have critical cells in the Potomac, Aquia, and Piney Point aquifers. Several of the localities in this region are aware of these challenges and are actively pursuing surface water withdrawals, including tidal freshwater withdrawals, as alternatives to groundwater. This region also has numerous domestic wells and small neighborhoods and developments with individual wells for each residence. These are unpermitted demands. These simulations indicate that even as permitted demands from large facilities have decreased, projected domestic increases as estimated could off-set those reductions. This underscores the importance of continuing to evaluate and pursue alternative sources, interconnection opportunities, and more robust conservation for groundwater users in this basin.

A.20 Lower York Minor Basin

A.20.1 Watershed Overview

The York River is formed at the confluence of the Pamunkey and Mattaponi Rivers. The Pamunkey and Mattaponi rivers flow through the Piedmont and Coastal Plain provinces, and are characterized by slight rolling hills at the headwaters and flatter areas dominated by farmland moving into the tidal portions. Cropland/pasture and forest make up the majority of land-use across the Lower York Minor Basin with increasing urban development nearing urban centers such as the City of Richmond and the City of Fredericksburg. The Lower York Minor Basin includes all of the tidal York River from the confluence of the Pamunkey and Mattoponi rivers down through the entrance to the Chesapeake Bay.

The total spatial area of the basin occupies 1,230 sq. miles and includes all or portions of the localities listed in Table 98. The major population centers within or adjoining the basin include the cities of Williamsburg, Hampton, and Newport News.

A.20.2 Existing Water Sources

Surface water within this basin is generally tidal and high in salinity so groundwater is the primary source for most demands. However there are withdrawals from the York River, and in several reservoirs and ponds. Groundwater within the basin is primarily withdrawn from confined Coastal Plain aquifers like the Potomac, and the basin is part of the Eastern Virginia Groundwater Management Area.

Withdrawals within the basin are used for public water supply, power generation, agriculture, irrigation, commercial, and industrial/manufacturing.

The location of wells and surface water intakes identified to DEQ within the basin are shown in figure 382. This figure does not include private or domestic wells. Groundwater wells outnumber surface water intakes significantly, as is expected given the limited non-tidal surface water available in this area.

Table 98: Population Trend by Locality in Lower York Basin

Localities	20 Year % Change
Essex	4.16
Gloucester	3.18
James City	34.48
King and Queen	1.02
Mathews	-10.03
Middlesex	5.67
New Kent	37.48
York	15.44
Hampton	-12.36
Newport News	-3.20
Poquoson	2.77
Williamsburg	18.39

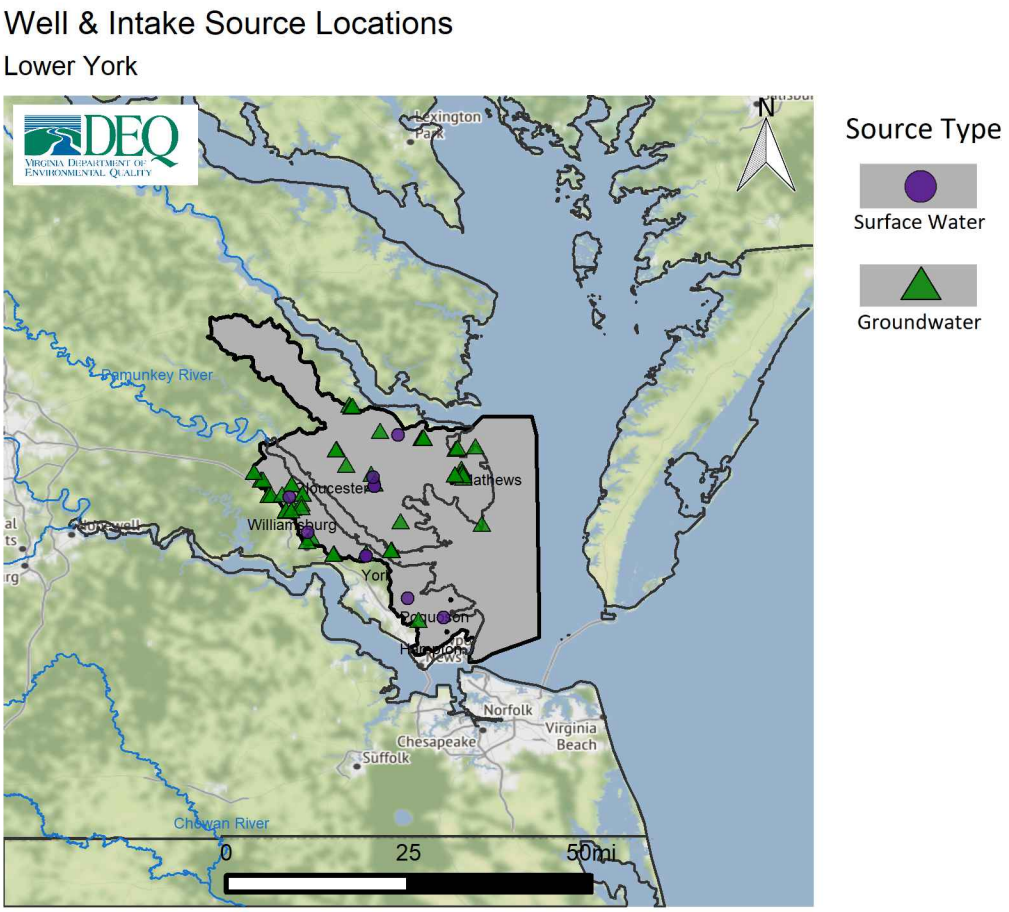

Figure 382: Spatial distribution of groundwater wells and intakes in the Lower York Minor Basin

A.20.3 Existing Water Use

The following section discusses existing (current) water use within the basin, which is based on existing demand information submitted to DEQ in the water supply plans. Table 99 provides a summary of all demands within the basin by system type and source type including power generation. This basin includes Yorktown Power Plant, which has a current demand that makes up 97% of all demands in this minor basin. However, this is a tidal withdrawal that is largely non-consumptive (most of the water is returned to the York River). Current water use for the Yorktown Power Plant is also lower than projected in the water supply plans as the coal fired units have been or are in the process of being shutdown. Table 100 excludes power generation facilities so trends in water use for all other categories can be compared.

Table 99: Summary of Lower York Minor Basin Water Demand by Source Type and System Type (including Power Generation)

System Type	Source Count	2020 Demand (MGD)	2030 Demand (MGD)	2040 Demand (MGD)	20 Year Percent Change
Surface Water					
Agriculture	0	0.00	0.00	0.00	0.00
CWS	3	19.37	21.97	24.58	26.88
Large SSU	4	816.56	816.56	816.56	0.00
Small SSU	N/A	0.00	0.00	0.00	0.00
Total SW	**7**	**835.93**	**838.53**	**841.14**	**0.62**
Groundwater					
Agriculture	0	0.00	0.00	0.00	0.00
CWS	43	1.70	2.42	3.14	84.77
Large SSU	22	0.29	0.29	0.29	0.00
Small SSU	N/A	2.85	3.12	3.39	19.08
Total GW	**65**	**4.84**	**5.83**	**6.82**	**40.91**
Total (SW + GW)					
Agriculture	0	0.00	0.00	0.00	0.00
CWS	46	21.07	24.39	27.71	31.54
Large SSU	26	816.86	816.86	816.86	0.00
Small SSU	N/A	2.85	3.12	3.39	19.08
Minor Basin Total	**72**	**840.78**	**844.37**	**847.96**	**0.85**

* Small SSU demands are county-wide estimates of private well usage below 300,000 gallons a month. The number of private wells is not known.

Table 100: Summary of Lower York Minor Basin Water Demand by Source Type and System Type (excluding Power Generation)

System Type	Source Count	2020 Demand (MGD)	2030 Demand (MGD)	2040 Demand (MGD)	20 Year Percent Change
Surface Water					
Agriculture	0	0.00	0.00	0.00	0.00
CWS	3	19.37	21.97	24.58	26.88
Large SSU	3	0.01	0.01	0.01	0.00
Small SSU	N/A	0.00	0.00	0.00	0.00
Total SW	**6**	**19.38**	**21.98**	**24.59**	**26.88**
Groundwater					
Agriculture	0	0.00	0.00	0.00	0.00
CWS	43	1.70	2.42	3.14	84.77
Large SSU	20	0.29	0.29	0.29	0.00
Small SSU	N/A	2.85	3.12	3.39	19.08
Total GW	**63**	**4.84**	**5.83**	**6.82**	**40.91**
Total (SW + GW)					
Agriculture	0	0.00	0.00	0.00	0.00
CWS	46	21.07	24.39	27.71	31.54
Large SSU	23	0.30	0.30	0.30	0.00
Small SSU	N/A	2.85	3.12	3.39	19.08
Minor Basin Total	**69**	**24.22**	**27.81**	**31.40**	**29.64**

* Small SSU demands are county-wide estimates of private well usage below 300,000 gallons a month. The number of private wells is not known.

The total existing demand from all surface and groundwater sources is approximately 24.22 MGD, with groundwater supplying approximately 4.84 MGD or around 20% of total water demands. Surface water demand within the basin (excluding power generation) totals approximately 19.38 MGD, or around 80% of current demands. The majority of total surface water demand is from City of Newport News' Harwood's Mill WTP.

The five largest facility demands for each source type (excluding power generation) are provided in Table 100. The largest groundwater demands include Gloucester County's Community Water System (CWS), James City County Service Authority's Central System, and the City of Newport News' Skimino-Banbury-Lightfoot Systems. The largest surface water demands include Yorktown Power Station, City of Newport News' Hardwood's Mill WTP, and City of Williamsburg's Waller Mill Reservoir.

Table 101: Top 5 Users in 2040 by Source Type in the Lower York Minor Basin (including Power Generation)

Facility Name	System Type	Locality	2020 Demand (MGD)	2030 Demand (MGD)	2040 Demand (MGD)	20 Year Percent Change	% of Total Surface Water
Surface Water							
Yorktown Fossil Power Plant	Large SSU	York	816.56	816.56	816.56	0.00	97.08
Harwood's Mill WTP	CWS	York	15.35	16.82	18.3	19.22	2.18
Williamsburg City Of -Number 1	CWS	York	3.34	4.12	4.91	47.01	0.58
Gloucester County Public Utilities	CWS	Gloucester	0.68	1.03	1.37	101.47	0.16
Eaglewood Golf Course	Large SSU	Hampton	0.01	0.01	0.01	0.00	0.00
Total SW			835.94	838.54	841.15	0.62	100
Groundwater							**% of Total Groundwater**
Gloucester County Public Utilities	CWS	Gloucester	0.69	1.04	1.38	100	20.23
Jcsa - Central System	CWS	James City	0.56	0.87	1.18	110.71	17.3
Combined Skimino Banbury And Lightfoot Systems	CWS	York	0.33	0.36	0.39	18.18	5.72
Colonial Williamsburg	Large SSU	Williamsburg	0.13	0.13	0.13	0.00	1.91
Bethel Landfill	Large SSU	Hampton	0.08	0.08	0.08	0.00	1.17
Total GW			1.79	2.48	3.16	76.54	46.33

Table 102: Top 5 Users in 2040 by Source Type in the Lower York Minor Basin (excluding Power Generation)

Facility Name	System Type	Locality	2020 Demand (MGD)	2030 Demand (MGD)	2040 Demand (MGD)	20 Year Percent Change	% of Total Surface Water
Surface Water							
Harwood's Mill WTP	CWS	York	15.35	16.82	18.3	19.22	74.42
Williamsburg City Of -Number 1	CWS	York	3.34	4.12	4.91	47.01	19.97
Gloucester County Public Utilities	CWS	Gloucester	0.68	1.03	1.37	101.47	5.57
Eaglewood Golf Course	Large SSU	Hampton	0.01	0.01	0.01	0.00	0.04
Piankatank River Golf Club	Large SSU	Middlesex	0.00	0.00	0.00	0.00	0.00
Total SW			19.38	21.98	24.59	26.88	100
Groundwater							**% of Total Groundwater**
Gloucester County Public Utilities	CWS	Gloucester	0.69	1.04	1.38	100	20.23
Jcsa - Central System	CWS	James City	0.56	0.87	1.18	110.71	17.3
Combined Skimino Banbury And Lightfoot Systems	CWS	York	0.33	0.36	0.39	18.18	5.72
Colonial Williamsburg	Large SSU	Williamsburg	0.13	0.13	0.13	0.00	1.91
Bethel Landfill	Large SSU	Hampton	0.08	0.08	0.08	0.00	1.17
Total GW			1.79	2.48	3.16	76.54	46.33

Table 99 also provides the proportion of each use category that is supplied by either surface water or groundwater including. Use categories include Community Water System (CWS), Large Self-Supplied User (Large SSU), Small Self-Supplied User (Small SSU), and Agricultural Self-Supplied User (AG). These categories are defined below. Surface water demand is primarily comprised of power generation and CWS demands. Groundwater demand is primarily comprised of CWS and Small SSUs. The largest water users are shown in Table 101 and Table 102, with the Yorktown Fossil Power Plant, Harwood's Mill WTP, and Gloucester County Public Utilities being the largest demands in the basin.

The CWS cateogry includes any public and private waterworks that serve at least 15 service connections used by year-round residents or regularly serve at least 25 year-round residents, and are regulated under the Virginia Department of Health's Waterworks Regulation (12VAC5-590). In the Lower York Minor Basin, approximately 1.70 MGD of groundwater demand and 19.37 MGD of surface water demand is from CWS. Significant groundwater users within this category are once again Gloucester County's CWS, James City County Service Authority's Central System, and the City of Newport News' Skimino-Banbury-Lightfoot Systems. Significant surface water users from this category include: Hardwood's Mill WTP, and City of Williamsburg Waller Mill Reservoir.

Large SSUs include any non-CWS or AG who withdraw more than 300,000 gallons per month from a well or surface water intake. In the the Lower York Minor Basin, approximately 0.29 MGD of groundwater demand and 0.01 MGD of surface water demand is from Large SSUs. This however does not include the Yorktown Power Plant. Significant groundwater users within this category include the City of Williamsburg and several golf courses. There is not significant surface water use in this category.

Small SSUs include any users who withdraw less than 300,000 gallons per month from wells. Small SSUs generally consist of residential or domestic use for those who live outside service areas and provide their own water. Small SSU demand is generally met with groundwater. In the Lower York Minor Basin, approximately 2.85 MGD of groundwater demand is from Small SSUs. Gloucester County had the greatest contribution from Small SSU estimates.

The AG category includes crop farms, livestock operations, aquaculture and other agricultural facilities. In the Lower York Minor Basin, there were no demands associated with AG operations, although that does not mean no agricultural operations exist, only that they were identified in the plans.

A.20.4 Projected Population and Water Use

Projected Population: Trends in water use are generally driven by trends in population change or economic development. Increasing population within an area generally means increased connections for community water systems or additional demands from homeowners that construct wells. Increasing population in an area also tends to incentivize both new and expanded industrial and commercial water use.

Table 98 shows the projected change in population by percent between 2020 and 2040 for each locality located partly or wholly within this minor basin. James City County and the City of Williamsburg are projected to grow significantly, but not all that growth will occur in the Lower York. More rural localities like Middlesex, Mathews counties, and the Town of Poquoson are not projected to grow significantly, which is consistent with wider population trends in Virginia.

Projected Water Use: The following section discusses projected water use through 2040 within the Lower York Minor Basin, based on projections provided in local and regional water supply plans. Table 100, included in the existing demand section above, is the basis for information discussed in this section.

Total demand within the basin is projected to increase from 24.22 MGD in 2020 to 31.40 MGD in 2040, or around a 30% increase. Surface water demand is projected to increase by approximately 5.21 MGD, or 27% by 2040. Groundwater demand is projected to increase by 1.98 MGD, or 41% by 2040. Surface water demand increases are driven primarily by projected increases from City of Newport News' Hardwood's Mill WTP, and City of Williamsburg's Waller Mill WTP. For groundwater, increases in demand are driven by projected increases for Gloucester County's WTP and JCSA's Central System.

Demand from CWS users within the basin is projected to increase approximately 31.5% by 2040. Within this category surface water use is projected to increase by 27%, while groundwater use is projected to increase by 84%. CWS is the only use category projecting increased demands from surface water sources over the planning period. Once again, projected increases for Gloucester and JCSA drive the increase in CWS groundwater demands.

Demand from Large SSUs within the basin is not projected to change between 2020 and 2040. Large SSU use is primarily made up of irrigation for golf courses, Colonial Williamsburg, and the College of William and Mary.

Demand from Small SSU users within the basin is projected to increase by 19% by 2040. As noted previously, Small SSU demand is entirely met with groundwater and represents domestic well use. Projected increases in population align with increased demands from Small SSUs over the planning period.

As noted previously, no agriculture demands were identified in this basin and therefore no change in agricultural demands are projected.

A.20.5 Cumulative Impact Analysis

The York Lower Minor Basin does not include significant non-tidal surface water segments and therefore surface water cumulative impact analysis was not completed in this basin. The Trends and Goals sections below discusses results from the Cumulative Impact Analysis Groundwater Modeling completed in the Eastern Virginia Groundwater Management Area. The methods and results for the groundwater modeling scenarios are provided in Chapter 4, Section 4.3.3, Virginia Coastal Plain Model Results, which may warrant review prior to reading the following sections.

A.20.6 Spatial Overview of Groundwater Demands

A substantial portion of the demands in this basin are supplied by groundwater. Figure 383 identifies the location and size of projected groundwater demands in the basin for 2040 based on information provided by localities in water supply plans.

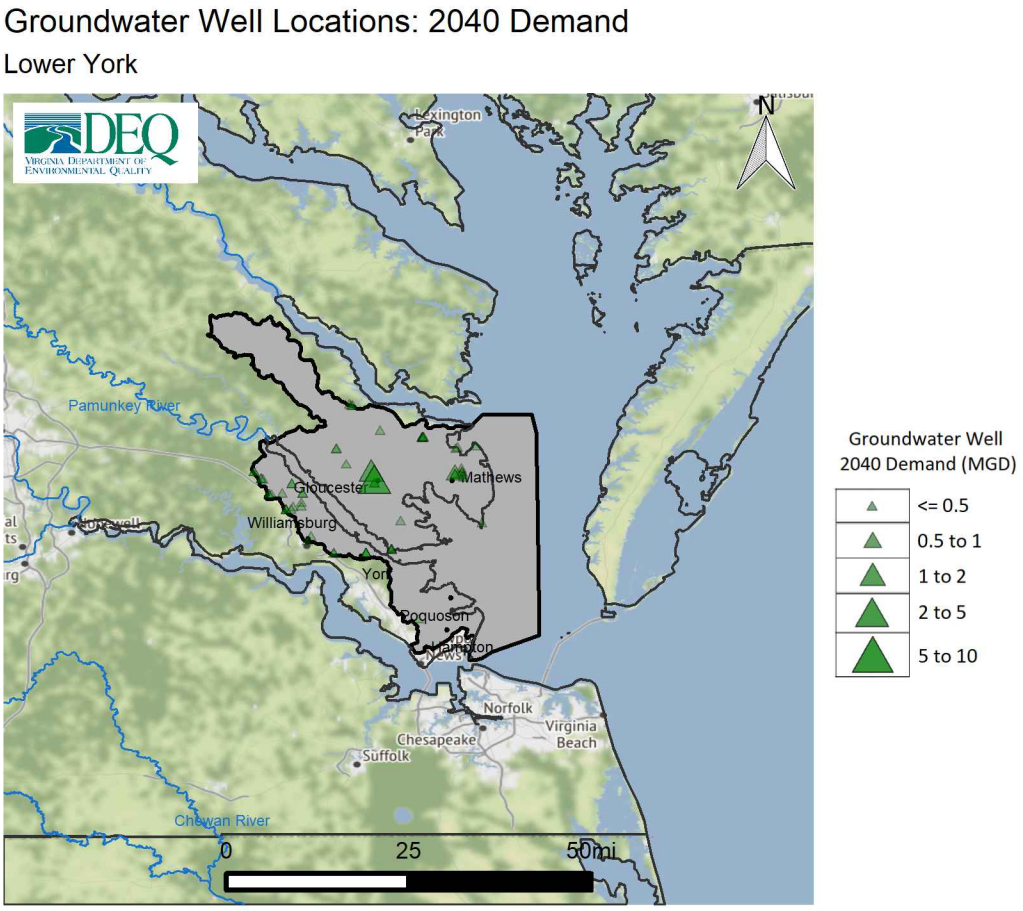

Figure 383: Projected 2040 Groundwater Demands in the York Lower Minor Basin

A.20.7 Trends and Goals

The Code of Virginia mandates that the State Water Control Board should take into consideration as principle that "adequate and safe supplies shall be preserved and protected for human consumption, while conserving maximum supplies for other beneficial uses" .[125] This principle is the key driver of the challenges in water resource management, which is that all beneficial uses must be adequately considered when evaluating impacts to water resources. The State Water Control Board is tasked with ensuring that water supply quantity needs are met at all times while also protecting Virginia's natural resources, and furthermore, ensuring equitable allocation during a time of shortage.[126]

The primary purpose of this section is to identify where the most significant challenges to long-term sustainability of water supply and other beneficial uses are indicated based on the CIA and information collated from local water supply plans within this basin. Goals for future planning and areas for additional data collection or analysis are also suggested where appropriate.

- **Coastal Plain Groundwater Demand Scenarios:** The Lower York Minor Basin is characterized by limited freshwater surface water availability with the primary exceptions being larger freshwater reservoirs or impoundments. A significant portion of demand for localities like James City County, Gloucester County, and others in this basin are met through groundwater withdrawals from confined aquifers such as the Potomac Aquifer. Cumulative impact analysis groundwater modeling of the 2020 and 2040 demand scenarios was completed using the VAHydro Virginia Coastal Plain Groundwater Model for the State Plan. The results of these simulations are covered in detail in a number of figures provided in Chapter 4, section 4.3.3, and in the discussion in section 4.3.4. These figures inform this discussion.
- **Potomac Aquifer:** Statewide, in the 2020 demand scenario water levels in the Potomac Aquifer are simulated to recover gradually from 2020 through 2050, before marginally declining through 2070. This indicates that demands as estimated in the 2020 demand scenario appear to allow for stabilized water levels in most of the Coastal Plain. However, in the 2040 demand scenario, due to both projected increases in domestic (Small SSU) and permitted demands, water levels decline continuously from 2020 to 2070. This results in significantly more areas of the Coastal Plain where water levels fall below the critical surface and critical cells are simulated. No critical cells are simulated within this basin - see section 4.3.3 for figures showing model results. However, large groundwater withdrawals which produce a significant area of impact can impact critical cells regionally - and so future permitting in these areas could be impacted.
- **Other Aquifers:** Critical cells are simulated in the Piney Point Aquifer in the 2040 scenario in the western edge of the basin including James City County, New Kent County, and the City of Williamsburg. These cells are not simulated in the 2020 demand scenario. This suggests that increasing demands on the Piney Point aquifer to 2040 levels would impact future viability of withdrawals in the aquifer. Critical cells were not simulated in the Aquia Aquifer in this region in either scenario
- The results suggest the potential for challenges in permitting large groundwater withdrawals, particularly in the western portions of the basin, such as James City County. James City County has been issued a permit to construct a surface water intake as an alternative and to supplement their groundwater use. Gloucester County uses a combination of surface water and groundwater to meet CWS demands. In general, these results underscore the importance of continuing to develop alternative or supplemental sources - and show the efforts already underway in these localities are critical.

[125] § 62.1-44.36 of the Code of Virginia
[126] 9VAC25-390-20.1

B Appendix - Additional Technical Documentation

B.1 Potential Unmet Demand Summaries

"Potential Unmet demand" is calculated at each modeled intake based on the difference between the "base demand", and the actual modeled demand at every time-step. During most days in a long-term water supply simulation, unmet demand will be zero; but during drought, unmet demands may increase. Factors that will result in simulated unmet demand include: insufficient available water at the intake and drought trigger demand reductions (voluntary or mandatory reductions in demand). Available water for a direct withdrawal intake is based on the current flow simulated in the stream minus any minimum instream flow requirements (aka flow-bys) that the intake is required to respect. Available water in reservoirs is based on "usable storage remaining", which is a function of intake locations and water quality stratification in the reservoir. Some systems in Virginia have well-defined "drought triggers" that prescribe percentage reductions in demand when certain drought criteria are met. The VAHydro model simulates these triggers and demand reductions when they are known, and the unmet demand counter is increased to reflect this demand that would otherwise be met were drought restrictions not in effect. Modeled unmet demands for a given system, or for all systems in a watershed are an effective means of estimating potential need for conservation measures, increased storage, new water sources, or increased yield from existing sources.

B.1.1 Competing Demands in a Single Watershed

When the sum of all system demands within a watershed exceed the available water budget in the stream or in an impoundment, the model simulation calculates an overall demand reduction percentage needed to make demands in the watershed equivalent to available water, then each system in the watershed reduces its demand by the calculated percentage, and records the demand reduction as part of its unmet demand for that time step.

B.1.2 Limitations due to Model Assumptions

The vast majority of intakes in Virginia do **not** have a required minimum instream flow, so their available water is essentially equal to the entire stream flow at a given time. However, there are physical limits to each intake, and many intakes will be unable to physically withdraw water once flow drops below a certain level. Also, since a majority of the unpermitted facilities in the current model are lumped into large HUC10 segments, the actual water availability is likely less since many intakes will not be on the main river channel. As a result, unmet demand for many unpermitted facilities may be underestimated. Therefore, unmet demands should be considered a conservative estimate of actual new source/storage/drought measures needed to meet current and future demands during drought. Future simulation must expand model resolution to explicitly simulate all side-streams for all facilities, and to include an assessment of the minimum flow at which intakes are operable. Areas of high modeled unmet demand can be used to prioritize model expansion, and alternatives analysis.

B.1.3 Changes in Unmet Demands from 2020 to 2040

7-day unmet demand, which is the maximum daily unmet demand over a seven day period during the simulation, exceeds 10% of daily surface water demands (160 MGD versus 1,200 MGD) in the 2020 demand scenario and is nearly 15% of daily surface water demands (229 MGD versus 1,600 MGD) in the 2040 demand scenario. Statewide, the total 90 day unmet demand nearly doubles in volume (56 MGD to 97 MGD), and increases from 5% in the 2020 demand scenario to nearly 6% of average demand in the 2040 demand scenario. To determine the amount of additional water supply or conservation reductions needed by a given system or watershed, the 90 day rate of unmet demand in MGD can be multiplied by 90 days. For the 2040 scenario this is approximately 9 billion gals of total additional storage or conservation. The number of systems with unmet demands increases nearly 10% from 122 in 2020 to 132 in 2040. The exempt scenario results in 315 systems having unmet demands, an increase of over 250% from current conditions. This type of analysis can be applied over many systems in a watershed to determine optimal solutions for meeting potential unmet demands with the most cost-effective means, and with the least impact to instream flows.

Table 103: Unmet Demand Summaries for non-tidal surface water withdrawals, 2020 versus 2040 demands.

Metric	2020 (mgd)	2040 (mgd)
Unmet 7-day	160	229
Unmet 30-day	101	153
Unmet 90-day	56	97
Withdrawal	1,241	1,461

B.2 Understanding Model Error and Predictive Uncertainty

The concept of "model error", generally refers to the extent to which the simulated values of a model differ from observed data over some historical time period. For water supply models, model error refers to when the model "over-simulates" or "under-simulates" the available water during some time period. Predictive uncertainty refers to how model errors affect the ability to use a historically calibrated model to ask "what if" questions about future management scenarios. In the case of water supply models, the main "what if" revolves around "flow alteration", i.e. changes to stream flows as a result of withdrawals, discharges and reservoir operations. Predictive uncertainty is therefore the greatest concern when using a model to inform management water supply actions since it governs our assessment of risk of unmet demands, reduced assimilative capacity, aquatic life impacts, recreational/navigational impacts and other beneficial uses. Generally speaking, all models will possess some amount of error, but by applying appropriate techniques, model predictive uncertainty can be accounted for when using the model to insure sustainable future water supply.

Because the effect of a given water withdrawal from the stream is a very straight-forward calculation, there is little predictive uncertainty surrounding the magnitude of flow decrease resulting from a given withdrawal on the stream budget. In other words, model errors will never affect the direction or sign (+-) of cumulative impacts due to water withdrawal from a stream. However, because model error affects the starting flow budget, model predictive uncertainty does affect the ability to predict precise percent changes in flows due to cumulative water supply management operations. In short, model flow errors can result in under-estimating, or over-estimating the potential for flow decreases due to consumptive water use, but will never indicate an increase in flow as a result of increased water use.

B.2.1 Sources of Model Error

Model flow errors can be caused by model errors in base flows (groundwater recharge), model rainfall input errors, or uncertainty in historical point source discharges and withdrawals during the model period. Since models are calibrated against long term stream gages, any error in stream gage readings will also introduce uncertainty in model performance, however, gage errors should be a small contributor to model error since the majority of USGS gages are within 5-10% mean stage error, and seldom less than 2% error [Survey, 1992].

B.2.2 Using Predictive Uncertainty to Estimate an Uncertainty Interval/Volume of Available Water

When the exact sources of model error and predictive uncertainty are not known, the differences between simulated and observed historical flows can be considered using a margin of safety calculation. This entails calculating the difference between observed and simulated flow, and using this interval to calculate an "uncertainty interval" of flow alteration, and a corresponding volume of water, or "uncertainty volume" available for beneficial uses. Water supply managers and users can use the uncertainty interval/volume to formulate appropriate margins of safety to insure that maximal beneficial uses are served. For example, when simulated available water exceeds the observed amount, the uncertainty volume can be subtracted from remaining storage to create a "lower bound" of storage remaining. Alternatively, the uncertainty volume can divided by the period length to estimate the amount of additional water conservation that could be needed to insure water supply meets demands. Although this approach can allow effective planning over a wide range of model errors, when areas of high model error coincide with high water supply demand pressures, efforts should made to improved model calibration in order to make the bounds of uncertainty smaller, and improve the ability to formulate cost-effective management responses. Because the model predictive-uncertainty for a water supply model is a product of both the model error and the amount of simulated change, large predictive uncertainty will result when both error and changes are large, whereas, when either model error or simulated alteration are small, the resulting predictive uncertainty may be relatively small.

B.2.3 Model Calibration Error and Adjusted Flow Alteration

The uncertainty volume, or margin of safety, for a 90-day low flow can be calculated as the difference between the upper and lower flow value, multiplied by 90 days. For example, if the baseline 90-day low flow at a

stream location were 100 cfs, and the difference between the simulated and observed 90-day low flow were 5%, or 5 cfs, the calculated margin of safety would be:

$$5ft^3/s * 90days * \frac{1.0MGD}{1.547ft^3/s} = 291MG \tag{1}$$

The uncertainty volume of 291 MG could then be used to determine potential additional storage needed, or amount of conservation needed to meet off-stream needs in total without reducing remaining storage below a certain desired threshold.

B.2.4 Model Error Analysis - State Plan Surface Water CIA

Model calibration error rates were calculated for mean daily flow, 7q10, 30 day low-flow, and 90 day low-flow metrics, and then these error rates were applied to the water supply management induced flow changes in the 2040 model scenario to produce an error adjusted distribution of flow changes (see Equation B.2.5 for details). Figure 384 shows an overview of the model errors in mean daily flow, 90 day low flow, 30 day low-flow and 7q10 for the base Phase 5.3/6.0 watershed models in Virginia rivers with long-term stream gauges. Model errors tend to increase as the length of the analysis period (say 90 to 7 days) and flow magnitudes decrease (drought flows), so short term drought flows can have errors in excess of 50% in some places (see Figure 384). Table 104 shows a comparison of raw and error-adjusted model percent alteration in the top 1%, 5% and 10% most altered river segments in the 2040 model analysis. This shows that when alteration rates are relatively small, the difference between the modeled flow alteration (flow change) and the error-adjusted flow alteration calculated based on that model error is relatively small. For example, if a given river segment has a +50% error in model calibration error (model simulates 50% greater flow during 90 day drought than recorded by USGS gage), and the future demand scenario shows a reduction of -5% in 90 day low flow, the error adjusted model alteration would be -7.5% (see B.2.5 for adjustment equations). In this situation, the recommendation would be to consider that the likely change to 90-day low flow will be between -5% and -7.5%, and to plan management responses accordingly. Evaluating 90-day low flow alterations with the "uncertainty interval" calculation method, 90% of river segments had an uncertainty interval of between of between +3% and -3%, and the highest single river segment interval was 15%. When both alteration rates and error rates are high, the uncertainty interval will be large, and therefore efforts should be made to ensure that model calibration is improved in those river segments. Note that the flow alteration CIA results provided in the State Plan in Chapter 4 and in Appendix A did not include error adjusted margins as communicating ranges in this format would not be practical. However, the method described herein can be used by DEQ and other stakeholders to derive margins of safety based on the results of the CIA as needed for specific project evaluations or other resource evaluations.

A comparison of the original modeled flow alteration, and the "model error adjusted" flow alterations for the mean flow, 90 day low flow, 30 day low flow, and 7q10 from the 2040 demand scenario are presented in Figures 385, 386, 387, and 388.

Table 104: Baseline model and error-adjusted model percent alteration of 90-day low flow in most highly impacted river segments in 2040 compared to 2020.

	Highest 1%	Highest 5%	Highest 10%
Modeled Alterations	-19.2	-3.3	-1.9
Adjusted Alterations	-20.0	-4.0	-2.0

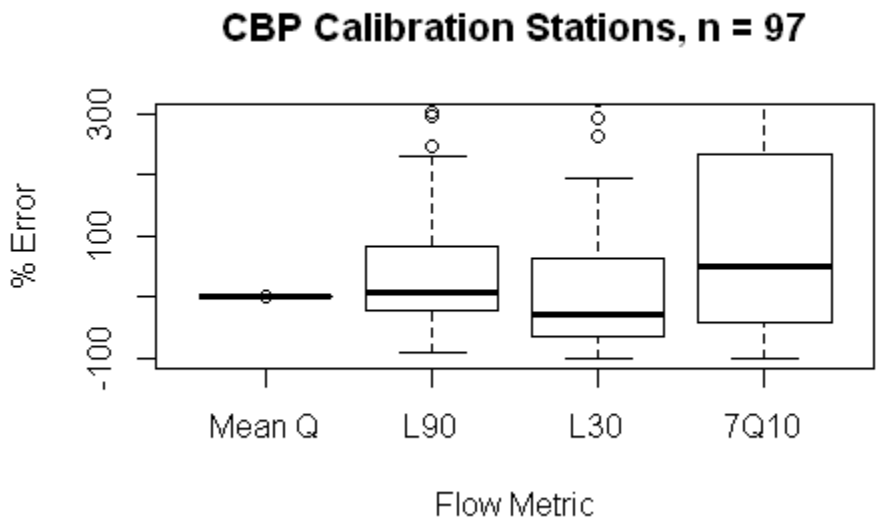

Figure 384: Model errors for mean flow, 90 day low flow, 30 day low flow and 7q10.

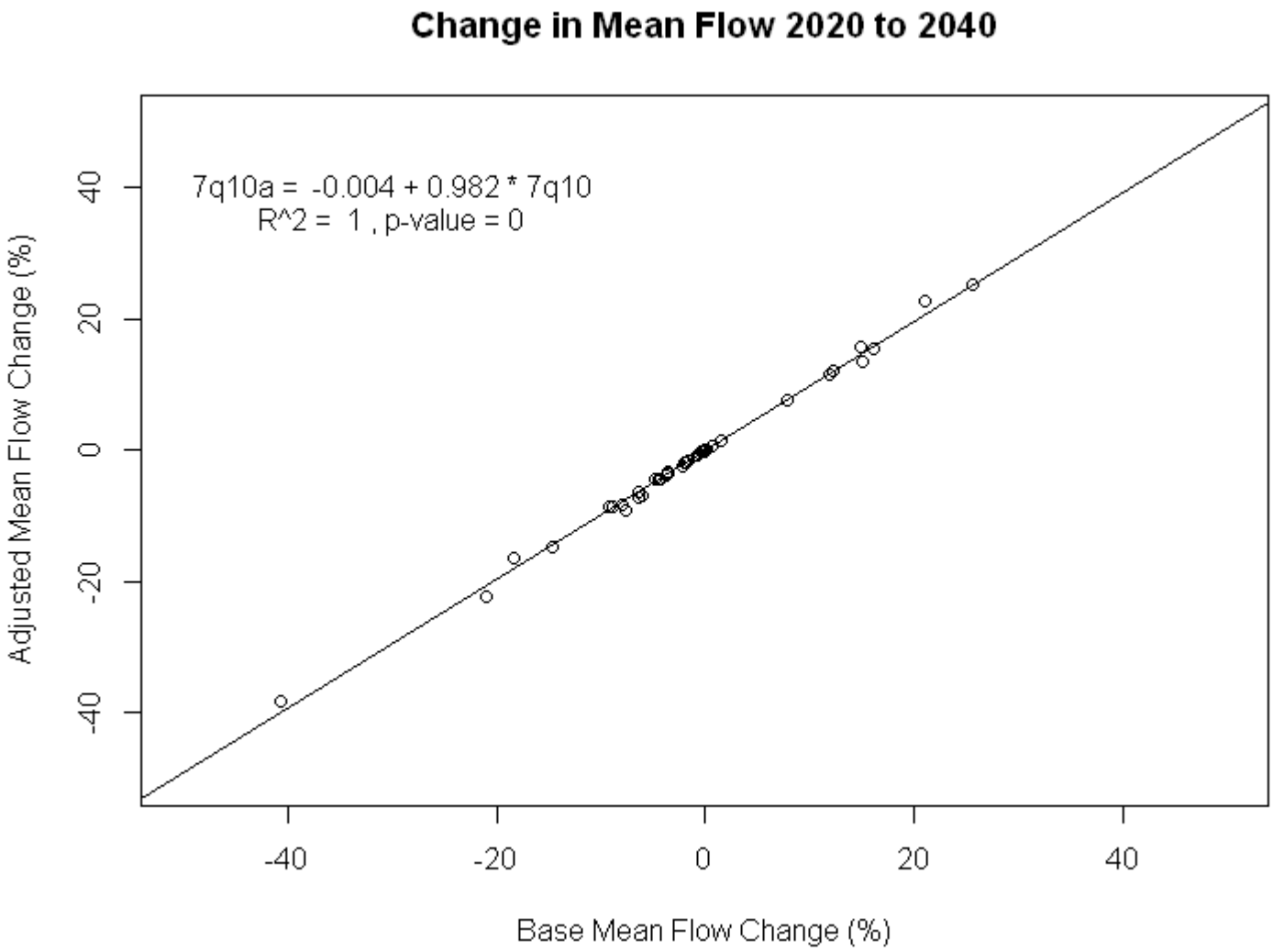

Figure 385: Comparison of modeled alterations, and error adjusted model alterations to mean daily flow from projected 2040 surface water supply demands.

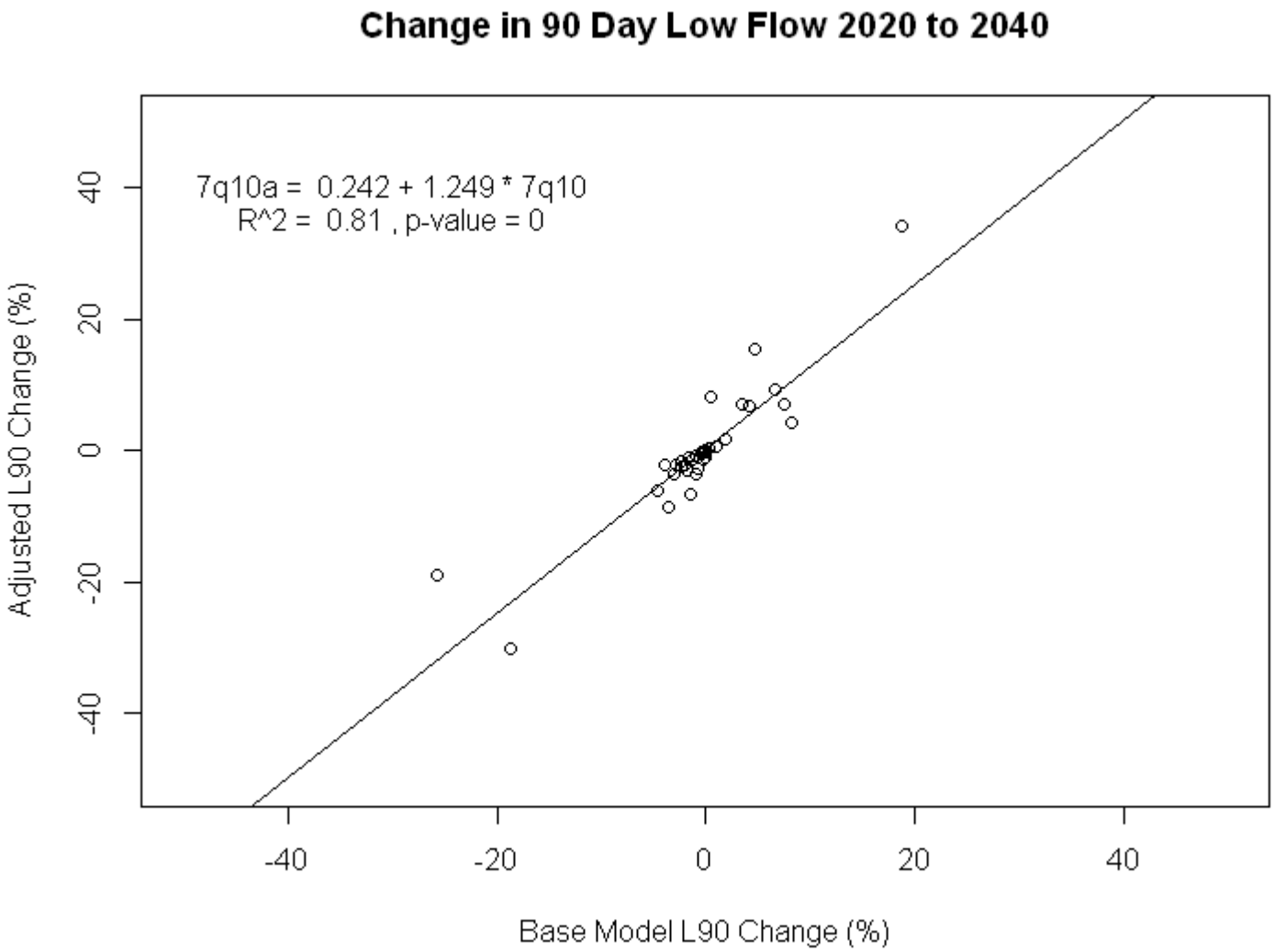

Figure 386: Comparison of modeled alterations, and error adjusted model alterations to 90 day low flow from projected 2040 surface water supply demands.

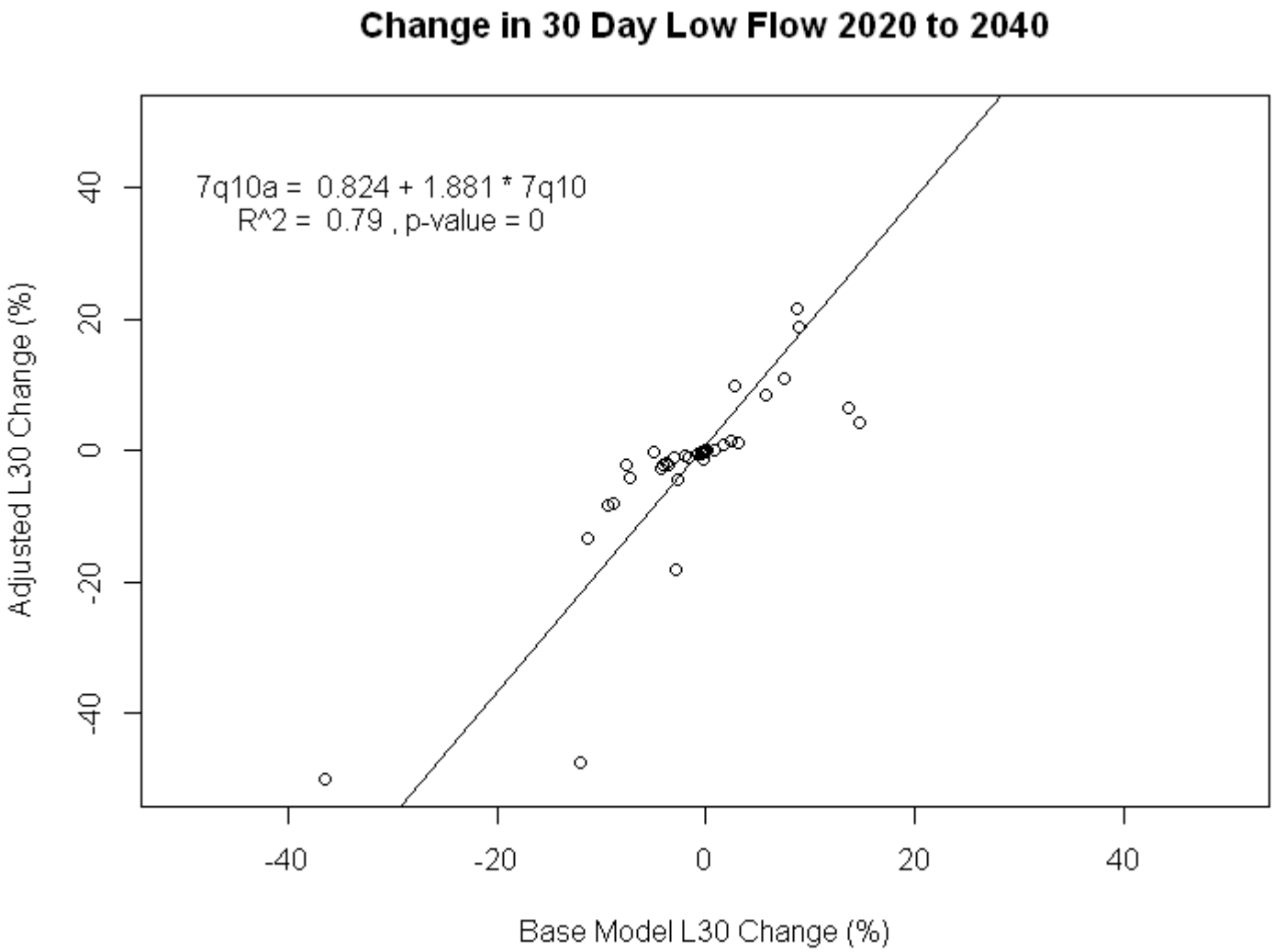

Figure 387: Comparison of modeled alterations, and error adjusted model alterations to 30 day low flow from projected 2040 surface water supply demands.

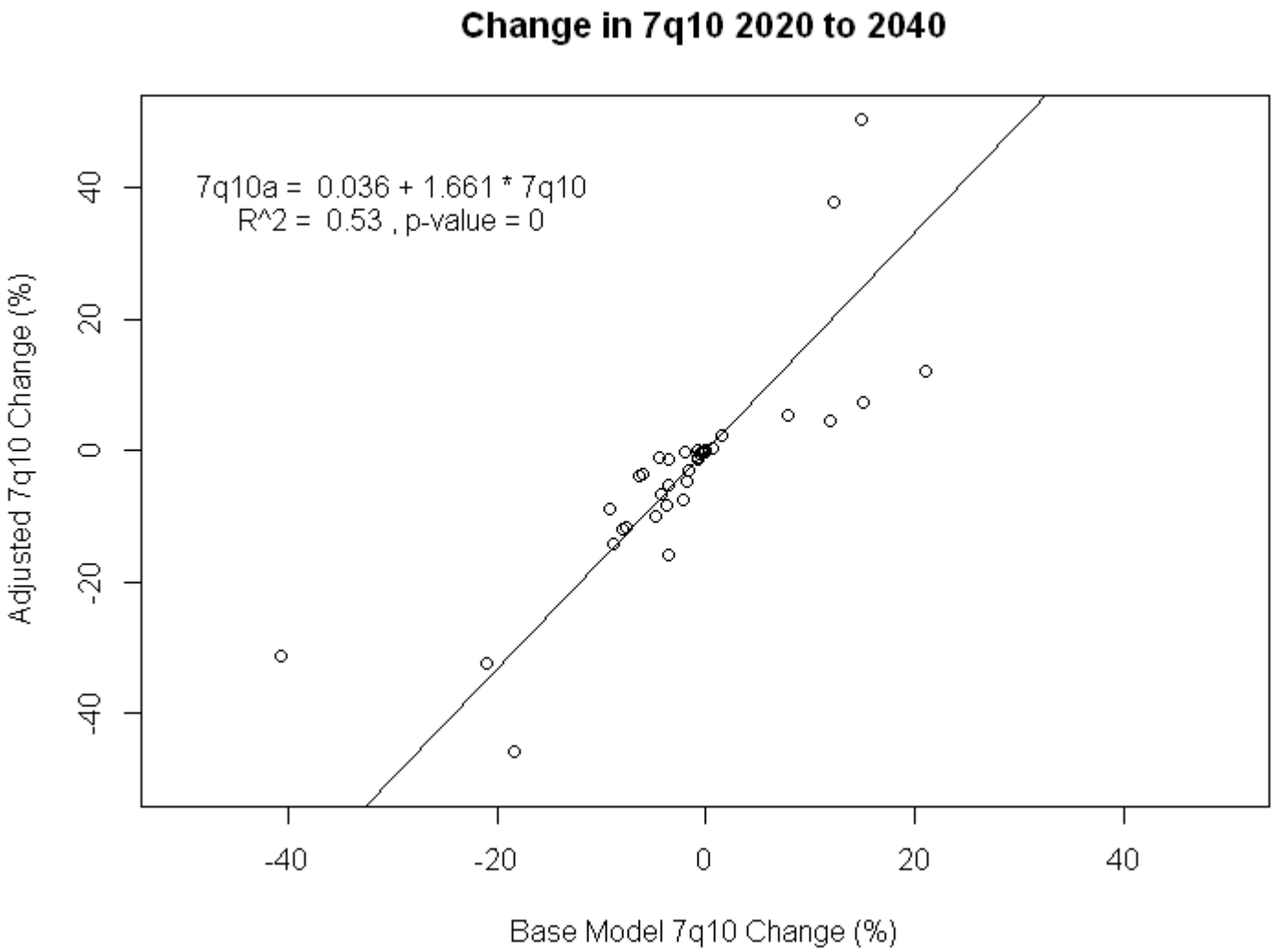

Figure 388: Comparison of modeled alterations, and error adjusted model alterations to 90 day low flow from projected 2040 surface water supply demands.

B.2.5 Bias Corrected Flow Alteration Equations

The following equations were used to calculate the error adjusted flow alteration in this analysis.

- Model flow error, e_q, can be calculated as follows:

$$e_q = \frac{(Q_m - Q_a)}{Q_a} \tag{2}$$

  where Q_m = modeled flow metric, Q_a = actual (observed) flow metric

- If given any model error fraction (100 * %) and a modeled flow change we can calculate the actual alteration (A_a) from the modeled alteration (A_m) as follows:

$$A_a = A_m * (e_q + 1.0) \tag{3}$$

  where A_m = modeled alteration fraction, A_a = actual alteration fraction

- Example: Q_m = 100.0 Q_a = 130.0
  e_q = (100.0 - 130.0) / 130.0 = -0.231
  $Q_s cen$ = 93.0
  A_m = ($Q_s cen$ - Q_m) / Q_m = (93.0 - 100.0) / 100.0 = -0.07 = -7%
  $A_a m$ = -7% * (-0.231 + 1.0) = -5.4%

B.3 Climate Change Modeling Background

Global circulation models (GCMs) used to simulate the effect of increased CO_2 in the atmosphere project that mean daily temperatures and maximum seasonal and annual temperatures will increase in the coming decades. This section aims to quantify the extent to which monitored and modeled trends may suggest the potential for water supply impacts due to climate change, the potential for regional differences in impacts, and how available models might be used to understand the potential magnitude of management responses needed to address these impacts. The following questions about global climate models were considered in the context of their application in this analysis:

- **Will increased air temperatures lead to increased precipitation every year?** No/uncertain. None of the models currently under consideration project that these changes will occur every year, however, the analytical approaches that have been thus far developed do not *attempt* to answer that question. These models are "down-scaled" models, and were produced by super-imposing a set of modeled mean annual and event based changes in precipitation on the historical meteorological record.

- **How will future temperature increases impact evapotranspiration?** All climate models in the 31 model ensemble evaluated by the CBP predict increasing temperatures due to increasing atmospheric CO_2, and those increased temperatures will lead to increased evaporative losses, especially during the growing season. These increased evaporative losses will effect water bodies, power-cooling, and transpiration (plants).

- **Will increases in precipitation offset increased evapotranspiration?** This depends on model used, and timing. Considering change expressed in terms of inches per year of Evap and Precip, model scenarios show a range of changes, with precipitation increases sometimes exceeding evaporation, and vice-versa. During the winter precipitation far exceeds evaporation and therefore even large changes in evaporation will result in negligible impacts to the flow regime. Because ET is of little consequence in the winter, changes in the winter precipitation is therefore projected to have the greatest impact on mean annual flows through the year 2055. From roughly May-September, evaporation exceeds precipitation in all but the wettest years, therefore evaporation changes will have a greater impact to flows during these months than precipitation changes, with the exception of high-intensity storms during which the daily rate of precipitation can exceed evaporation.

- **Is temperature change or precipitation change responsible for the greatest potential climate change impacts?** The scenarios that were considered in this analysis, and in the CBP's 2019 report were chosen based on the understanding that increasing temperature would lead to increased precipitation on average. The range of changes in precipitation from these ensembles is larger than the range of changes in evaporation, therefore precipitation may play the largest role in determining flow increases and decreases in these scenarios. Though this is a reasonable approach when looking at long term average flows, extreme drought flows are mostly a function of 12-24 month meteorology, and therefore, the lack of a "high evaporation, low precipitation" scenario means that the "dry" scenario used herein may underestimate the potential severity of future drought flows if a combination of high temperatures and low precipitation should occur simultaneously.

- **How will increasing storm intensities impact water supply systems?** More intense storms during warm months can be a benefit to systems with significant reservoir storage as they may result in significant runoff and therefore restore depleted storage. On the other hand, direct intakes will see negligible benefits from more intense storms as flows will leave the system quickly.

- **Are the climate change model scenarios used in the State Plan consistent with those that are used to project conditions for the CB TMDL?** The climate scenarios used in the State Plan were drawn from the suite of simulations that the CBP/USGS analyzed as part of their recent climate change modeling evaluations. Because water supply analyses tend to place additional emphasis on extreme droughts that can cause water supply system failure, and critical conditions for aquatic organisms, the 10th percentile scenario ended up being the one that showed greatest negative impacts from our perspective, whereas, the water quality simulation might be expected to be more sensitive to the 90th percentile scenario.

B.3.1 Representative Concentration Pathways and Ensemble Models

Meteorological inputs include the basic elements needed for a water balance: precipitation, and fundamental variables (temperature, relative humidity) driving potential evapotranspiration. The following are additional technical details about the models employed in this analysis that are especially relevant to its use as a water supply planning tool. For more information, see the Chesapeake Bay Programs documentation of climate change models and scenarios [Bhatt, 2019].

B.3.2 Method of Calculating Potential Evapotranspiration

Potential evapotranspiration (PET) is calculated using temperature, relative humidity, and solar radiation. Historical PET estimates were done with the Penman method, and future simulations of PET were conducted using the Hargreaves-Semani method (CBP 2019, pp.25-26). The Hargreaves-Semani method performs better with the higher temperatures forecasted to occur in 2055 conditions, however it does not produce identical results to the historical method under equivalent input conditions. This can lead to slightly counter-intuitive estimates when increases in future temperature are small, such as in the p10 scenario. Future versions of the baseline model using the Hargreaves-Semani method would make these comparisons more straight-forward.

B.3.3 Representative Concentration Pathways

The IPCC has adopted the term "Representative Concentration Pathway" (RCP), to represent ranges of potential future global greenhouse gas emissions. RCP 4.5 is on the continuum from RCP 2.6 to RCP 8.5, with RCP 2.6 being the lowest future CO_2 concentration, and 8.5 being the highest future CO_2 concentration. The CBP evaluated 31 climate change models based on the RC P4.5 emissions scenario. From these models, 4 "integrated" ensemble scenarios were created by CBP to explore a range of watershed responses to increased CO_2 in the year 2055. OWS performed water supply planning simulations based on 3 of these scenarios: the 50th, the 10th and 90th percentile temperature and precipitation responses (the 4th integrated a different method of modeling evapotranspiration but performed poorly with increasing temperatures, see CBP2020 pp.25-26). The 50th percentile scenario was used by the CBP for their final analysis of changes to flow, nutrients and sediment responses (p. 101 "CBP 2019 Climate Change Documentation"), and represents a median range of potential water supply impacts from climate change. The 10th and 90th percentile scenarios were developed by CBP to "define the range of uncertainty in projected future" (p. 27, CBP2019). Because water supply systems are most sensitive to short duration critical drought conditions, specifically in the range of 1-90 days in duration, the 10th and 90th percentile scenarios proved useful in showing a range of effects from climate uncertainty in the potential cumulative impacts of projected changes to surface water demands, with the 10th percentile scenario resulting in "dry" conditions, and the 90th percentile scenario yielding "wet" conditions.

B.3.4 Defining a "Worst Case" Climate Change Scenario

The 10th and 90th percentile scenarios refer to the relative position of these scenarios in a set of selected ensemble models, and not a probability of occurrence, so the "dry" scenario does not have a 10% chance of happening. It should also be noted that while the 10th and 90th percentile scenarios do offer a range of conditions from drier to wetter, they do not represent "worst" and "best" case climate scenarios in terms of water resources. Indeed, 10% of the scenarios in the 31 model ensemble collected by CBP were wetter, and drier than either of these selected scenarios, and, the 31 models in this ensemble only represent 1 of the 4 main RCPs.

B.4 For Future Study: Consumptive Use Analysis of Point Source and Withdrawal Data in Virginia

This section contains supplemental information used to perform estimates of consumptive use across multiple water use type sectors. Estimates were based on a combination of paired facility withdrawal and discharge data, reported disaggregated use data, and literature review values.

B.4.1 Consumptive Use for Industrial and Commercial Users

The analysis of point source and withdrawal data for industrial users had a large difference between literature (0.1) and median study value (0.39, see 389). Also, purchases from municipal sources, or discharges into the municipal wastewater treatment streams may affect the calculated consumptive use water balance for commercial and industrial users. Due to size of sample and size of facilities represented, literature was considered to be more reliable estimate, but future updates to this analysis should attempt to determine consumptive use factors on a facility by facility basis where data is available. Matched facility value was 0.13, literature was 0.1, and total volume of study was 0.1, selected study total/literature due to the fact that some return flows for commercial operations may enter via the municipal treatment system. Results of VPDES study indicated that the winter base rate method would be most appropriate for municipal return flows.

B.4.2 Winter Base Rate Method Formula

This analysis used February demand as an estimate of baseline non-consumptive use amount per month. A separate CU factor (C) is then calculated for months where demand is greater than February demand (1), and for months less than February Demand (2), as shown in the equation below:

$$C_m = \frac{W_m - W_f}{W_m}; W_m >= W_f \tag{4}$$

$$C_m = 0.0; W_m < W_f \tag{5}$$

B.4.3 Estimating Transmission Losses

"Unaccounted Losses", or "transmission losses" are reported in disaggregated water use section of the water supply plan, and ranges from 0% - 67%, with the median value at approximately 13%. These values were under-reported, since many systems do not have a reliable means of estimating transmission losses, and even when systems have metering at all relevant points, pipe leaks may result in outflow ("exfiltration") to or inflow from surrounding soil (called "infiltration") depending on sub-surface moisture levels. In the case of infiltration, total discharged water can actually exceed the original withdrawal yielding a negative consumption fraction. For exfiltration, it is assumed that some portion of water that exfiltrates will be removed from the water budget via transpiration, some portion may be detained so that it reaches the stream at some later time (when conditions are wetter), and that some other portion portion of these losses may make their way back to the stream as base flow. Further confounding the transmission loss category is the fact that a majority of systems did not report data for process loss, instead lumping process water into the unaccounted loss category. Since process water most often returns to the stream of origin immediately, including process water in the unaccounted loss category would over-estimate transmission losses.

Because this quantity is under-reported, and because the reported data often over-estimates transmission loss by lumping process water with transmission losses, this analysis used a fixed transmission loss fraction of 10% of all municipal withdrawals in addition to consumptive losses before discharge to the stream, based on a comparison of reported losses with literature values for municipal consumptive use (see 389). By adding the 10% unaccounted loss factor, a median total consumptive use percent of 20% for municipal withdrawals is calculated. This compares well with the literature value of 20%. Because this value is 5% lower than that given in the total volume analysis, it is considered a conservative estimate of consumptive use. The lower value was selected for this analysis primarily because of the potential for augmented base flows due to transmission losses, the short duration of values available in our point source analysis, and evidence of possible inconsistent data reporting noted by the study's authors. Another potential reason for the total

volume analysis to produce higher consumptive uses at times is that it includes drought months when there is a higher than normal consumptive water use by municipal systems. Future analyses should contain a methodology for estimating the potential increases in municipal consumptive use during drought conditions to address this shortcoming.

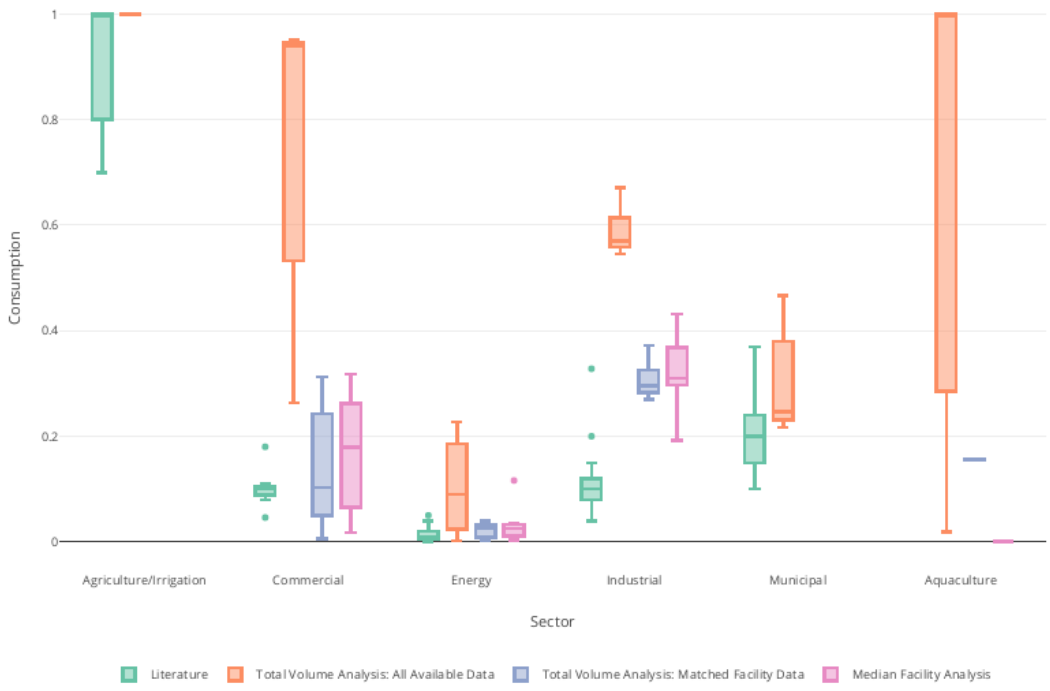

Figure 389: Comparison of literature values with data from the VPDES discharge monitoring reports and VWUDS annual water withdrawal reporting data.

C Appendix - Projected Population and Projected Water Demand By Locality

Table 105: Virginia Population Trend

Locality	2020	2030	2040	20 Year Percent Change
Virginia, Statewide	8,655,021	9,331,666	9,876,728	14.12
Accomack	32,754	29,292	25,558	-21.97
Albemarle	111,039	125,718	138,485	24.72
Alleghany	14,950	13,620	12,157	-18.69
Amelia	13,088	13,792	14,310	9.34
Amherst	31,831	31,402	30,599	-3.87
Appomattox	15,866	16,742	17,391	9.61
Arlington	249,298	274,339	295,383	18.49
Augusta	75,734	80,035	83,245	9.92
Bath	4,377	3,980	3,545	-19.00
Bedford	79,241	84,604	88,794	12.05
Bland	6,365	6,042	5,652	-11.20
Botetourt	33,387	34,484	35,130	5.22
Brunswick	16,320	15,045	13,617	-16.56
Buchanan	21,120	17,883	14,508	-31.30
Buckingham	16,946	17,455	17,736	4.66
Campbell	55,665	57,325	58,240	4.62
Caroline	30,740	34,821	38,372	24.83
Carroll	29,014	28,579	27,805	-4.16
Charles City	6,982	6,941	6,816	-2.38
Charlotte	11,929	11,527	10,993	-7.85
Chesterfield	353,841	396,647	433,508	22.51
Clarke	14,509	15,279	15,842	9.19
Craig	5,084	5,020	4,896	-3.72
Culpeper	52,422	61,073	68,757	31.16
Cumberland	9,792	10,105	10,286	5.05
Dickenson	14,267	13,052	11,706	-17.95
Dinwiddie	28,669	30,473	31,857	11.12
Essex	10,725	11,019	11,171	4.16
Fairfax	1,162,504	1,244,025	1,308,224	12.54
Fauquier	71,395	78,698	84,851	18.85
Floyd	15,754	16,519	17,062	8.31
Fluvanna	26,965	30,258	33,097	22.74
Franklin	56,237	60,354	63,626	13.14
Frederick	90,115	104,608	117,452	30.34
Giles	16,892	16,822	16,548	-2.03
Gloucester	37,343	38,181	38,530	3.18
Goochland	23,547	26,702	29,451	25.07
Grayson	15,319	13,701	11,956	-21.95
Greene	20,348	22,669	24,653	21.16
Greensville	11,340	11,144	10,817	-4.60
Halifax	34,389	32,457	30,176	-12.25
Hanover	109,244	119,360	127,755	16.94

Henrico	332,103	363,259	389,173	17.18
Henry	50,986	46,764	42,073	-17.48
Highland	2,258	2,080	1,881	-16.69
Isle Of Wight	38,060	41,823	44,977	18.17
James City	78,016	92,210	104,915	34.48
King And Queen	6,953	7,033	7,024	1.02
King George	26,429	31,053	35,180	33.11
King William	17,167	19,011	20,576	19.85
Lancaster	10,916	10,452	9,871	-9.58
Lee	23,718	23,632	23,258	-1.94
Loudoun	430,584	554,808	669,100	55.39
Louisa	36,737	41,959	46,534	26.67
Lunenburg	12,122	11,465	10,685	-11.86
Madison	13,299	13,542	13,612	2.35
Mathews	8,665	8,277	7,796	-10.03
Mecklenburg	30,691	29,527	28,030	-8.67
Middlesex	10,897	11,280	11,515	5.67
Montgomery	100,746	108,102	113,946	13.10
Nelson	14,828	14,850	14,688	-0.94
New Kent	23,474	28,104	32,272	37.48
Northampton	11,778	10,949	10,008	-15.03
Northumberland	12,047	11,789	11,393	-5.42
Nottoway	15,651	15,411	14,988	-4.23
Orange	36,119	40,969	45,194	25.12
Page	23,838	23,888	23,643	-0.82
Patrick	17,682	16,565	15,273	-13.62
Pittsylvania	61,379	60,523	58,946	-3.96
Powhatan	29,909	33,440	36,471	21.94
Prince Edward	23,272	24,905	26,190	12.54
Prince George	37,613	39,408	40,674	8.14
Prince William	478,134	571,844	656,178	37.24
Pulaski	34,109	33,148	31,805	-6.76
Rappahannock	7,202	7,237	7,184	-0.25
Richmond	9,141	9,206	9,157	0.18
Roanoke	94,145	97,249	99,082	5.24
Rockbridge	22,636	23,290	23,643	4.45
Rockingham	82,720	89,156	94,335	14.04
Russell	26,738	24,607	22,229	-16.86
Scott	21,949	20,961	19,740	-10.06
Shenandoah	43,233	46,984	50,064	15.80
Smyth	30,182	28,361	26,237	-13.07
Southampton	17,739	17,711	17,466	-1.54
Spotsylvania	136,192	158,025	177,369	30.24
Stafford	154,093	183,161	209,250	35.79
Surry	6,501	6,282	5,992	-7.83
Sussex	11,370	10,657	9,831	-13.54
Tazewell	41,428	39,450	37,038	-10.60
Warren	40,164	44,053	47,305	17.78
Washington	53,918	54,802	54,990	1.99
Westmoreland	18,047	18,467	18,649	3.34

Wise	37,844	36,400	34,545	-8.72
Wythe	28,587	28,791	28,638	0.18
York	69,582	75,492	80,327	15.44
Alexandria City	166,261	182,067	195,240	17.43
Bristol City	16,715	16,229	15,556	-6.93
Buena Vista City	6,302	6,222	6,066	-3.74
Charlottesville City	50,714	52,376	53,352	5.20
Chesapeake City	249,244	270,506	287,913	15.51
Colonial Heights City	17,631	17,766	17,680	0.28
Covington City	5,677	5,281	4,831	-14.91
Danville City	40,169	35,358	30,234	-24.73
Emporia City	5,462	5,317	5,111	-6.42
Fairfax City	25,047	26,397	27,388	9.34
Falls Church City	14,988	17,032	18,815	25.54
Franklin City	8,268	8,140	7,915	-4.27
Fredericksburg City	29,403	34,015	38,094	29.56
Galax City	6,508	6,286	5,993	-7.91
Hampton City	135,530	127,842	118,777	-12.36
Harrisonburg City	56,012	63,037	69,110	23.38
Hopewell City	22,852	22,781	22,433	-1.83
Lexington City	7,447	7,622	7,698	3.37
Lynchburg City	82,791	90,526	96,956	17.11
Manassas City	43,099	46,332	48,916	13.49
Manassas Park City	17,086	20,284	23,153	35.51
Martinsville City	13,002	11,573	10,038	-22.79
Newport News City	181,581	179,752	175,762	-3.20
Norfolk City	246,881	249,889	249,753	1.16
Norton City	3,906	3,857	3,762	-3.67
Petersburg City	31,671	30,166	28,328	-10.55
Poquoson City	12,382	12,635	12,726	2.77
Portsmouth City	95,027	90,715	85,397	-10.13
Radford City	18,446	19,403	20,097	8.95
Richmond City	232,533	245,483	255,094	9.70
Roanoke City	100,891	102,388	102,590	1.68
Salem City	25,953	26,141	26,002	0.19
Staunton City	25,293	25,577	25,541	0.98
Suffolk City	94,733	109,424	122,402	29.21
Virginia Beach City	457,699	467,187	470,700	2.84
Waynesboro City	22,613	23,835	24,734	9.38
Williamsburg City	15,463	17,008	18,306	18.39
Winchester City	28,804	31,005	32,770	13.77

Table 106: Withdrawal Demand (MGD) by Locality in Virginia

Locality	**2020 Demand**	**2030 Demand**	**2040 Demand**	**20 Year % Change**
Lynchburg	0.13	0.92	1.71	1217.09
Orange	2.64	4.38	6.11	131.11
Culpeper	6.66	10.98	15.30	129.96

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Caroline	5.26	8.13	11.00	109.16
Frederick	6.19	9.45	12.70	105.14
Greensville	3.22	4.68	6.15	91.26
Amelia	1.12	1.60	2.07	84.54
James City	8.01	11.10	14.20	77.30
Clarke	1.36	1.88	2.40	76.88
Spotsylvania	15.23	20.99	26.75	75.68
Hanover	10.14	13.79	17.44	71.97
Manassas	11.99	16.22	20.45	70.54
Prince George	0.34	0.45	0.57	69.12
Stafford	13.19	17.69	22.20	68.33
Dinwiddie	2.66	3.46	4.26	60.33
Powhatan	2.78	3.62	4.46	60.28
Martinsville	1.96	2.55	3.13	59.32
Salem	4.11	5.32	6.52	58.37
Gloucester	3.22	4.14	5.05	56.74
Fluvanna	3.77	4.82	5.88	55.82
Henrico	32.54	40.78	49.01	50.59
Augusta	12.65	15.75	18.85	49.10
Charles City	1.89	2.35	2.80	47.90
Fauquier	7.49	9.27	11.04	47.37
Goochland	5.06	6.15	7.24	43.19
Roanoke City	19.72	23.98	28.23	43.17
Chesapeake	7.75	9.38	11.01	42.10
Louisa	1835.36	2210.43	2585.49	40.87
Bedford County	17.97	21.58	25.19	40.19
Botetourt	7.00	8.35	9.69	38.41
Albemarle	15.31	18.17	21.03	37.31
Amherst	19.03	22.57	26.11	37.21
Virginia Beach	30.88	36.53	42.17	36.57
Roanoke County	8.81	10.37	11.93	35.46
New Kent	15.79	18.57	21.35	35.26
Chesterfield	109.49	128.68	147.88	35.06
Rockingham	26.38	31.00	35.61	34.99
Craig	2.74	3.18	3.63	32.49
Charlotte	3.44	3.99	4.54	32.14
King George	3.55	4.11	4.67	31.72
Franklin City	0.84	0.97	1.11	31.10
Loudoun	25.76	29.58	33.40	29.68
King William	17.22	19.72	22.23	29.15
Nottoway	1.53	1.74	1.94	26.58
Warren	12.41	14.06	15.70	26.56
Floyd	4.08	4.60	5.12	25.52
Southampton	5.80	6.54	7.28	25.51
Shenandoah	7.35	8.20	9.05	23.18
Prince Edward	2.53	2.82	3.11	23.10
Franklin County	6.88	7.66	8.43	22.60
Richmond City	64.15	71.21	78.27	22.02
Madison	1.80	1.99	2.18	21.02

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Rappahannock	0.95	1.05	1.14	20.36
Essex	1.47	1.61	1.76	19.59
Petersburg	0.04	0.04	0.04	17.86
Middlesex	1.03	1.11	1.19	16.30
Patrick	3.49	3.78	4.06	16.06
Smyth	8.10	8.74	9.39	15.89
Nelson	2.40	2.57	2.74	14.33
Fairfax City	0.06	0.07	0.07	13.56
Newport News	28.91	30.86	32.81	13.50
Fairfax County	107.70	114.91	122.13	13.40
Montgomery	25.00	26.58	28.15	12.60
Isle of Wight	24.48	25.98	27.49	12.28
Arlington	128.73	136.03	143.33	11.34
Appomattox	1.28	1.34	1.41	9.98
Rockbridge	3.76	3.94	4.13	9.81
Lancaster	0.93	0.98	1.02	9.76
Dickenson	6.69	7.00	7.31	9.21
Bland	0.72	0.75	0.78	8.97
Richmond County	0.75	0.79	0.82	8.85
Wythe	10.97	11.42	11.87	8.16
Carroll	3.17	3.30	3.42	8.03
Page	2.67	2.77	2.88	7.72
Accomack	9.63	10.00	10.37	7.70
Waynesboro	6.37	6.60	6.84	7.36
King and Queen	1.15	1.19	1.23	6.98
Northampton	2.80	2.90	2.99	6.79
Westmoreland	1.97	2.03	2.09	6.06
Suffolk	92.10	94.88	97.65	6.02
Mathews	0.74	0.76	0.78	5.86
Washington	10.72	11.03	11.33	5.64
Pittsylvania	14.73	15.12	15.51	5.31
Northumberland	2.49	2.55	2.62	5.06
Prince William	231.23	237.08	242.92	5.05
Giles	69.86	71.48	73.10	4.64
Hopewell	145.27	148.01	150.75	3.77
Lunenburg	1.21	1.23	1.24	2.60
Sussex	1.49	1.51	1.53	2.52
Brunswick	3.80	3.84	3.89	2.33
Buckingham	8.14	8.20	8.27	1.57
Mecklenburg	6.49	6.54	6.58	1.53
Halifax	15.45	15.57	15.69	1.51
York	835.92	838.24	840.56	0.55
Grayson	2.60	2.61	2.62	0.54
Pulaski	6.39	6.41	6.43	0.54
Scott	1.60	1.61	1.61	0.20
Henry	8.26	8.26	8.27	0.10
Danville	5.38	5.38	5.38	0.09
Surry	1816.49	1816.70	1816.90	0.02
Bath	13.37	13.37	13.37	0.00

Table 106 – continued from previous page

Highland	6.00	6.00	6.00	0.00
Lee	2.44	2.44	2.44	0.00
Bristol	0.00	0.00	0.00	0.00
Buena Vista	1.15	1.15	1.15	0.00
Charlottesville	0.03	0.03	0.03	0.00
Galax	1.75	1.75	1.75	0.00
Hampton	0.09	0.09	0.09	0.00
Harrisonburg	0.00	0.00	0.00	0.00
Norfolk	0.30	0.30	0.30	0.00
Williamsburg	1.36	1.36	1.36	0.00
Alleghany	41.38	41.35	41.32	-0.16
Radford	2.23	2.23	2.22	-0.16
Portsmouth	0.00	0.00	0.00	-0.29
Emporia	1.01	1.01	1.01	-0.48
Tazewell	5.45	5.38	5.30	-2.81
Covington	2.14	2.10	2.07	-3.37
Campbell	8.54	8.38	8.21	-3.93
Buchanan	2.11	2.00	1.90	-10.01
Wise	6.27	5.95	5.64	-10.02
Fredericksburg	0.05	0.04	0.04	-21.10
Greene	1.79	1.59	1.39	-22.12
Russell	1.96	1.72	1.48	-24.59
Norton	1.13	0.97	0.82	-27.33
Cumberland	1.60	1.22	0.85	-46.90

Appendix D: 2020 State Plan Public Comment Summary and Agency Responses

Response Themes (in order they appear in the document)	
Theme Number	**Theme Title**
1	Agriculture
2	Climate Change
3	Current and Future Water Demand
4	Ecological Flows and Elfgen Metric
5	Exempt User Surface Water Scenario
6	Form and Function of the State Water Resources Plan
7	Funding
8	Groundwater Modeling and Groundwater Withdrawal Impacts
9	Indirect Potable Reuse and Other Alternatives
10	Potential Unmet Demand
11	Power Generation
12	SWIFT
13	VAHydro Surface Water Model Methods and Results
14	Water Quality
15	General Comments and Requests for Additions or Revisions

Comments Received	
Theme 1	**Agriculture**

Th.1 – C.1 – David's Nursery LLC

Comment Summary: Comment acknowledges the need for regulating surface water in cases where there are downstream users, but there are almost never downstream users on the Eastern Shore. Recommends agricultural ponds continue to not be regulated. Should be wording (on p.xxxvii, 114, 148) that supports creation of more agricultural ponds on the Eastern Shore b/c (1) water pumped from ponds reduces groundwater uptake, (2) ponds provide catch basins for runoff from fields.

DEQ Response: The use of surface water from ponds on the Eastern Shore is an important alternative to groundwater where available. DEQ works with water users through both water withdrawal permitting and planning to identify and pursue alternatives where applicable. However, determining whether and how surface water use is regulated depends on the location and type of pond. Per 9VAC25-210-310.A.10, surface water withdrawals from privately owned agriculture ponds that are not located in the bed of a perennial or intermittent stream or wetland are excluded from the requirement for a Virginia Water Protection (VWP) withdrawal permit. Many ponds on the Eastern Shore do fall into this category as they are primarily dug ponds filled by a combination of storm water runoff, surficial groundwater, and supplemental refill via confined groundwater wells. Ponds or impoundments constructed in line with an intermittent or perennial stream, including those that discharge into tidal streams or the Chesapeake Bay, do require a VWP permit unless they meet other exclusions pursuant to 9VAC25-210-310.

Revision made to the Plan: The following language identifying surface water from impoundments and ponds as an alternative has been added to the executive summary on page xxxvii, in Chapter 4 on page 103, and in Appendix A page 148. "Surface water from dug ponds and other types of surface water impoundments can be an effective alternative to groundwater for agricultural water use."

Th.1 – C.2 – Northern Virginia Regional Commission

Comment Summary: Comment notes that agricultural land is projected to decrease throughout much of the Potomac basin but agricultural water consumption is projected to remain stable. However, Tables 71 and 75 show agricultural demands remaining constant in the Middle Potomac minor basin. Does DEQ believe per acre agricultural consumption will increase?

DEQ Response: Projected agricultural water demand in the Middle Potomac Minor Basin (Table 71) and within the Lower Potomac Minor Basin (Table 75) are projected to remain stable in 2020, 2030, and 2040. However, DEQ did not develop these estimates of agricultural demands; projections of use for all categories come from the local or regional water supply plans within the basins. For instance, the Northern Virginia Regional Water Supply Plan submitted in 2012 notes on page 5-9 that "estimates of existing use from the 2002 Census of Agriculture from USDA were used as a base number and no growth (0%) was assumed, recognizing a probable decrease in agricultural land in the future."

A common thread in many water supply plans was the challenge in developing accurate current or future use estimates for agricultural water use. DEQ recognizes this as an area for improvement in future water supply plan cycles.

No revisions made to the Plan.

Theme 2	Climate Change

Th.2 – C.1 – Fauquier Climate Change Group

Comment Summary: Comment notes that Fauquier Climate Change Group supports comprehensive water use projections, up-to-date climate science, and inclusion of 20 regional analyses. Agrees that water supply planning must occur at a regional scale. Supports DEQ's efforts to incorporate potential for droughts more severe than any on record. Encourages DEQ to incorporate Plan findings into future water planning to prepare for climate scenarios and protect resources long-term. Requests that DEQ examine alternative regulatory strategies for currently exempt facilities.

DEQ Response: The State Plan and the analysis included within is a first step, providing a screening tool to inform future planning efforts.

No revisions made to the Plan.

Th.2 – C.2 – James River Association

Comment Summary: Comment states that the Commonwealth must plan for climate change and DEQ's work to incorporate climate change scenarios within the Draft 2020 State Plan is appreciated. Comment encourages water supply planning to consider the dry climate scenario when evaluating resilience of water resources and the ability to meet demands.

DEQ Response: This comment is noted. The Dry Climate Scenario can be useful as a screening tool to determine where potential impacts to streamflow could be most pronounced if droughts are more severe in the future. DEQ notes several next steps that will help improve climate modeling capability in the section "Expanding Climate Change Simulation period and Spatial Area" (page 108) including refining and/or developing the next iteration of a dry climate scenario that could be used in a planning or other resource management framework.

No revisions made to the Plan.

Theme 3	Current and Future Water Demand

Th.3 – C.1 – City of Richmond

Comment Summary: Comment notes inconsistencies in water demand and raw water withdrawal projections (Table 5, 38, and Table 107).

DEQ Response: The City of Richmond's original projections submitted in the 2008 City of Richmond water supply plan included only the amount the City of Richmond uses for its residents and did not disaggregate amounts wholesaled to neighboring counties. During the five-year compliance process, the demand projection table (Whitman, Requardt & Associates 2018) was updated by the City directly in the DEQ database with the projected sales estimates by decade included. This updated projection entered by the City was applied to the City of Richmond water demands for the purpose of the Draft 2020 State Plan. Water demand projections for the City of Richmond can be reviewed and/or updated in DEQ's VAHydro content management system at any time. You may contact your regional water supply planner based on the contact map found on the Water Supply Planning Website (https://www.deq.virginia.gov/water/water-quantity/water-supply-planning) if you have questions or would like assistance with this.

No revisions made to the Plan.

Th.3 – C.2 – City of Richmond

Comment Summary: Comment notes that the Draft 2020 State Plan does not address peak day demands.

DEQ Response: This is correct as the model inputs from both water supply plans and withdrawal reporting are provided as monthly demands. With these data limitations, cumulative impact metrics such as 30 day low flow, 90 day low flow, consumptive use, and 7Q10 were selected in part due to the fact that they are not highly impacted by uncertainty in peak days. However, peak day demands are important at a facility scale and incorporating these higher demands into future evaluations, where sufficient data is provided, can be considered.

No revisions made to the Plan.

Th.3 – C.3– Chesterfield County
Comment Summary: Comment recommends revising Draft 2020 State Plan to include actual (instead of estimated) demand for Swift Creek WTP for 2020 (p.152, Table 30). Also recommend any projected/estimated values be replaced with actual values. **DEQ Response:** Swift Creek WWTP used the 2020 projected value of 8.13 MGD based on locally provided projections; as appropriate, and where staffing allows, DEQ has made updates to 2020 estimates based on reported use. However, much of the model development was completed prior to 2020 reported use data being received and reviewed by DEQ. DEQ is happy to work with Chesterfield County to update current use estimates in VAHydro for Swift Creek and other systems and recommends maintaining the most up to date information in the system at all times so that it is reflected in DEQ evaluations. If you wish to do so, please contact your Water Supply Planner based on the contact map that can be found here: https://www.deq.virginia.gov/water/water-quantity/water-supply-planning. **No revisions made to the Plan.**
Th.3 – C.4 – Chesterfield County
Comment Summary: Comment notes that the 2040 WSP Demand of 12.48 MGD for Swift Creek WTP exceeds the 12.0 MGD safe yield. Recommend capping Swift Creek WTP demand to the 12.0 MGD value and update Table 30 to reflect this. **DEQ Response:** The 2040 demands were estimated using locally provided projections and where noted, cases when 2040 demands exceed system capacity do occur. However, that is not always an indication of an error but can indicate a need for a system to be upgraded to accommodate increasing demands. Therefore a general rule of capping demands using the safe yield is not appropriate. DEQ appreciates the additional detail on how the Swift Creek WTP and the Appomattox River Water Authority system are operated and understand that in this case the maximum demand at Swift Creek WTP will be 12.0 MGD. DEQ will address this in future plan revisions and modeling scenarios and encourages all localities to review water demand information in VAHydro to ensure the most up to date information and accurate information is captured. Given the limited differences in demand compared to cumulative demands in the model segments, an observable change in the surface water modeling results as shown in the Draft 2020 State Plan is not expected. **No revisions made to the Plan.**
Th.3 – C.5 – Chesterfield County
Comment Summary: Comment recommends that Table 30 be updated to reflect all the locations for all facilities used by Chesdin Reservoir WTP such as Brasfield Dam and Hydroelectric facilities. **DEQ Response:** As noted in your comment, Table 30 and all other such "Top Five User" tables include the location of the facility responsible for the withdrawal and demand but does not include all localities that are served by or purchase water from that facility. Note also that hydroelectric facilities and other large power generation users that are largely non-consumptive are not included in Table 30 or other "Top Five User" tables. DEQ understands the concern your comment raises and agrees a source documenting where demands are transferred between systems would be valuable. However, DEQ lacks a consistent source of data to create such a table as local submission and maintenance of volumes of transfers and sales is not consistent and future projections of these uses are rare. Local submission of water transfers and sales is inconsistent and usually does not include sufficient information to

determine where water transferred or sold is ultimately used. In addition, water supply plans do not consistently report future projections of water sales or transfers. DEQ believes that better capturing the movement of water within and without systems would help improve evaluations on state and local levels. During development of local plans, DEQ was often informed that water suppliers considered the terms of the contracts and the associated volumes confidential information.

No revisions made to the Plan.

Th.3 – C.6 – Chesterfield County

Comment Summary: Comment notes that prior clarification with DEQ indicated that demand tables in the Draft 2020 State Plan do not account for transfers, sales, etc. and therefore do not capture where the water is ultimately used. Commenter recommends that DEQ continue to work with localities to improve collection of this information to provide a better account of where water is used in addition to where it is withdrawn.

DEQ Response: DEQ understands the concern your comment raises and agrees a source documenting where demands are transferred between systems would be valuable. However, DEQ lacks a consistent source of data to create such a table as local submission and maintenance of volumes of transfers and sales is not consistent and future projections of these uses are rare. Local submission of water transfers and sales is inconsistent and usually does not include sufficient information to determine where water transferred or sold is ultimately used. In addition, water supply plans do not consistently report future projections of water sales or transfers. DEQ believes that better capturing the movement of water within and without systems would help improve evaluations on state and local levels. During development of local plans, DEQ was often informed that water suppliers considered the terms of the contracts and the associated volumes confidential information.

No revisions made to the Plan.

Th.3 – C.7 – Interstate Commission on the Potomac River Basin (ICPRB)

Comment Summary: Comment states that the discussion of the Potomac Basin is confusing because non-Virginia water use is left out. Suggest modifying narrative stating no power generation in the Potomac to qualify that as none within Virginia and note Panda Stonewall project and any degree of impact on consumptive use in model. Similarly, details on how non-Virginia withdrawals and discharges were simulated in the model. Draft 2020 State Plan suggests 2020 CO-OP water supply study demands were used but there is no further information on how these withdrawals were derived. Citation of CO-OP water supply study needs to be corrected as provided in the comment letter.

DEQ Response: The Draft 2020 State Plan utilizes data that has been reported to the VA DEQ's Office of Water Supply and information collected through local and regional water supply plans. Water users in Virginia that meet the regulatory threshold are required to report withdrawals occurring in VA; water users outside of Virginia are not required to report although a few do so voluntarily. As noted in the comment, DEQ used demand information provided by ICPRB and summarized demands above "Point of Rocks" into a single withdrawal to capture demands above that point, as DEQ has very limited facility level data for withdrawals in West Virginia or other states.

Revision made to the Plan: The citation in references has been updated and the narrative on page 365 revised as follows: "<u>The Virginia portions of</u> this basin does not include any power generation associated withdrawals <u>facilities that withdraw water; however the Panda Stonewall Power Project is supplied</u>

through reuse from Town of Leesburg's wastewater treatment plant. Panda Stonewall's demands therefore do have an impact on streamflow in the Potomac River through the reduction of water that would otherwise be discharged by the Town of Leesburg"

Th.3 – C.8 – Interstate Commission on the Potomac River Basin (ICPRB)

Comment Summary: Comment states that corrections to Table 71 and 72 are needed as Washington Aqueduct's Dalecarlia plant provided Virginia localities an estimated 21.8 MGD to Arlington County DES and Fort Myer, 13.6 MGD to Falls Church, or a total of 35.4 MGD in 2020, projected to increase to 40 MGD in 2040.

DEQ Response: Table 71 and 72 include a sum of demands from all facilities in Virginia and those that have reported to Virginia such as the Dalecarlia plant. Due to limitations in the data with respect to purchases and transfers, and the procedures used to develop these analysis products for each of the 20 basins, the tables are intended to provide only the total raw water demand associated with each facility and do not factor in distribution or sales. Therefore, the data in the tables will remain as is. However, the feedback is noted and these data could be used to develop products that improve the accuracy of where water is ultimately used in the next State Water Resources Plan.

No revisions made to the Plan.

Th.3 – C.9 – Hampton Roads Planning District Commission

Comment Summary: Comment suggests DEQ add an appendix with specific utility water demand projections. It appears DEQ generated demand projections for this area based on note in page 38. Encourage more collaboration with utilities in demand projections reported in this plan including confirming population projections, service area changes, and per capita water use for both public water systems and domestic use.

DEQ Response: The narrative noted in the comment was unclear and contributed to some misconceptions. First, DEQ did not generate or modify demand projections for any locality. All facility demands and projections included in the Draft 2020 State Plan came from local and regional water supply plans; however, under specific circumstances current demand estimates were updated by DEQ. These circumstances include new or reissued surface or groundwater withdrawal permits, additions of new facilities, or significant changes in water use for existing facilities. Locality provided projections were applied to these refined current use facility demands which can result in changes to the final 2040 demands in select cases. If you have questions about specific demands or projections, current use and future water demand projections for all facilities can be reviewed in detail in the Draft 2020 State Water Resources Plan Dataset which can be found on the DEQ Website, as well as in the data entered by localities in the planning module of VAHydro.

Revision made to the Plan: DEQ has removed Table 10 and revised the narrative as follows: On page 38 "Approximately 13% of localities provided partial or fully updated demand projections~~, with an additional 33% of locality projections revised by the DEQ to account for the most readily available water use data~~." On page 39 remove, "Table 10 provides a list of localities for which DEQ updated locality demands."

Th.3 – C.10 – Northern Virginia Regional Commission

Comment Summary: Comment requests clarification on the basis for the projected growth of groundwater use in Middle Potomac minor basin as well as the sources that have projected groundwater demand increases. Comment also requests clarification on the data source where the split between service area and non-service area comes from.

DEQ Response: Demand projections come from the regional water supply plans for both small self-supplied users (outside of a service area) and public water supplies. The majority of projected increases in groundwater use in the Middle Potomac minor basin comes from Small SSU demands in Loudoun County and several public water supplies that use groundwater (towns of Leesburg, Marshall, and Purcellville). For questions about specific demands or projections, current use and future water demand projections for all facilities can be reviewed in detail in the Draft 2020 State Water Resources Plan Dataset which can be found on the DEQ Website, as well as in the data entered by localities in the planning module of VAHydro. Note that because DEQ calculated demands on a facility level, the location of the facility is what determines in which minor basin demands were summarized. To the extent that the minor basins do not align with existing planning programs, variations in current or projected demand on a locality scale may be seen between the Draft 2020 State Plan and the locally developed water supply plans.

No revisions made to the Plan.

Th.3 – C.11 – Mission H2O

Comment Summary: Draft 2020 State Plan includes an inference that all municipal water systems are consumptive. That is not the case for all systems, particularly those that include storage facilities that enable augment flows. Caution is advised against general classifications of consumptive use.

DEQ Response: Storage facilities that augment flows through releases may not have a traditional consumptive use, although when considering the additional evaporation that occurs with reservoirs or large impoundments, consumptive use of some type still occurs and with large reservoirs, this can be significant. DEQ believes that accurately capturing the consumptive use for a specific user or use type is critical in modeling surface water impacts from withdrawals and your feedback and perspective is appreciated on this subject. This has been a traditional information gap and DEQ has prioritized addressing it through a variety of means including a USGS Water Use and Data Research (WUDR) grant funded project. The simulations in the Draft 2020 State Plan were informed by this project and represented a large step forward in accounting for consumptive use compared to the 2015 State Plan. This project resulted in Virginia sector-specific and facility specific consumptive use coefficients (where data was available) and also employed a well-established methodology to assess consumptive use in Public Water Supply systems. Pages 55-60 in Chapter 4 provide explicit details on how consumptive use was handled in the various scenarios. More information on this topic is also provided on pages 526-527 in Appendix B. We look forward to continuing to improve this methodology for future plans. One of the most important elements of uncertainty lies in the assumption that future consumptive use patterns will resemble historical patterns.

No revisions made to the Plan.

Th.3 – C.12 – Fairfax Water

Comment Summary: Comment states Plan should note that majority of CWS use is returned to river basins through municipal or community treated wastewater discharge.

DEQ Response: DEQ agrees that many Community Water Systems (CWS) return a significant portion of their withdrawals to the source exceptions to this are numerous, particularly in sub-urban or rural areas that have a higher use of septic systems. In addition, the location that the water is returned to the source also can reduce flow significantly in portions of the source between the withdrawal and discharge or the return discharge is in another watershed, both of which are types of consumptive use. To manage the resource the simple comparison of withdrawal and discharge volumes does not consider other details that effect other beneficial uses. When Municipal water supply consumptive use methodology and assumptions are discussed on page 57 in Table 14 and Figure 27, and described further in the narrative on page 59. As noted in Table 14, DEQ used a winter base rate method for estimating consumptive use factors for CWS systems with a variation of between 0 and 30% consumptive use that accounts for increased consumptive use during summer months. This method is similar to that used to implement the Low Flow Allocation Agreement.

No revisions made to the Plan.

Th.3 – C.13 – Rivanna Water and Sewer Authority

Comment Summary: Commenter notes several sources for updated data for Rivanna Water and Sewer Authority (RWSA) systems including population and demand data for the RWSA Urban System as documented in the Urban System Water Demand Forecast Report (Hazen and Sawyer, July 2020), updated safe yield information in the Safe Yield and Reliability Analysis Update Report (Hazen and Sawyer, July 2020), and updated population and demand data for the Crozet system as documented in the Drinking Water infrastructure plan – Crozet Area (Hazen and Sawyer, June 4 2019).

DEQ Response: Although this information will certainly be instrumental in future regional plan development as well as the next State Plan, it is not possible at this time to integrate this new data into the analysis for the Draft 2020 State Plan. The information in the State Plan will always be a snapshot in time and during its preparation, local information may change. This is largely unavoidable. Please note that locality population and demand data can be updated at any time in the planning module of VAHydro and doing so is the best method of ensuring the most up to date information is reflected in DEQ's evaluations. If you wish to update this information for RWSA systems, please contact your Water Supply Planner based on the contact map that can be found here: https://www.deq.virginia.gov/water/water-quantity/water-supply-planning. Population projections provided in the Draft 2020 State Plan are for informational purposes only and do not impact the demand calculations or simulations; all population information in the plan comes directly from the Weldon Cooper Center for Public Service. More information on how safe yield was handled for the RWSA systems can be found in in our response to another RWSA comment.

No revisions made to the Plan.

Theme 4	Ecological Flows and Elfgen Metric

Th.4 – C.1 – Fairfax Water

Comment Summary: Discussion of species impacts and species richness is premature. Given the metric's limitations and limited peer review, and the difficulty in distinguishing other non-flow related changes from flow-related, caution against inclusion of predicted results in the State Plan is encouraged.

DEQ Response: The inclusion of the elfgen framework in the 2020 State Plan is an introduction to this tool. The species richness metric (utilized in the elfgen framework) is useful for describing "potential

risk" to fish biodiversity from changes in consumptive water use. However, this metric's inclusion in the Draft 2020 State Plan is not intended to predict species loss that could occur by 2040. Instead it is a screening tool that may be useful to indicate locations with the greatest potential risk of ecological impacts should consumptive use increase as local projections in some parts of Virginia suggest. DEQ appreciates that future implementation of this tool in a resource management framework will require a process to define that implementation, during which stakeholder input would be sought.

The elfgen framework builds upon decades of literature using the Instream Flow Incremental Method (IFIM) and Percent of Flow based flow recommendations worldwide, which have a strong track record in terms of protecting aquatic life. In that context, elfgen is not an entirely novel approach, but rather, one that began with an evaluation of the experience gained and data gathered through decades of public management of aquatic resources. The study of historical management approaches and their pros and cons drove the development of the elfgen framework, which uses widely available data to evaluate the impacts of flow management on aquatic life. The elfgen framework produces analyses that are highly consistent with the established practice of IFIM and Percent of Flow recommendations, and does so without the potentially extensive study costs required by these traditional approaches.

Two manuscripts published in the Journal of American Water Resources Association (JAWRA) in 2020 which has international circulation also underwent substantial peer review by experts in the field of ecological flows, including the JAWRA Editor-in-Chief, as well as additional blind USGS peer review (as required for all USGS publications). While DEQ has participated in AWRA in some capacity for years as has others like the Interstate Commission on the Potomac River Basin, the peer review process for the JAWRA was not impacted in any way by that participation and we had no role in it. Additionally, since publishing in 2020, this research received the Lanfear Award for Outstanding Technology Paper of the Year for the journal as determined by the international group of associate editors and metrics like the paper's impact factor, number of papers citing the study, potential for advancing water resources management, etc. DEQ also has presented this work in a variety of formats to industry and academic groups. Presenting the elfgen framework in the 2020 State Plan provides an additional avenue for peer review; however, it would be incorrect to characterize the peer review associated with these papers as limited.

Lastly, DEQ acknowledges there are many factors beyond changes in flow that may impact the health of instream communities, such as impervious cover and bank erosion. Impervious surfaces in particular can exert a dominant influence on ecological integrity, and have had a confounding influence in many other studies that have attempted to identify practicable flow-ecology relationships. The elfgen framework is designed to isolate the effect streamflow magnitude has on instream biodiversity. Because elfgen is built upon ecological limit functions, it identifies the most diverse streams in each area of analysis, and therefore largely avoids the problem of areas that are degraded due to significant impervious cover. This is a strength, rather than weakness of the elfgen approach.

DEQ also acknowledges the elfgen framework is best suited to locations with average annual flow below 530 cfs (see page 81). Rather than being a limitation of the elfgen tool, this highlights the natural relation between fish biodiversity and stream size, and the need to analyze ecological impacts in those streams with the greatest potential risk of ecological loss (stream locations with mean annual flow below the local threshold of streamflow-biodiversity patterns). It also highlights the need to use the best tool depending on factors such as watershed size, among other factors. Habitat modeling based on IFIM data and Percent of Flow methods may be better suited to larger watersheds.

Revision made to the Plan: The following "Caveats and Limitations" section has been added on page 81.

"Caveats and Limitations:

The information presented in the 2020 State Plan can be used to evaluate ways of applying research on relations between aquatic species richness and streamflow to allow low-cost site-specific quantification of potential impacts to aquatic life as a result of withdrawals or diversions. It is not intended to be a replacement for IFIM and other habitat methods, although it may be useful to assist localities and water users to determine where these more resource intensive approaches may be necessary to evaluate and understand local impacts.

DEQ currently views this as a screening level metric that will be further adapted and refined as it is applied in our suite of cumulative impact analysis tools. A process for incorporating these tools into informed resource management decisions remains necessary and may benefit from constructive input from the public and stakeholders.

DEQ acknowledges the elfgen framework is best suited to non-tidal locations with average annual flow below ~530 cfs. This highlights the natural relation between fish biodiversity and stream size, and the need to analyze ecological impacts in those streams with the greatest potential risk of ecological loss."

Th.4 – C.2 – Mission H2O

Comment Summary: Comment recognizes several concerns related to elfgen framework: 1) species richness is not defined in the draft 2) peer review by AWRA may not be sufficient given DEQ is represented in the organization, recommend DEQ follow EPA's guidance on peer review that peer reviewers should not be associated with generating the work product, 3) unclear how this modeling will be used in other regulatory programs that aim to protect species, 4) some inconsistencies in narrative on page 81 and page 106 related to impacts, and 5) caveats and limitations with elfgen framework should be clearly stated in the Draft 2020 State Plan.

DEQ Response: Species richness is defined on page xxxv of the Executive Summary, a detailed definition has been added in the glossary.

With respect to the concerns related to the novelty and peer review process, the elfgen framework builds upon decades of Instream Flow Incremental Method (IFIM) and Percent of Flow based flow recommendations, which have a strong track record in terms of protecting aquatic life. In that context, elfgen is not an entirely novel approach, but rather, one that began with an evaluation of the experience gained and data gathered through decades of public management of aquatic resources. The study of historical management approaches and their pros and cons drove the development of the elfgen framework, which seeks to use widely available data to evaluate the impacts of flow management. The elfgen framework produces analyses that are highly consistent with the established practice of IFIM and Percent of Flow recommendations, and does so without the potentially extensive study costs required by these traditional approaches.

Two manuscripts published in the Journal of American Water Resources Association (JAWRA) in 2020 which has international circulation also underwent substantial peer review by experts in the field of ecological flows, including the JAWRA Editor-in-Chief, as well as additional blind USGS peer review (as required for all USGS publications). While DEQ has participated in AWRA in some capacity for years as

has others like the Interstate Commission on the Potomac River Basin, the peer review process for the JAWRA was not impacted in any way by that participation and we had no role in it. Additionally, since publishing in 2020, this research received the Lanfear Award for Outstanding Technology Paper of the Year for the journal as determined by the international group of associate editors and metrics like the paper's impact factor, number of papers citing the study, potential for advancing water resources management, etc.. DEQ also has presented this work in a variety of formats to industry and academic groups. Presenting the elfgen framework in the 2020 State Plan provides an additional avenue for peer review; however, it would be incorrect to characterize the peer review associated with these papers as limited. DEQ is not clear why the EPA peer review process is superior to the one used by the USGS.

With respect to how this tool may be used by or with other regulatory programs or agencies, it is worth noting that species richness assessments are consistent with the Division of Wildlife Resources (DWR) standard guidance regarding surface water withdrawals, which is that an intake not withdraw more than 10% of instantaneous flow (90% flow-by). DWR arrived at the "10% of instantaneous flow" value through extensive habitat studies and physical habitat modeling, where changes in stream discharge below 10% were considered to not have any significant negative impact on aquatic life. The consumptive use metric used in the 2020 State Plan describes the overall change in flow expected for a river segment for a particular model scenario. Through analyses like those presented in Table 18, the relation between percent consumptive use (i.e. changes in stream discharge) can be compared to ecological response in the form of richness change.

The elfgen framework builds upon existing DWR guidance by quantifying potential impacts to instream fauna on a site-specific basis. In this way, richness change can be a powerful tool for assessing potential ecological risk in areas where extensive habitat studies are unavailable. Richness values are available for 11,000 fish sampling locations statewide compared to just 24 sites with habitat data. However, DEQ recognizes that a formal process to incorporate this new tool into existing management structures will be an important step, and such a process will certainly include an opportunity for the public to provide input as required by law.

Revision made to the Plan: In response to the comment regarding the discussion of richness results in the 2040 scenario, the referenced statement on page 81 has been revised.

"Although the exempt user scenario shows the greatest risk of richness loss in Table 18, the 2040 scenario ~~also projects significant richness loss for a small number of river segments~~ projects richness loss above 1% for a small number of river segments."

The following "Caveats and Limitations" section has been added on page 81.

"Caveats and Limitations:

The information presented in the 2020 State Plan can be used to evaluate ways of applying research on relations between aquatic species richness and streamflow to allow low-cost site-specific quantification of potential impacts to aquatic life as a result of withdrawals or diversions. It is not intended to be a replacement for IFIM and other habitat methods, although it may be useful to assist localities and water

users to determine where these more resource intensive approaches may be necessary to evaluate and understand local impacts.

DEQ currently views this as a screening level metric that will be further adapted and refined as it is applied in our suite of cumulative impact analysis tools. A process for incorporating these tools into informed resource management decisions remains necessary and may benefit from constructive input from the public and stakeholders.

DEQ acknowledges the elfgen framework is best suited to non-tidal locations with average annual flow below ~530 cfs. This highlights the natural relation between fish biodiversity and stream size, and the need to analyze ecological impacts in those streams with the greatest potential risk of ecological loss.

Th.4 – C.3 – James River Association

Comment Summary: Comment notes the duty of Commonwealth is to consider all beneficial uses, including aquatic life. Notes appreciation for inclusion of elfgen tool and consumptive use metric and attention to in-stream beneficial uses. Comment notes that even with withdrawals that are largely non consumptive, consideration should be given to distance between intake and discharge and where impacts may occur in the bypassed region, and DEQ and local planning efforts should consider those impacts. The application of elfgen also indicates the potential for impacts to species richness in the James River, and that this be considered in any evaluation of current statute related to exempt surface water withdrawals. DEQ should work to fully incorporate consumptive use and elfgen into future resource management decisions, and ensure that water supply planning consider impacts to in-stream uses.

DEQ Response: The inclusion of the elfgen framework in the Draft 2020 State Plan is an introduction to this tool for most readers, and any feedback related to it or its potential applications is welcome. The species richness metric (utilized in the elfgen framework) is useful for describing "potential risk" to fish biodiversity from changes in consumptive water use. It is best viewed as a screening tool that may be useful to indicate locations with the greatest potential risk of ecological impacts should consumptive use increase as local projections in some parts of Virginia suggest, and can help direct where more resource intensive evaluations of species richness and habitat impacts are more needed. DEQ hopes that its inclusion in the Draft 2020 State Plan will inform and support future decision making at both the state and local levels, as that is the ultimate goal of DEQ's ongoing investment of resources in the development and improvement of the data and tools. However, DEQ appreciates that future implementation of this tool in a resource management framework will require a process to define that implementation, consistent with the Administrative Process Act.

No revisions made to the Plan.

Th.4 – C.4– Virginia Municipal Drinking Water Association (VMDWA)

Comment Summary: Comment notes that the elfgen framework, while innovative, should include a caveat explaining that the framework's capability/accuracy is still being evaluated.

DEQ Response: DEQ has added a "Caveats and Limitations" section to page 81 that addresses this and similar comments.

Revision made to the Plan: The following "Caveats and Limitations" section has been added on page 81.

"Caveats and Limitations:

The information presented in the 2020 State Plan can be used to evaluate ways of applying research on relations between aquatic species richness and streamflow to allow low-cost site-specific quantification of potential impacts to aquatic life as a result of withdrawals or diversions. It is not intended to be a replacement for IFIM and other habitat methods, although it may be useful to assist localities and water users to determine where these more resource intensive approaches may be necessary to evaluate and understand local impacts.

DEQ currently views this as a screening level metric that will be further adapted and refined as it is applied in our suite of cumulative impact analysis tools. A process for incorporating these tools into informed resource management decisions remains necessary and may benefit from constructive input from the public and stakeholders.

DEQ acknowledges the elfgen framework is best suited to non-tidal locations with average annual flow below ~530 cfs. This highlights the natural relation between fish biodiversity and stream size, and the need to analyze ecological impacts in those streams with the greatest potential risk of ecological loss.

Theme 5	Exempt User Surface Water Scenario

Th.5 – C.1 – City of Richmond

Comment Summary: Comment notes that exempt user scenario volumes are not clear. Comment raises concerns with DEQ's statement "DEQ...does not agree that the maximum values used in this scenario represent an allocation for, or the expectation of, a future withdrawal of that volume; nor does DEQ concede that any particular exempt user is necessarily entitled to withdraw any particular maximum value used in this scenario." Comment states that there is no need for DEQ to disagree or disavow because adjudicating water rights is outside DEQ's purview or authority and notes that the caveat ignores riparian rights and water rights. The comment also discusses background on the City of Richmond's riparian rights and requests that the language in disclaimer be revised to acknowledge that some exempt users also hold water rights outside the purview of DEQ, or at least not suggest that no exempt users hold such water rights.

DEQ Response: The exempt user scenario utilizes the highest possible volume of the range of datasets referenced for this scenario for each exempt surface water user. However, as noted in the Draft 2020 State Plan, the demands used in this scenario do not necessarily represent an allocation for, or the expectation of, a future withdrawal of that volume. This scenario is not intended to validate or invalidate any specific user's exempt claim amount, or other claims to water rights. It simply tries to put bounds on a worst case scenario. The 2020 State Plan Dataset is available upon request. See the included Data Dictionary for information on how to locate this and other information related to demands and scenario results.

No revisions made to the Plan.

Th.5 – C.2 – Fairfax Water

Comment Summary: Comment states that the maximum possible exempt demands represent an unrealistic assessment of current and future basin flows - a more accurate simulation of baseline and

future demands should be modeled by DEQ using water withdrawal reporting data. Comment also notes that in almost all cases withdrawals exempt from VWP permit requirements are required to have drought response and contingency plans in place.

DEQ Response: The exempt user scenario utilizes the highest possible volume of the range of datasets referenced for this scenario for each exempt surface water user. However, as noted in the Draft 2020 State Plan, the demands used in this scenario do not necessarily represent an allocation for, or the expectation of, a future withdrawal of that volume. This scenario is not intended to validate or invalidate any specific user's exempt claim amount, or other claims to water rights. It simply tries to put bounds on a worst case scenario. DEQ agrees that in some cases, the demands used in this scenario are unrealistic and can exceed available streamflow in a river segment. However, this data comes from existing sources and was provided by the users or was taken from other agency permits that apply to a given facility. Therefore, it is important for DEQ to assess the potential impact of these amounts on existing permitted and unpermitted users and other protected beneficial uses of water. This is necessary to inform the discussion. For instance, this scenario does identify cases where commonly referenced values for exemption claims are not sustainable during drought periods for individual and/or cumulative withdrawals. As noted in the Draft 2020 State Plan, the demands used in this scenario do not necessarily represent an allocation for, or the expectation of, a future withdrawal of that volume. This scenario is not intended to validate or invalidate any specific user's exempt claim amount. The State Plan is not the appropriate vehicle for evaluating statutory or regulatory exemptions from permitting requirements for specific facilities. Instead, this scenario offers a baseline for evaluating the maximum possible cumulative impact from all surface water users including permitted and unpermitted. This evaluation is a first step, and as noted, a process for incorporating the evaluation of exempt user demands in the VWP withdrawal permit and other resource management programs needs to be developed to avoid over allocating the resource. It is hoped that this scenario may provide perspective for that effort.

DEQ recognizes your suggestion that reported water withdrawal information be used as a basis for modeling impacts instead. Reported water withdrawal information was used in combination with local projections to inform facility demands in the 2020 and 2040 water supply plan demand scenarios, which provide the baseline and future demand evaluations DEQ agrees are critical. Indeed these WSP demand scenarios are intended to be the primary water supply planning screening tools for evaluating impacts as a result of changing demands, and reported water use also forms the basis for scenarios used to evaluate VWP permit applications. In contrast, the demands used in the exempt user scenario are not used in evaluating permit requests, potentially adding risk that over allocations will be made.

While DEQ agrees that many exempt users in the public water supply category may have drought response and contingency plans in place that can provide an important management tool during a drought, many exempt users in other water use categories do not. In addition, some of these drought response and contingency plans may be at odds with larger resource management goals by not considering other beneficial uses of water resources and may not be adequate to protect other downstream beneficial uses.

No revisions made to the Plan.

Th.5 – C.3 – Mission H2O

Comment Summary: Discussion of statutory grandfathering provision is incomplete and more background should be provided in the Draft 2020 State Plan. Withdrawals in existence on July 1, 1989

do not require a Virginia Water Protection Permit. Va. Code § 62.1-44.15:22.B. That exemption continues until a new Section 401 certification is required to increase a withdrawal. *Id.* In order to quantify the maximum volume of withdrawal exempted from permitting, DEQ enacted regulations requiring withdrawers to provide DEQ with the estimated maximum capacity of the intake structure in place as of 1989. 9 VAC 25-210-310.A.1.b.

DEQ Response: The exempt user scenario utilizes the highest possible volume of the range of datasets referenced for this scenario for each exempt surface water user. However, as noted in the Draft 2020 State Plan, the demands used in this scenario do not necessarily represent an allocation for, or the expectation of, a future withdrawal of that volume. This scenario is not intended to validate or invalidate any specific user's exempt claim amount, or other claims to water rights. It simply tries to put bounds on a worst case scenario.

Neither the statutory or regulatory citations referenced in the comment nor the information submitted to comply with the regulation cited created an allocation of those water withdrawal volumes, formally recognize them as accurate, or memorialize them as the basis for when a permit or a new § 401 certification would be required. The exempt user scenario utilizes the highest possible volume for surface water users exempt from Virginia Water Protection permit requirements, or otherwise unpermitted. Developing this scenario required collecting a range of datasets that are commonly referenced by exempt surface water users as their exempted volume. It is important to note that there are withdrawals exempt from the requirement to obtain a VWP permit beyond those that are "grandfathered" that are included in the exempt user scenario. "Grandfathered" withdrawals are a subset of exempt withdrawals. The scenario is built using the largest value from: 1) VDH Waterworks Operations permits issued for the facility; 2) information supplied by withdrawers with the estimated maximum capacity of the intake structure in place as of July 1, 1989; 3) the maximum annual water withdrawal reported prior to July 1, 1989; or 4) the maximum annual water withdrawal reported after July 1, 1989. This data comes from existing sources and was provided by the users or by other agency permits that apply to a given facility. DEQ has added additional clarification to the introduction of the exempt user scenario in response to your comment on page 54 as follows:

Proposed Revisions: Add the following to page 54: "The State Plan includes a new scenario that evaluates the potential impacts from the cumulative maximum possible demands from surface water users excluded, or exempt, from VWP permit requirements. Exempt users are those exempted by ~~per~~ Va. Code § 62.1-44.15:22 B, <u>and 9 VAC 25-210-310.A. The scenario uses the largest value from: 1) VDH Waterworks Operations permits issued for the facility; 2) information supplied by the user with the estimated maximum capacity of the intake structure in place as of July 1, 1989; 3) the maximum annual water withdrawal reported prior to July 1, 1989; or 4) the maximum annual water withdrawal reported after July 1, 1989. This data comes from existing sources and was provided by the users or by other agency permits that apply to a given facility. Future state plans will continue to explore this topic.</u>"

Similar language was added to the executive summary on page xxxiii.

Th.5 – C.4 – Mission H2O

Comment Summary: Comment recommends DEQ refer to exempt demands in the scenario as "maximum exempted" instead of "maximum possible exempt demand".

DEQ Response: While DEQ appreciates the rationale for this suggestion, the exempt user scenario evaluates both users who have been in existence prior to July 1, 1989 and are therefore exempt per Va. Code § 62.1-44.15:22 B, as well as users that were not in existence prior to July 1, 1989, are

unpermitted, and may or may not meet one or more of the exemptions under 9VAC25-210-310.A. Given this complexity, and given this is a statewide analysis that handles a variety of datasets applied to over 1,500 distinct users, DEQ does not intend to use this scenario to validate or invalidate the amount of "exempted" demand for a given facility, and the State Water Resources Plan is not the appropriate vehicle for such determinations. The current usage of "maximum possible exempt demand" is intended to capture a range of possible values as described in Table 12 (page 54) that cannot all constitute the specific exempted demand for a given facility. Therefore using "*maximum exempted*" could generate confusion rather than provide clarification.

No revisions made to the Plan.

Th.5 – C.5 – Mission H2O

Comment Summary: Comment states that the exempt user scenario does not recognize many exempt withdrawals are not consumptive in nature.

DEQ Response: DEQ invested significant effort in developing facility specific consumptive use estimates that scale with demand for the surface water cumulative impact analysis scenarios, including the exempt user scenario. While many exempt surface water users may have lower consumptive use, DEQ does not believe it is accurate to characterize many as non-consumptive. Additionally, considering that the significant variety of use types for exempt users includes those that are nearly 100% consumptive, such as agriculture and commercial irrigation, it is important to avoid broad generalizations related to this important qualifier. DEQ agrees that many Community Water Systems (CWS) return a significant portion of their withdrawals to the source exceptions to this are numerous, particularly in sub-urban or rural areas that have a higher use of septic systems. In addition, the location that the water is returned to the source also can reduce flow significantly in portions of the source between the withdrawal and discharge or the return discharge is in another watershed, both of which are types of consumptive use. To manage the resource the simple comparison of withdrawal and discharge volumes does not consider other details that effect other beneficial uses. When Municipal water supply consumptive use methodology and assumptions are discussed on page 57 in Table 14 and Figure 27, and described further in the narrative on page 59. As noted in Table 14, DEQ used a winter base rate method for estimating consumptive use factors for CWS systems with a variation of between 0 and 30% consumptive use that accounts for increased consumptive use during summer months. More information on this topic is also provided on pages 526-527 in Appendix B.

No revisions made to the Plan.

Th.5 – C.6 – Mission H2O

Comment Summary: Comment states that DEQ's statement in the Draft 2020 State Plan that it does not "concede that any particular exempt user is necessarily entitled to withdraw any particular maximum value used in this scenario" is counter to the regulatory language and that DEQ should consider these withdrawals as already allocated and that any adverse impacts are therefore the result of DEQ's permitting of new facilities without sufficient consideration of existing allocations. Comment also notes that the scenario is misleading as the demands simulated have never occurred and that actual withdrawal volumes would provide a more accurate reflection of expected withdrawals for these facilities.

DEQ Response: The exempt user scenario utilizes the highest possible volume of the range of datasets referenced for this scenario for each exempt surface water user. However, as noted in the Draft 2020

State Plan, the demands used in this scenario do not necessarily represent an allocation for, or the expectation of, a future withdrawal of that volume. This scenario is not intended to validate or invalidate any specific user's exempt claim amount, or other claims to water rights. It simply tries to put bounds on a worst case scenario.

DEQ agrees that in some cases, the demands used in this scenario are unrealistic and can exceed available streamflow in a river segment. For instance, this scenario identifies cases where commonly referenced values for exemption claims are not sustainable during drought periods for individual or cumulative withdrawals. It also indicates that even in river segments, which have no permitted withdrawals at all, the maximum possible exempt demands can exceed the water budget, which underscores the importance of such a scenario, particularly given that permitted withdrawals represent only 25% of reported surface water withdrawal volumes in Virginia on average per year. The potential for conflicts between exempt users is significant.

No revisions made to the Plan.

Th.5 – C.7 – Chesterfield County

Comment Summary: Comment disagrees with the exempt demand of 21.6 MGD used for Swift Creek, which while consistent with the total intake capacity of all three pumps, is not consistent with the operation of the system which would never use all three pumps at once (one is backup). Commenter recommends 12 MGD be used for the Swift Creek WTP in this scenario.

DEQ Response: The exempt user scenario utilizes the highest possible volume of the range of datasets referenced for this scenario for each exempt surface water user. This scenario is not intended to validate or invalidate any specific user's exempt claim amount, or other claims to water rights. It simply tries to put bounds on a worst case scenario. Developing this scenario required collecting a range of datasets that are commonly referenced by exempt surface water users seeking to document their exemption volume. This includes cases such as Swift Creek where the maximum pump capacity as defined in the VDH Waterworks Operations Permit, which could theoretically be referenced by a user to document a claim, is higher than the system is designed to operate. However, the intent of this scenario is to evaluate the maximum possible cumulative impact from all surface water users including permitted and unpermitted including the full range of datasets users could conceivably reference. This evaluation is a first step, but as noted in the Draft 2020 State Plan, a process for incorporating the evaluation of exempt user demands in the VWP withdrawal permit and other resource management programs needs to be developed. It is hoped that this scenario may provide perspective for that effort but DEQ has not suggested in the Draft 2020 State Plan or elsewhere that this scenario would necessarily be the basis for such a process, revisions to the methodologies are expected.

To the extent that Swift Creek WTP cannot and will not operate at the maximum exempt demand used in the simulation, the potential unmet demand simulated in Table 31 would not occur and an evaluation of this particular metric may not be relevant to Chesterfield County's future planning efforts.

No revisions made to the Plan.

Th.5 – C.8 – Interstate Commission on the Potomac River Basin (ICPRB)

Comment Summary: Comment states that the exempt user scenario is not indicative of potential future conditions in the Middle Potomac, and the value used for Fairfax Water is so large that the Middle Potomac Exempt User scenario is not meaningful.

DEQ Response: As noted in the comment, the exempt user scenario utilizes the highest possible volume of the range of datasets referenced for this scenario for each exempt surface water user. DEQ agrees that in some cases, the demands used in this scenario are unrealistic and can exceed available streamflow in a river segment. However, this data comes from existing sources and was provided by the users or was taken from other agency permits that apply to a facility. Therefore, it is important for DEQ to assess the potential impact of these amounts on existing permitted and unpermitted users and other protected beneficial uses of water. This is necessary to inform the discussion. For instance, this scenario does identify cases where commonly referenced values for exemption claims are not sustainable during drought periods for individual and/or cumulative withdrawals. As noted in the Draft 2020 State Plan, the demands used in this scenario do not necessarily represent an allocation for, or the expectation of, a future withdrawal of that volume. This scenario is not intended to validate or invalidate any specific user's exempt claim amount. The State Plan is not the appropriate vehicle for evaluating statutory or regulatory exemptions from permitting requirements for specific facilities. Instead, this scenario offers a baseline for evaluating the maximum possible cumulative impact from all surface water users including permitted and unpermitted. This evaluation is a first step, and as noted, a process for incorporating the evaluation of exempt user demands in the VWP withdrawal permit and other resource management programs needs to be developed to avoid over allocating the resource. It is hoped that this scenario may provide perspective for that effort.

No revisions made to the Plan.

Th.5 – C.9 – James River Association

Comment Summary: Comment notes that DEQ is forced to rely on incomplete information when it comes to unpermitted surface water use. DEQ must act conservatively by incorporating exempt user claims into cumulative impact analyses and within management decisions for permit applications. Comment also notes that exempt users are not required to make adjustments to demand during drought flows or to adhere to flow-by or release requirements. Comment urges DEQ to continue to evaluate better ways to characterize exempt users to improve accuracy of modeling, planning, and application review. Virginia must consider whether state water policy should be amended to reduce the percentage of withdrawals that qualify for exemption from permit requirements.

DEQ Response: The exempt user scenario represents a first step, to assess whether there is a potential resource management issue associated with have so many withdrawals exempt for management by permits. Given the large volumes identified by users and in permits issued by other agencies to achieve complimentary purposes, there is the potential for over allocating the resource. There are likely a number of policy approaches to address the concern and this evaluation provides some information to potentially inform any future discussion. The recommendation that Virginia consider whether state water policy should be amended with respect to exempt users would require a statutory change.

No revisions made to the Plan.

Th.5 – C.10 – Hampton Roads Planning District Commission

Comment Summary: Comment notes support for MissionH20 comment regarding exempt user scenario recommending a process to incorporate the evaluation of potential exempt user demands into the VWP permit application process.

DEQ Response: The exempt user scenario utilizes the highest possible volume of the range of datasets referenced for this scenario for each exempt surface water user. However, as noted in the Draft 2020 State Plan, the demands used in this scenario do not necessarily represent an allocation for, or the expectation of, a future withdrawal of that volume. This scenario is not intended to validate or invalidate any specific user's exempt claim amount, or other claims to water rights. It simply tries to put bounds on a worst case scenario. DEQ agrees that in some cases, the demands used in this scenario are unrealistic and can exceed available streamflow in a river segment. However, this data comes from existing sources and was provided by the users or was taken from other agency permits that apply to a facility. Therefore, it is important for DEQ to assess the potential impact of these amounts on existing permitted and unpermitted users and other protected beneficial uses of water. This is necessary to inform the discussion. For instance, this scenario does identify cases where commonly referenced values for exemption claims are not sustainable during drought periods for individual and/or cumulative withdrawals. As noted in the Draft 2020 State Plan, the demands used in this scenario do not necessarily represent an allocation for, or the expectation of, a future withdrawal of that volume. This scenario is not intended to validate or invalidate any specific user's exempt claim amount. The State Plan is not the appropriate vehicle for evaluating statutory or regulatory exemptions from permitting requirements for specific facilities. Instead, this scenario offers a baseline for evaluating the maximum possible cumulative impact from all surface water users including permitted and unpermitted. This evaluation is a first step, and as noted, a process for incorporating the evaluation of exempt user demands in the VWP withdrawal permit and other resource management programs needs to be developed to avoid over allocating the resource. It is hoped that this scenario may provide perspective for that effort.

No revisions made to the Plan.

Theme 6	Form and Function of the State Water Resources Plan

Th.6 – C.1 – City of Richmond

Comment Summary: Comment notes that the stated goal of the Draft 2020 State Plan does not align with the statutory goal of water supply planning, does not acknowledge the City of Richmond's water rights, and does not address affordability as a water planning consideration.

DEQ Response: DEQ believes that the State plan provided what we think is relevant for planning purposes. DEQ continues to evaluate how best to meet these mandates and expects that each iteration of the State Plan will improve upon the previous effort in this area. We will consider this comment in future versions of the State Plan.

No revisions made to the Plan.

Th.6 – C.2 – MissionH2O

Comment Summary: Comment states that the broader focus of the Plan on policy issues dilutes the purpose and power of a water supply plan, does not thoroughly address need for developing a water supply planning framework, and that much of the information is more relevant to annual water resources report than it is to the assessment of projected demands, available supplies, and promotion of alternative sources.

DEQ Response: DEQ believes that the State plan provided what we think is relevant for planning purposes. DEQ continues to evaluate how best to meet these mandates and expects that each iteration of the State Plan will improve upon the previous effort in this area. We will consider this comment in future versions of the State Plan.

No revisions made to the Plan.

Th.6 – C.3 – Fairfax Water

Comment Summary: The Plan and future priorities go well-beyond the evaluation of water supply related information and includes policy advocacy which is beyond the scope. Section 5.2.6 should be removed from the report.

DEQ Response: DEQ believes that the State plan provided what we think is relevant for planning purposes. As noted in the 2012 Water Supply Advisory Committee Final Report, "the SWRP should be used as an informational tool for future water supply decisions." The State Water Resources Plan addresses this both through cumulative impact evaluations but also by looking ahead at issues that may lead to water resources conflicts in the future. DEQ believes in data driven, evidence based decision-making, and one key to supporting such decision-making is critically evaluating the currency of data and evidence for making decisions frequently. Subjects discussed in Chapter 5 all have bearing in the near or long term on the protection and preservation of water supplies and other beneficial uses; the agency perspective gained through facilitation of water supply planning and other resource management programs is important information and the Plan conveys that to localities and other stakeholders to inform local or regional planning. DEQ continues to evaluate how best to meet these mandates and expects that each iteration of the State Plan will improve upon the previous effort in this area. We will consider this comment in future versions of the State Plan.

No revisions made to the Plan.

Th.6 – C.4 – Fairfax Water

Comment Summary: State Plan should highlight recent water trends from 2015-2020 period.

DEQ Response: DEQ already publishes the Annual Water Resources Report each year, which evaluates water use over the last five years on an annual basis. DEQ will consider this comment in future versions of the State Plan.

No revisions made to the Plan.

Th.6 – C.5 – Mission H2O

Comment Summary: Comment states the Plan should include an upfront overview of changes since the prior plan and explanation of how challenges identified in 2015 plan have been addressed over the last five years, or whether they remain challenges under current conditions.

DEQ Response: The Draft 2020 State Plan was developed during a period of transformation within the water supply planning program that remains ongoing. First, the original submissions of the local and regional water supply plans are all at least 10 years or older in age. Although some were updated and improved to address outstanding compliance items during the five year update process, most of the planning programs did not make substantive changes to the plans outside of these identified items. All plans are due to be resubmitted in 2023, although there is likelihood that the regulatory action for HB542 will impact that timeline.

Due in part to the age of the plans, and the information therein, and due to the upcoming changes to the water supply planning program mandated by HB542, the Draft 2020 State Plan straddles a need to

evaluate current local information as well as a need to support a transition towards new plan developed under a revised regulatory and planning framework. While much of the structure is similar to the 2015 Plan, many of the analyses have been improved or enhanced significantly as described in Chapter 4. New scenarios and metrics have been developed and implemented. Demand estimates have been tweaked or adjusted using current use reporting and new QA/QC processes as staffing and resources allowed. Figures and maps have been revised dramatically to provide a high resolution and more locally meaningful level of analysis. In summary, the extent of the changes are significant enough that comparisons to the 2015 Plan beyond the surface are challenging. A limited comparison in changes to locally provided data is provided in Chapter 3 Section 5, and throughout Chapter 4 details on the improvements to CIA methods are provided. DEQ recognizes the ultimate intent of the State Water Resources Plan is for it to be a living document that can be updated (and used) regularly by both state and local stakeholders, for which the form and function will need further changes. While the Draft 2020 State Plan does represent a step forward from the 2015 State Plan, DEQ is already evaluating what form a 2025 State Plan will need to take in order to fully accomplish the mission of the document.

As noted, the structure of the Draft was changed and a section on challenges and recommendations was not included in this report. Note for the five years following the 2015 State Plan Publication, DEQ's annual publication of the Annual Water Resources Report provided updates on the challenges identified in the 2015 Plan. The Draft 2020 State Plan addresses in Chapter 4 and Chapter 5, and summarizes in the executive summary, the most significant challenges identified in the 2015 Plan that DEQ expects to become increasingly critical in the coming five years. Given the scope of the potential changes to the program resulting from HB542, there is no added value to including the summary requested by the comment at this time/ DEQ will consider this comment in future versions of the State Plan.

No revisions made to the Plan.

Th.6 – C.6 – Virginia Municipal Drinking Water Association (VMDWA)

Comment Summary: Comment notes that publication of a "Final" State Water Resources Plan is at odds with the goal of an ongoing process". Comment recommends DEQ include a statement at the beginning indicating that this is a "continual development and planning process" and that DEQ will incorporate revisions to the Plan as appropriate.

DEQ Response: DEQ shares the value that the planning process should be continuous and ongoing. The 2020 State Plan is a snapshot in time and represents a final look back at the five-year period between of 2015-2020.

No revisions made to the Plan.

Th.6 – C.7 – Virginia Municipal Drinking Water Association (VMDWA)

Comment Summary: Comment notes that the Draft 2020 State Plan as is serves as an additional non-regulatory tool to help localities effectively plan. Should DEQ consider using predictions and analysis from the Plan for regulatory determinations, a much more comprehensive review by stakeholders would be warranted.

DEQ Response: Should DEQ propose to incorporate review or evaluation of the State Water Resources Plan into guidance or regulation, DEQ would seek input from stakeholders as required by the Administrative Procedures Act.

No revisions made to the Plan.

Theme 7	Funding

Th.7 – C.1 – Hampton Roads Sanitation District (HRSD)

Comment Summary: Comment notes that the capital to install reclaimed water systems drives costs significantly above potable water rates in the state, particularly when compared to groundwater. However, when considering the true value of water, the economic impact of water supply shortages on commercial development and residential growth must be included. The state must prioritize the development of a fund and regulations to support water reuse projects.

DEQ Response: DEQ appreciates the economic challenges in developing reuse projects when compared to the costs associated with more traditional water sources, and agrees that the full value of clean water is not always understood until shortages arise. The state currently provides funds for water reuse projects through the Virginia Clean Water Revolving Loan Fund, which includes a portion for water reuse projects. Additionally, the state provides access to other funds for water reuse projects, which can be found on the DEQ Waste Water Reclamation and Reuse page: https://www.deq.virginia.gov/water/wastewater/water-reclamation-reuse

Additional or new funding to support water reuse projects would require an action from the General Assembly. Question related to the regulations governing water reclamation or reuse are best directed towards that program (contacts on the provided webpage).

No revisions made to the Plan.

Th.7 – C.2 – James River Association

Comment Summary: Comment notes the complexity of water resources management made clear by the Draft 2020 State Plan and notes that DEQ needs adequate and sustained resources. Commenter states it is vital that the Commonwealth make necessary investments to fund DEQ's work, particularly in light of additional regulatory responsibilities. Investment in modeling, monitoring, and collection of data must continue.

DEQ Response: Data driven decision-making is a critical part of the mission of the water supply planning program and other water resources programs at DEQ. Increasing the tools and our capacity to fulfill that mission is an ongoing task that periodically requires new investments to stay current.

No revisions made to the Plan.

Theme 8	Groundwater Modeling and Groundwater Withdrawal Impacts

Th.8 – C.1 – Interstate Commission on the Potomac River Basin (ICPRB)

Comment Summary: Comment notes that groundwater withdrawals are not incorporated into the model. Groundwater withdrawals are a key component of water balance in the Potomac Basin and their absence may be adversely affecting model calibration and low flow performance.

DEQ Response: DEQ shares the concern that groundwater pumping from surficial and fractured rock aquifers can impact stream flows; ultimately groundwater impacts were not included the VAHydro model simulation for a number of reasons. Firstly, the Phase 5 and Phase 6 Chesapeake Bay Program watershed models include historical groundwater pumping implicitly in their calibration; therefore

simulating groundwater impacts should only account for increases in groundwater demand over historic use. For much of the Potomac Basin within Virginia, projected demand increases for groundwater sources were not significant and therefore the impact of these increases may not be significant. However, there are localities in the region such as Loudoun County where groundwater makes up a larger part of projected demand growth and this impact could be more pronounced if modeled.

Secondly, groundwater transport into and out of streams is highly variable depending on local and regional geology, and in some cases happens over periods of months or years. Only a portion of these increased demands would be reflected directly in low flow depletion. Estimating this portion with any confidence would be an extremely difficult challenge and due to the highly localized hydrogeology of fractured rock aquifers, would not necessarily be readily transferrable to a regional scale. DEQ agrees that understanding the complex interactions between groundwater and surface water, particularly when under the influence of withdrawals, is critical. DEQ has collaborated with localities and the USGS on several local evaluations of groundwater transport in Virginia, but such studies are resource intensive and as noted do not necessarily transfer beyond their study extent. DEQ will continue to support and initiate such studies as resources allow, and will continue to assess methods for better accounting for groundwater interactions in the model.

No revisions made to the Plan.

Th.8 – C.2 – Hampton Roads Planning District Commission

Comment Summary: Comment notes that the Draft 2020 State Plan raises concerns about future demands on the Coastal Plain aquifers and proposes several changes to the plan to better evaluate groundwater demands: 1) confirm local population projections and the portion projected to be outside of public water service areas, 2) identify model cells that are critical in the model base year of 1891 as DEQ management goals should not include raising water levels in these cells, 3) for 2040 groundwater demand scenarios, the scenario should be run from 2040-2090 rather than 2020-2070, and 4) include groundwater level monitoring data for the last ten years as part of the analysis of the stress and/or recovery of the aquifer system.

DEQ Response: Population projections included in the Draft 2020 State Plan (Table 106) are a product of the University of Virginia's Weldon Cooper Center as noted in Section 3.3, page 29. Specific details about the Weldon Cooper population projections can be found at the Weldon Cooper website. However, these projections do not factor into either the surface water or groundwater cumulative impact evaluations. The groundwater evaluations use locally supplied demand projections of small self-supplied users in combination with permitted demands as documented in Figure 52 and Tables 19 and 20. Small self-supplied user demands are those outside of service areas while the permitted demand portion covers municipal systems and other large users.

DEQ agrees that there is a need to address cells where predevelopment water levels are below the critical surface is warranted, although we believe the State Water Resources Plan is not the appropriate vehicle for that discussion. DEQ is in the process of having this changed so that these cells are not a source of confusion regarding the extent of impacts resulting from existing use.

With respect to the starting date for groundwater simulations, the model does not distinguish between 2020 and 2040 so as long as the same demands are used in a fifty-year simulation, the results will be the same whether the simulation begins in 2020 or 2040. This approach allowed DEQ to isolate the change

to the aquifer from the projected demand in a more straightforward way. Nevertheless, DEQ agrees that starting a 2040 demand simulation in 2020 can lead to confusion and will consider this comment in future versions of the State Plan.

Finally, DEQ agrees that monitoring recent trends in water level observation wells is an important part of evaluating aquifer response due to changes in demands or management. While this was not included in the Draft 2020 State Water Resources Plan, such evaluations are provided in limited form at least annually in the Groundwater Stakeholder Forum as well as recently in meetings of the Eastern Virginia Groundwater Management Advisory Committee. DEQ will consider this comment in future versions of the State Plan.

No revisions made to the Plan.

Theme 9	Indirect Potable Reuse and Other Alternatives

Th.9 – C.1 – Hampton Roads Sanitation District (HRSD)

Comment Summary: Comment notes that given potential water supply shortfalls and the water resources planning statute's objectives to ensure adequate and safe drinking water supplies encourage, promote and develop incentives for alternative water sources (Va. Code 62.1-44.38.1), the absence of a broader discussion on alternative water management approaches is a barrier to informing local and regional solutions for addressing shortfalls. For instance, although the Draft 2020 State Plan references the SWIFT project and examples of reuse in Northern Virginia, it fails to document the significant barriers to implementing reuse projects, particularly those imposed by the state itself.

DEQ Response: Due to the complexity of local factors that determine whether alternatives are viable, the Draft 2020 State Plan does not aim to identify strategies that would best address local or regional supply shortfalls. The regulation does not require much information related to the alternatives available to meet future demand. 9VAC25-780-130 simply requires a description of the likely source of the water and the potential volume. This information is insufficient to look at potential trade-offs among various alternatives and assess whether any are more or less successful in ensuring that the supply of water for all beneficial uses, including drinking water, is adequate. The State Plan is consistent with the information available to DEQ and the regulatory requirements. A discussion of barriers to alternative sources of supply is outside the current scope of the program.

No revisions made to the Plan.

Th.9 – C.2 – Hampton Roads Sanitation District (HRSD)

Comment Summary: Comment notes that existing water use regulation must be updated to streamline permitting and balance requirements with actual risk of negative impacts. Existing regulation is unnecessarily complex and does not address indirect potable use in a meaningful way. While commenter supports use of cumulative impact evaluations to evaluate reuse projects, elfgen framework should not be used unless it has undergone public review and comment and is promulgated as a rule in accordance with the Administrative Procedure Act.

DEQ Response: DEQ appreciates the need to update regulations over time to reflect changes in circumstances, technology, or otherwise. DEQ initiates periodic review of regulations at least once every four years, during which there is an opportunity for stakeholders to provide input. A review of the Water Reclamation and Reuse Regulation was completed in 2018 and no changes were made.

With respect to the comments regarding the elfgen framework, as noted on page 106 of the Draft 2020 State Plan, the use of elfgen in the draft "…represents the initial implementation of this framework for evaluating the potential for impacts to aquatic life. More work is needed to define and implement procedures for evaluating the potential for changes in species richness in a resource management context." Its inclusion in the Draft 2020 State Plan is intended as an introduction to the tool. DEQ is not currently using the elfgen framework to evaluate permit applications, whether for withdrawals or reuse projects, and would proceed in a manner consistent with the Administrative Process Act to do so.

No revisions made to the Plan.

Theme 10	Potential Unmet Demand

Th.10 – C.1 – City of Richmond

Comment Summary: Comment finding on potential unmet demand for Richmond 2040 does not agree with Richmond's safe yield analysis in WSP (p.214-215, Sect. A.5.7, Demand Scenarios), which indicated that James River has adequate capacity to support the City's projected maximum day raw water withdrawal beyond 2070. The comment also suggests clarification about whether and how Lake Moomaw and Cobbs Creek reservoirs are handled in the model.

DEQ Response: The potential unmet demand metric was developed in response to localities that expressed that the State Plan should include more emphasis on impacts to public water supply. Potential unmet demand, as described in the plan document is an amount of water that "... could be managed through water conservation, through alternative sources, operational changes, or from available storage". In short, this metric is intended as a screening tool at facility scale that identifies conditions where a facility may require conservation, alternative sources or expanded storage. When drought triggers are known by DEQ for a given facility, the modeling simulations include a temporary reduction in demand, and record the conservation reduction as "potential unmet demand". In the specific case of the City of Richmond, the potential unmet demand value reflects modeled conservation demand reductions based on drought triggers in the U.S. Army Corps of Engineers permit for intake operations. The model does factor in drought restrictions, Cobb's Creek releases, and operational rules for Lake Moomaw.

No revisions made to the Plan.

Th.10 - C.2 – City of Richmond

Comment Summary: Comment notes that the Draft 2020 State Plan identifies potential unmet demand for the City of Richmond in the dry climate scenario but that this is not consistent with the Regional Water Conservation Plan submitted to DEQ in 1998.

DEQ Response: As noted in the previous response, potential unmet demand includes a portion of the demand that can or will be addressed via conservation measures such as the City of Richmond has in place. This metric is a screening tool to identify where a facility may need to rely on conservation or additional water source alternatives in a given scenario. Chapter 4 Section 2.4 provides an overview of model inputs and assumptions for the dry climate scenario.

No revisions made to the Plan.

Th.10 – C.3 – Rivanna Water and Sewer Authority

Comment Summary: Comment requests clarification about whether potential unmet demand noted in Table 39 in the dry climate scenario takes into consideration construction of the new pipeline from South Rivanna Reservoir to Ragged Mountain Reservoir. Similarly, narrative on page 214 which notes decreases in short-term drought flows does not appear to take into account additional safe yield created by construction of the pipeline. Once the pipeline is constructed, streamflow and consumptive use noted on page 214 below Sugar Hollow Reservoir would not be impacted by water supply demands.

DEQ Response: The potential unmet demand is a screening metric that will be helpful in identifying the conditions under which systems may need to use existing alternatives, operational controls, or other methods for load balancing. DEQ collaborated with RWSA during multiple Virginia Water Protection permit processes that included a fully built system safe yield. No update to that safe yield was performed during the development of the Draft 2020 State Plan. The model scenarios were simulated based on the current Urban System permit tier conditions, which consists of the infrastructure prior to completion of the pipeline. It is correct that impacts below Sugar Hollow would change significantly post pipeline construction. The post-pipeline operational tier was not re-evaluated during the development of the 2020 plan, for either demand or climate change scenarios. DEQ agrees that once the pipeline is operational, future State Plan updates should reflect that in the simulations. Similarly, the maximum current permitted capacity of the Observatory WTP was used in the analysis, and when treatment capacity upgrades are completed they will be reflected in the State Plan. Potential unmet demand in a given scenario does not mean RWSA could not manage demands using the tools available to it, particularly once the planned infrastructure is complete.

No revisions made to the Plan.

Th.10 – C.4 – Interstate Commission on the Potomac River Basin (ICPRB)

Comment Summary: Comment notes that the potential unmet demand identified in Table 73 should be clarified given the upstream reservoirs can be used to augment Potomac River flows during droughts. Also, comment requests clarification as to whether the calculation of unmet demand takes into account the minimum flow-by at Little Falls dam.

DEQ Response: As defined in the Draft 2020 State Plan, potential unmet demand is “the portion of surface water demand for a specific facility that is limited by available streamflow as simulated in a given model scenario, including any known operational limits such as flow-by requirements. This unmet demand, if realized, could be managed through water conservation, alternative sources, operational changes, or from available storage.” The metric is intended as a screening tool, although in cases where existing management structures can accommodate drought flows in the Potomac River, unmet demand can be met through those structures. The narrative on page 383 notes that unmet demand at the Dalecarlia WTP can be met through releases from upstream storage. The minimum flow-by at Little Falls and Great Falls are simulated in the model.

No revisions made to the Plan.

Theme 11	Power Generation

Th.11 – C.1 – Town of Leesburg

Comment Summary: Comment requests DEQ clarify statement (Sect. A. 13.3) "this (Potomac) basin does not include any power generation associated withdrawals" considering GenOn Facility and Stonewall Energy (which use Leesburg reclaimed water). Comment also notes that Washington

Suburban Sanitation Commission (WSSC) is not mentioned in the appendix although it withdraws from the Potomac River. Comment asks DEQ to clarify this.

DEQ Response: The Draft 2020 State Plan utilizes data that has been reported to the DEQ's Office of Water Supply and information collected through local and regional water supply plans. Water users in Virginia that meet the regulatory threshold are required to report withdrawals occurring in Virginia; water users outside of Virginia are not required to report although a few do so voluntarily. As noted on page 363, "while much of the Middle Potomac basin is outside of Virginia, the following sections focus on demands and impacts within Virginia only." A clarification about the Panda Stonewall Power Project has been added to page 365.

Revision made to the Plan: The narrative on page 365 revised as follows:

"The Virginia portions of this basin does not include any power generation associated withdrawals facilities that withdraw water; however the Panda Stonewall Power Project is supplied through reuse from Town of Leesburg's wastewater treatment plant. Panda Stonewall's demands therefore do have an impact on streamflow in the Potomac River through the reduction of water that would otherwise be discharged by the Town of Leesburg"

A clarification has been added to the referenced line on page 365. "This basin does not include any power generation withdrawals; however, reclaimed water from the Town of Leesburg is used to supply the Panda Stonewall Power Project located in that area."

Theme 12	Sustainable Water Initiative for Tomorrow (SWIFT)

Th.12 – C.1 – Mission H2O

Comment Summary: Comment notes that Draft 2020 State Plan recognizes potential benefits of Hampton Roads Sanitation District's (HRSD) Sustainable Water Initiative for Tomorrow (SWIFT) but continues to advocate for further reductions in groundwater use in Eastern Virginia. Plan fails to recognize Eastern Virginia Groundwater Management Advisory Committee report recognizes SWIFT as viable alternative, and downplays pilot injection results. Clear criteria for when SWIFT Injection levels will support reinstatement of previously cut groundwater withdrawals should be established and added to discussion on page 110.

DEQ Response: The Draft 2020 State Plan addresses SWIFT as a key potential alternative to groundwater both in narrative but also through the results of a new groundwater modeling scenario included in the Plan that simulates the SWIFT project at full scale combined with projected future demands. This scenario evaluates for the first time the potential benefits of SWIFT in the context of projected growth across the Eastern Virginia Groundwater Management Area. The SWIFT project has the potential for significant promise but we are early in the project development process and its ultimate benefits are still to be demonstrated. Until the SWIFT project can demonstrate actual regional head improvements, potential reductions to offset the growth in unpermitted individual withdrawal may be warranted and suggesting so is prudent management. As noted in the Draft 2020 State Plan, the results are promising, but the aquifer response must still be validated at a regional scale. This must be measured and documented before criteria are established for reallocating withdrawals. DEQ depiction of SWIFT is consistent with its response to the Eastern Virginia Groundwater Management Advisory Committee report recommendations.

No revisions made to the Plan.

Th.12 – C.2 – Hampton Roads Sanitation District (HRSD)

Comment Summary: Comment notes that while the Draft 2020 State Plan acknowledges the potential benefits of SWIFT for groundwater users in eastern Virginia, it also notes that additional time is necessary to validate actual aquifer response to modeled response. Comment states that "given the magnitude of the investment for SWIFT and the investment by permittees in pursuing other alternative sources, it is critical to establish, now, the criteria necessary to allow the reinstatement of previously permitted withdrawal volumes." Comment also recommends that a synopsis of the Eastern Virginia Groundwater Advisory Committee's recommendations, including the recommendation of SWIFT as an alternate source, be added to section 5.1.1.

DEQ Response: The Draft 2020 State Plan addresses SWIFT as a key potential alternative to groundwater both in narrative but also through the results of a new groundwater modeling scenario included in the Plan that simulates the SWIFT project at full scale combined with projected future demands. This scenario evaluates for the first time the potential benefits of SWIFT in the context of projected growth across the Eastern Virginia Groundwater Management Area. The SWIFT project has the potential for significant promise but we are early in the project development process and its ultimate benefits are still to be demonstrated. As noted in the Draft 2020 State Plan, the results are promising, but the aquifer response must still be validated at a regional scale. This must be measured and documented before criteria are established for reallocating withdrawals. DEQ depiction of SWIFT is consistent with its response to the Eastern Virginia Groundwater Management Advisory Committee report recommendations.

Revision made to the Plan: The following brief synopsis of EVGWAC recommendations to 5.1.1 (groundwater management) was added:

"Eastern Virginia Groundwater Advisory Committee (EVGWAC) was created by the General Assembly in response to recognition of the current and future challenges in ensuring sustainability of the Potomac and other aquifers in the EVGMA. Based on a series of whole committee and workgroup meetings, the EVGWAC produced a Final Report in August of 2017. The report identified 12 recommendations: 1) Commonwealth should support storage, recovery, and recharge projects (such as SWIFT), 2) Commonwealth should promote the development of the list of alternative water sources and solutions included in the report, 3) lengthening the maximum groundwater permit term to 15 years, 4) General Assembly should establish additional incentives for voluntary regional planning, 5) General Assembly should create incentives for local governments and well owners to connect to surface water sources, 6) General Assembly should require new non-agricultural irrigation wells be screened in water table where able, 7) General Assembly should develop a statement of regulatory intent to encourage use of ponds and stormwater ponds for irrigation/agriculture, 8) DEQ should establish an annual "State of the Water Resources" forum, 9) General Assembly should authorize DEQ to develop a groundwater banking system, 10) General Assembly should direct DEQ with a timeline and resources to create a framework for groundwater trading, 11) General Assembly should provide funding to ensure a robust groundwater management program (see report for identified priorities), and 12) General Assembly should fund essential operation costs for DEQ to manage groundwater.

Many of these recommendations have been acted on by DEQ or the General Assembly as described in the 2020 State Plan and in the annual publication of the Annual Water Resources Report. The EVGWAC was reestablished by the General Assembly effective July 1, 2020 and will provide annual reports on these recommendations and other topics covered by the committee. More information and the latest annual report issued by the EVGWAC can be found on the DEQ Website."

Theme 13	VAHydro Surface Water Model Methods and Results

Th.13 – C.1 – Fairfax Water

Comment Summary: Comment states that use of the Bay Program Model, which was developed specifically for the Chesapeake Bay Program (CBP) to use, may overestimate the impact of water withdrawals statewide as documented by Schultz et al. (2014). Caution needs to be used in applying it for applications beyond its intended use.

DEQ Response: The flow simulation of the Chesapeake Bay watershed model is used to provide a baseline hydrology for all watersheds in the Commonwealth. DEQ's VAHydroSW model is used to provide flow routing in channels as well as reservoir operational rules, two aspects that when combined improve model low-flow simulation in areas where we have increased the model resolution. While the underlying hydrology model under-predicts extreme low flows in some locations, the model also has areas of over-prediction, and cannot be characterized as systematically under-estimating low flows state-wide. The Phase 6 model, which now underlies all simulations in Virginia's Chesapeake Bay tributaries, has an improved low-flow simulation over the Phase 5 version. DEQ also opted to evaluate low flows primarily using 30 and 90 day timespans (30 day low flow and 90 day low flow) because the model performance improves substantially over these longer periods.

There are many causes of low flow error in a rainfall runoff model when comparing to historic gage data, not all of which are exclusively due to systematic model limitations. Unknown withdrawals, gage error, and emergency releases from upstream reservoirs are just a couple of examples. Despite the improvements in low flow performance in the Phase 6 model, and improvements to simulations due to the expanded network of reservoirs simulated in VAHydroSW, some amount of model error will always exist. To account for this, DEQ developed a strategy of using model calibration error to estimate a range of potential changes to instream flows because of the range of factors that may cause model calibration to deviate from monitored stream gage values. See Appendix B.2, page 569 for more information on this effort and the results.

No revisions made to the Plan.

Th.13 – C.2 – Interstate Commission on the Potomac River Basin (ICPRB)

Comment Summary: Comment notes that the Chesapeake Bay Program watershed model is known to under-simulate flows as indicated by Calibration Plots for Potomac River at Little Falls gage in Watershed model documentation. Commenter acknowledges DEQ's use of bias-correction factors, but concern that correction factors may not be sufficient and it is not clear if the factors are applied prior to calculated potential unmet demand. Additionally, the factors may not be sufficient for use with the dry climate scenario due to decreases in low flows.

DEQ Response: The flow simulation of the Chesapeake Bay watershed model is used to provide a baseline hydrology for all watersheds in the Commonwealth; however, the VAHydroSW model is used to provide flow routing in channels as well as reservoir operational rules, two aspects that when combined to improve model low-flow simulation in areas where DEQ has increased the model

resolution. While the underlying hydrology model under predicts extreme low flows in some locations, the model also has areas of over-prediction, and therefore cannot be characterized as systematically under-estimating low flows state-wide. The Phase 6 model, which now underlies all simulations in Virginia Chesapeake Bay tributaries, also has an improved low-flow simulation compared to the Phase 5 version. DEQ has also opted to evaluate low flows and potential unmet demand on 30 and 90 day timespans because the model performance improves substantially over these longer periods.

As noted in the comment, DEQ did complete a model error analysis which is documented in Appendix B.2 on page 518. Note that this analysis was designed to evaluate model error and was not used to correct or adjust the results provided in the Draft 2020 State Plan. As noted on page 518, the purpose of this analysis is to inform discussions with stakeholders about margins of safety and uncertainty when reviewing the results.

No revisions made to the Plan.

Th.13 – C.3 – Northern Virginia Regional Commission

Comment Summary: Comment states that while the use of existing tools is appreciated, use of the Chesapeake Bay Program Watershed Model (CBPWM) is inappropriate due to the compromises made for a model to be representative of 64,000 square miles. Compromises made for climate change modeling for the watershed as a whole and may not accurately reflect results in sub watershed segmentation. Information used as input to CBPWM is collected at county scale or larger, which limits usefulness of model in smaller scales. Comment also notes lack of groundwater withdrawal simulation impacts baseflow for small and moderate sized streams, which will impact low flow simulations. The CBPWM model also does not take into account specific reservoir management operations that are in place in many larger river systems. While the CBPWM may be a good starting point, it would need to be modified further before it should be emphasized as in the Draft 2020 State Plan.

DEQ Response: While the Chesapeake Bay Program watershed model's end-point is the Chesapeake Bay, the model in Virginia has been calibrated to well over 100 Virginia stream gages, and is well suited for a planning level analysis of cumulative impacts. While the models performance during low flow events varies from place to place (with both under-simulation and over-simulation), the calibration is outstanding for mean flows (the basis for evaluating ecological risks to consumptive use), and is currently the best available tool for simulating the hydrologic response to historically varying meteorological drivers and changing land use in Virginia. With regard to specific reservoir management operations, DEQ agrees that the base Chesapeake Bay Program model uses simple stage-storage relationships to characterize reservoirs, and that this methodology can be problematic when simulating drought events. As documented in Chapter 4 in the Draft 2020 State Plan, the runoff simulation of the Chesapeake Bay watershed model is used to provide a baseline hydrology for all watersheds in the Commonwealth. However, the VAHydroSW model is used to provide flow routing in channels as well as reservoir operational rules (see section 4.2.2.3). These two aspects improve model low-flow simulation in areas where DEQ has increased the model resolution. We think it important to note that the Phase 6 model, which now underlies all simulations in Virginia bay tributaries, has an improved low-flow simulation over the Phase 5 version.

In terms of the compromises that may have been made in the selection and implementation of climate change models, DEQ believes this is an area where, despite limitations, the Chesapeake Bay model provides an invaluable opportunity for planning level analysis. Hydrologic models, like many other calibrated models, perform best when evaluated under input "forcing" data sets that are within the

range of natural variability. DEQ performed extensive review of the various model meteorological data sets that went into the chosen scenarios and examined the variability in both rainfall and precipitation geospatially. The variability between potential wet and dry scenarios is far greater than spatial variability within sub-watersheds in a single scenario. The variation between scenarios is well within the historically observed inter-annual variation in climate forcing functions (temperature and rainfall), with the exception of a few days that are simulated to exceed the maximum temperatures ever recorded. In short, the range of potential precipitation and evaporation changes simulated by the Phase 6 model are within the bounds of the calibrated model for any individual watershed segment. However, DEQ agrees that improving all aspects of model performance at these smaller watershed scales will enhance the precision with which we can estimate the potential for climate change to necessitate a greater factor of safety when evaluating reservoir capacity and water conservation capabilities.

Model uncertainty analysis techniques like those introduced in Appendix B.2 are an important part of model performance. Despite the improvements in low flow performance in the Phase 6 model, and improvements to simulations due to the expanded network of reservoirs simulated in VAHydroSW, low flow errors still exist. To account for this we developed a strategy of using model calibration error to estimate a range of potential changes to instream flows because of the factors that may cause model calibration to deviate from monitored stream gage values.

No revisions made to the Plan.

Th.13 – C.4 – Interstate Commission on the Potomac River Basin (ICPRB)

Comment Summary: Comment notes that the simulation periods of 1984-2014 (demand scenarios) and 1990-2000 (climate scenarios) are short and do not capture the interannual variability of Potomac basin stream flow where the two most serious droughts in the historical record occurred in 1966 and 1930

DEQ Response: DEQ agrees that the current simulation periods should be expanded to include a wider range of historic meteorological conditions. However, because withdrawals and discharges are unknown during many historically severe droughts that took place before the 1980s, an equally large degree of uncertainty arises when using stream gage flows as a basis for model simulations. Land use conversion from forest to non-forest pervious land uses can also have an effect on drought flows, and under some conditions result in elevated base flows. DEQ is currently working, as staffing and resources allow, to expand the meteorological datasets that underpin the rainfall runoff models to include the ability to simulate near real time conditions, as well as to encompass known historically severe drought conditions. DEQ chose a simulation period that offered the greatest chance of being as accurate as possible with the water budget to avoid the introduction of unknown sources of uncertainty in the simulation.

No revisions made to the Plan.

Th.13 – C.5 – Interstate Commission on the Potomac River Basin (ICPRB)

Comment Summary: Comment notes that water quality releases from Jennings Randolph and Little Seneca reservoirs are not represented in the model. These releases could be expected to have a significant impact on projected changes in the metrics used in the Draft 2020 State Plan, including the 30 day low flow, 90 day low flow, and 7Q10.

DEQ Response: The VAHydroSW model includes releases from Jennings Randolph and Savage reservoirs, as well as many other reservoirs that are not included in the baseline Chesapeake Bay Program watershed model. However, the model does not include drought response releases from Jennings Randolph and Little Seneca and including such releases would be expected to have an impact on the noted low flow metrics. Although drought releases are not simulated, "potential unmet demand" was tabulated for intakes on the Potomac River during drought conditions when minimum instream flow targets could not be met. In the Potomac River, this metric can be interpreted as the amount of water that would need to be released by Jennings Randolph and Little Seneca, if not met by other alternatives or conservation. As described in the Draft 2020 State Plan, the term "potential unmet demand" represents an amount of water that "…could be managed through water conservation, through alternative sources, operational changes, or from available storage". In all droughts simulated, stored water was more than sufficient to meet "potential unmet demands" in the Middle Potomac River.

No revisions made to the Plan.

Th.13 – C.6 – Virginia Municipal Drinking Water Association (VMDWA)

Comment Summary: Comment notes that members of VMDWA have questions regarding DEQ's "use of conservative modeling methodology that affects cumulative impact predictions." VMDWA welcomes an opportunity to learn more about the methodology and accuracy of the predictions.

DEQ Response: DEQ is available to go over these materials in more detail with VMDWA or its members. For reference, the methods and assumptions used in the CIA are captured in detail in Chapter 4 Section 2, but in addition, Appendix B goes into much more technical detail about some aspects including discussing the model error analysis that DEQ completed. These sections may be helpful in addressing the subjects highlighted in your comment.

No revisions made to the Plan.

Theme 14	Water Quality

Th.14 – C.1 – Fairfax Water

Comment Summary: Section of page 13 should include high-level issues that impact source waters like emerging contaminants and PFAS.

DEQ Response: The intent of this section is only to identify the lead role of VDH in source water protection and directs readers to the VDH resources that address the issues identified in the comment.

No revisions made to the Plan.

Th.14 – C.2 – Mission H2O

Comment Summary: The potential impact of emerging contaminants on water resource availability is not reflected in the Draft 2020 State Plan, including discussions about potential regulatory standards and cost of treatment options to meet those standards should they be active.

DEQ Response: The intent of this section is only to identify the lead role of VDH in source water protection and directs readers to the VDH resources that address the issues identified in the comment. To date there is not a consensus on what regulatory standards may be appropriate and these are being evaluated at the federal level. Until targets or criteria are established, it is not possible to determine

what the impact could be on water availability. It is possible depending on events that this comment could be addressed in future versions of the State Plan.

No revisions made to the Plan.

Th.14 – C.3– James River Association

Comment Summary: Comment urges DEQ and local and regional water supply planners to consider the 7Q10 metric within planning efforts, as the 7Q10 metric is critical to ensuring sufficient flow to assimilate permitted concentrations of pollution without adversely impacting water quality. If flow is too low, Virginia Pollution Discharge Elimination System (VPDES) permit holders may not be able to safely operate within the confines of their permit. This metric is also important to understand the potential for future conflicts between water withdrawals and permitted discharges.

DEQ Response: The 7Q10 metric is often considered by DEQ when evaluating VPDES permit applications and is a primary flow frequency used to evaluate the waste assimilative capacity of a waterbody. One of the primary purposes of the Draft 2020 State Plan, and the cumulative impact analyses in particular, is to inform local and regional water supply planning efforts when they may need to look more closely at other effects of decreasing flows such as assimilative capacity, so they are factored into the operation of supplies and discharges when necessary.

No revisions made to the Plan.

Theme 15	General Comments and Requests for Additions or Revisions

Th.15 – C.1 – Fairfax Water

Comment Summary: Plan should note that intakes for Washington Aqueduct are located in Maryland and majority of water (70%) of water withdrawn by Aqueduct is used in Maryland.

DEQ Response: Clarifying language has been added on page 366.

Revision made to the Plan: The following language has been added:

"The Dalecarlia WTP is a part of the Washington Aqueduct system, a federally owned and operated water supply agency. Current demands from the Dalecarlia WTP are 128.61 MGD, or approximately 51.2% of total surface water demands in the basin. Note that the majority of water withdrawn by the Washington Aqueduct system is used in Maryland or the District of Columbia."

Th.15 – C.2 – Fairfax Water

Comment Summary: Comment suggests removing "total surface water use" calculation from Table 72 as intakes not in Virginia are not listed or included in the percentage calculations. Therefore this does not characterize total surface water withdrawn.

DEQ Response: Language has been added on page 366.

Revision made to the Plan: The following language has been added on page 366 when introducing the Table. *Note that due to revisions to the plan elsewhere, the referenced Table 72 is now Table 71.*

"Total SW" column includes only intakes in Virginia and/or intakes outside of Virginia that voluntarily report to Virginia."

Th.15 – C.3 – Fairfax Water

Comment Summary: Comment states that VDH consultation and involvement is necessary in final preparation of the State Plan.

DEQ Response: DEQ and VDH work closely and regularly consult on matters related to public water supply and source water, among other areas. VA Code § 62.1-44.38:1.A requires the solicitation of advice and guidance from the Commissioner of Health in establishing the planning process included in the regulations. This was done and VDH continues to be an active participant in the current effort to amend the regulation. The regulation, 9VAC25-780-140.B, outlines the process used for agency consultation including with VDH. DEQ followed this process. VDH was involved in review of the local and regional water supply plan submittal and provided information for the development of the Draft 2020 State Plan. VDH provided the data used in compiling potential exempt user claims based on limits in permits that they have issued. VDH participated in a DEQ presentation to review cumulative impact analysis results prior to draft publication and was invited to provide comments on the draft.

No revisions made to the Plan.

Th.15 – C.4 – Mission H2O

Comment Summary: Comment suggests DEQ collaborate and obtain input from other resource agencies prior to public comment.

DEQ Response: DEQ values input from state or federal resource agencies, and has made a significant effort to solicit that input throughout this process. VA Code § 62.1-44.38:1.A requires the solicitation of advice and guidance from the Commissioner of Health in establishing the planning process included in the regulations. This was done. The regulation, 9VAC25-780-140.B, outlines the process used for agency consultation. DEQ followed this process, these agencies continue to be active participants as their mission, and resources dictate. A number of Virginia agencies were involved in review of the local and regional water supply plan submittals and provided information for the development of the Draft 2020 State Plan. VDH, DWR, DCR, and other agencies participated in DEQ presentation to review cumulative impact analysis results prior to draft publication. All agencies were included in mailings inviting comments on the draft. VDH and DWR are also currently participating on the Regulatory Advisory Panel for the process to development amendments to the Local and Regional Water Supply Planning regulations

No revisions made to the Plan.

Th.15 – C.5 – Rivanna Water and Sewer Authority

Comment Summary: Comment notes that on p.193, A.5.2 - South Rivanna, Ragged Mountain and Totier Creek should be listed as reservoirs.

DEQ Response: DEQ has made the revisions suggested in the comment.

Revision made to the Plan: Language has been added to include South Rivanna, Ragged Mountain, and Totier Creek to the list of reservoirs on page 193.

Th.15 – C.6 – Rivanna Water and Sewer Authority

Comment Summary: Commenter notes discrepancy between population projections for Albemarle County provided in Table 36 compared to RWSA's population projections.

DEQ Response: Population projections in the Draft 2020 State Plan come from Weldon Cooper Center, are provided for informational purposes, and do not impact simulations or local demand projections.

No revisions made to the Plan.

Th.15 – C.7 – Rivanna Water and Sewer Authority

Comment Summary: Comment recommends several changes to narrative wording including changing "improvement" to "optimization", and "manage" to "operate" on page 214, and "improve" to "regulate" on page 215.

DEQ Response: DEQ has made the recommended revisions.

Revision made to the Plan: The following language was added to page 214:

"However, there is likely room for ~~improvement~~ optimization in system management as ongoing data collection improves with better understanding of the reservoir inflows, releases, and stream flow in the system. As demands increase to the projected system capacity, ongoing evaluation of how to best ~~manage~~ operate the system to minimize impacts to aquatic life will be necessary."

And to page 215:

"A VWP withdrawal permit, if issued, would include release requirements that would ~~improve~~ regulate downstream flows below the reservoir."

Th.15 – C.8 – Hampton Roads Sanitation District (HRSD)

Comment Summary: Comment notes that the Draft 2020 State Plan makes repeated reference to need for collective engagement and collaboration; a holistic evaluation of water management is necessary to ensure sustainability of water uses for future generations. HRSD and other wastewater utilities must play a significant role in water resource planning.

DEQ Response: DEQ agrees that wastewater utilities potentially have a significant role to play in water resource planning, whether from a policy or technical perspective, though not all wastewater utilities see the benefit of participating at that level. DEQ recognizes that improving the understanding of how much water is discharged back into our streams and rivers is just as important as improving our understanding of how much is withdrawn. Discharges are a critical part of the model water budget that was used in all the surface water CIA scenarios discussed in the plan.

No revisions made to the Plan.

Th.15 – C.9 – Northern Virginia Regional Commission

Comment Summary: Comment states that projected population growth for Loudoun County is excessive. The County is not projecting a growth from 350 to 440 (thousand) from 2020-2040.

DEQ Response: Population projections included in the Draft 2020 State Plan (Table 106) are a product of the University of Virginia's Weldon Cooper Center as noted in Section 3.3, page 29. Specific details

about the Weldon Cooper population projections can be found at the Weldon Cooper website. Note that population projections provided in the Plan are just informational and were not used to determine water demands.

No revisions made to the Plan.

Th.15 – C.10 – City of Richmond

Comment Summary: Comment requested explanation about Weldon Cooper population projection numbers used (Table 106).

DEQ Response: Population projections included in the Draft 2020 State Plan (Table 106) are a product of the University of Virginia's Weldon Cooper Center as noted in Section 3.3, page 29. Specific details about the Weldon Cooper population projections can be found at the Weldon Cooper website. Note that population projections provided in the Plan are just informational and are not used to determine locally specific water demands.

No revisions made to the Plan.

Th.15 – C.11 – Fairfax Water

Comment Summary: Comment recommends deleting the reference to flow-by at Great Falls and Little Falls as it does not adequately characterize the findings of 1981 Maryland Department of Natural Resources Study.

DEQ Response: During follow up phone conversation, the commenter clarified that the use of the word mandate does not align with the way that the 1981 Study is used. DEQ notes that the 1981 Study, in addition to recommending the flow-by, also recommended that the flow-by be refined or increased as storage is added within the watershed. It also noted some significant methodological limitations that current assessment methods may no longer have, to creating a protective flow-by.

Revision made to the Plan: The following revised language has been added on page 383:

"Currently a 300 MGD flow by is ~~mandated~~ required at Great Falls."