Regional Resilient Design Guidelines for Hampton Roads

October 2025
Version 1.1

HAMPTON ROADS PDC

For accommodation requests or cost-free translation assistance, please contact Quan McLaurin (qmclaurin@hrpdcva.gov).

El servicio de traducción para los documentos de HRPDC y HRTPO se ofrece sin costo a los miembros de la comunidad. Para recibir asistencia, comuníquese con Quan McLaurin (qmclaurin@hrpdcva.gov).

Libreng ibinibigay sa mga miyembro ng komunidad ang suporta sa pagsasalin para sa mga dokumentong HRPDC at HRTPO. Para sa tulong, kumontak kay Quan McLaurin (qmclaurin@hrpdcva.gov).

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HAMPTON ROADS PLANNING DISTRICT COMMISSION
RESOLUTION 2025-01

RESOLUTION OF THE HAMPTON ROADS PLANNING DISTRICT COMMISSION ENCOURAGING LOCAL GOVERNMENTS IN HAMPTON ROADS TO CONSIDER ADOPTING POLICIES TO IMPLEMENT REGIONAL RESILIENT DESIGN GUIDELINES

WHEREAS, the tide gauge at Sewell's Point in Norfolk has recorded approximately 1.5 feet of relative sea level rise since 1927, equivalent to a change of 1.57 feet per 100 years.

WHEREAS, reports by the Hampton Roads Planning District Commission and Hampton Roads local governments have found the Hampton Roads region and many of its localities to be vulnerable to flooding and sea level rise.

WHEREAS, the "Virginia Coastal Resilience Master Plan Phase I," completed in 2021 by the Virginia Department of Conservation and Recreation at the request of the General Assembly, found that sea level rise will have significant impacts on Coastal Virginia in the near-term and long-term.

WHEREAS, several federal agencies have found, as described in the technical report, "Global and Regional Sea Level Rise Scenarios for the United States," published in 2022, that "By 2050, the expected relative sea level (RSL) will cause tide and storm surge heights to increase and will lead to a shift in U.S. coastal flood regimes, with major and moderate high tide flood events occurring as frequently as moderate and minor high tide flood events occur today. Without additional risk-reduction measures, U.S. coastal infrastructure, communities, and ecosystems will face significant consequences."

WHEREAS, the Virginia Institute of Marine Science Sea-Level Report Card for Norfolk, Virginia, projects relative sea level rise of 1.5 feet of sea level rise between 1992 and 2050, with a 95% confidence that sea level will rise between 1.0 feet and 2.1 feet over the same interval.

WHEREAS, the City of Virginia Beach has adopted, based on locally and regionally specific analysis of sea level and precipitation trends and projections, resilient design standards related to stormwater management and climate adaptation as part of its "Public Works Design Standards Manual."

WHEREAS, several Hampton Roads localities, including Chesapeake, Gloucester County, Hampton, Isle of Wight County, Newport News, Norfolk, Portsmouth, Suffolk, and Virginia Beach, have adopted or are developing plans and programs to address floodplains, coastal resiliency, or sea level rise.

WHEREAS, incorporating resilient design guidelines into local policies for stormwater management and other planning and engineering applications is sound public policy that will help mitigate current and long-term flood risk and help protect and promote the health, safety, and welfare of Hampton Roads communities and residents.

Now, therefore, be it resolved that the HRPDC hereby:

1. Encourages localities in Hampton Roads to consider amending their stormwater management and other policies to incorporate sea level rise and increased rainfall as described in the attached document, "Regional Resilient Design Guidelines for Hampton Roads," which has been developed by the HRPDC staff in concert with the HRPDC Coastal Resiliency Committee and other local, regional, state, and federal partners;

2. Recommends that the adopted policies include planning for 1.5 feet of relative sea level rise above the 1983-2001 National Tidal Datum Epoch by 2050, 3 feet of relative sea level rise by 2080, and 4.5 feet of sea level rise by 2100;

3. Recommends that the adopted policies include accounting for watershed-specific tailwater conditions that account for sea level rise in areas that drain to tidal waterbodies;

4. Recommends that the adopted policies include precipitation levels that account for projected climate change, with a minimum of a 10% increase above NOAA Atlas 14;

5. Recommends that the adopted policies include design storms that include both tidal elevations and rainfall, accounting for both sea level rise and increased rainfall due to climate change; and

6. Directs the HRPDC staff and Coastal Resiliency Committee to keep apprised of developments in the monitoring, research, and analysis of sea level and precipitation trends and projections and provide updated information and recommendations to the Commission and to its member localities as appropriate.

APPROVED and ADOPTED by the Hampton Roads Planning District Commission at its meeting on the 16th day of January 2025.

Douglas G. Pons
Chair

Robert A. Crum, Jr.
Executive Director/Secretary

Regional Resilient Design Guidelines for Hampton Roads

This project was included in the HRPDC FY 2021 Work Program, approved on May 21, 2020, HRPDC FY 2022 Work Program, approved on May 20, 2021, HRPDC FY 2023 Work Program, approved on May 19, 2022, HRPDC FY 2024 Work Program, approved on May 18, 2023, HRPDC FY 2025 Work Program, approved on May 16, 2024, and HRPDC FY 2026 Work Program, approved on May 15, 2025.

Approved by the Hampton Roads Planning District Commission

January 16, 2025

Prepared by the staff of the Hampton Roads Planning District Commission

HAMPTON ROADS PDC

January 2025 – Version 1
October 2025 – Version 1.1

REPORT DOCUMENTATION

REPORT TITLE:
Regional Resilient Design Guidelines for Hampton Roads

REPORT DATE:
October 2025

GRANT/SPONSORING AGENCY:
LOCAL FUNDS

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ABSTRACT

This document summarizes recommendations for Hampton Roads localities to use in adopting policies for resilient stormwater management, including policies related to sea level rise scenarios, design tidal/tailwater conditions, precipitation design storms, and joint tidal/precipitation events. Methodologies for each of these recommendations are included in attached appendices.

ACKNOWLEDGEMENTS

This project was completed with the assistance of the HRPDC Coastal Resiliency Committee and participating stakeholders. In addition, the HRPDC staff wishes to acknowledge the assistance provided by employees of the City of Virginia Beach and Dewberry during the development of the design tidal elevations. The HRPDC staff also wishes to thank staff from the Virginia Institute of Marine Science for assistance with sea level trend data and analysis.

Parts of this project were produced in part through financial assistance from the Virginia Coastal Zone Management Program in the Virginia Department of Environmental Quality through grants from the National Oceanic and Atmospheric Administration. The views expressed herein are those of the authors and do not necessarily reflect the views of NOAA or any of its sub-agencies.

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Change log

The following changes were made since the Hampton Roads Planning District Commission approved the guidelines at its meeting on January 16, 2025:

- Minor grammatical and textual edits and clarifying text
- Added abstract and acknowledgements
- Added table of contents, list of figures, and list of tables
- Added list of references
- Moved summary of design guidelines to the introduction section
- Replaced footnotes with inline citations throughout
- Removed references to the U.S. Army Corps of Engineers Sea Level Analysis Tool (SLAT) and replaced with references to NASA Sea Level Projection Tool (pages 3 and 11)
- Added hyperlinks for the NASA Sea Level Projection Tool, NOAA Sea Level Calculator, and NOAA Atlas 14 (page 3)
- Updated references to the U.S. Interagency Sea Level Task Force (page 6)
- Updated the NOAA sea level trend chart for Sewells Point and updated annual trend value (page 7)
- Added the NOAA sea level trend chart for Yorktown (page 7)
- Updated the VIMS sea level rise projection for Norfolk (page 8) and added VIMS sea level rise projection for Yorktown (page 9)
- Added a chart showing NOAA sea level curves and regional sea level rise scenarios (page 13)
- Assigned table numbers to design tidal elevation tables (Appendix B)

Table of Contents

List of Figures

List of Tables

Introduction

Flooding is a significant concern for most Hampton Roads communities. Coastal areas are vulnerable to high tides and storm surge, upland areas in the western part of the region must plan for riverine flooding, and the entire region is susceptible to stormwater flooding from intense rainfall events. Observed changes to rainfall patterns and sea level rise have increased flood risk in Hampton Roads over the last several decades. In addition to permanently inundating some areas, future climate change is projected to further increase the region's vulnerability to flooding from high tides or storm surge or from stormwater due to both more intense rainfall and reduced tailwater capacity from sea level rise.

An important strategy for addressing flood risk is the adoption of public policies that regulate the development of land and infrastructure. These include state regulations such as the Virginia Uniform Statewide Building Code and stormwater management regulations as well as local ordinances regulating floodplains. These policies are generally based on data from past observations, such as NOAA Atlas 14 (Bonnin G. M., et al., 2006).[1] However, in a changing climate, relying on past data may underestimate current and future flood risk. Developing and implementing design standards based on expected future conditions is essential to protecting lives, property, and infrastructure now and into the future.

These guidelines are built on the HRPDC Sea Level Rise Planning Policy and Approach that was adopted by the Hampton Roads Planning Commission in October 2018 (Hampton Roads Planning District Commission, 2018). That policy recommends three regional sea level rise planning scenarios using 1992 as the baseline year: 1.5' between 2020 and 2050, 3.0' between 2050 and 2080, and 4.5' between 2080 and 2100. It also recommends evaluating the scenarios when new information becomes available. Several recent developments, including the release of new sea level rise curves from NOAA (Sweet, et al., 2022), the development of future intensity-duration-frequency curves by MARISA (Miro, et al., 2021), and the adoption of Virginia Beach's Public Works Design Standards Manual (City of Virginia Beach, 2022), have resulted in the need to reevaluate the 2018 policy and to develop new policy recommendations, with a new emphasis on stormwater management. The rationale behind the recommendations remains largely the same:

- **Sea level rise will significantly affect Hampton Roads.** Climate modeling and science continue to advance. Recent projections from federal agencies and research institutions combine observed trends and scenario-based predictions that provide sound estimates of future sea level rise that are suitable for local decision-making.
- **More frequent and intense rainfall is already having an impact on Hampton Roads communities.** Academic and agency efforts to analyze recent trends in precipitation since the publication of authoritative references such as NOAA Atlas 14 combined with studies considering how projected climate change will affect future weather patterns have resulted in tools that can be used to project precipitation intensity, duration, and frequency at the local level.

[1] NOAA Atlas 14 data and documents are available at https://hdsc.nws.noaa.gov/pfds/pfds_map_cont.html.

- **State and federal efforts to increase precipitation standards are not keeping pace with observed impacts.** Although efforts are underway to develop and implement state and federal policies for sea level rise, efforts to develop updated precipitation projections and policies at the state and federal level are not scheduled to be completed before the end of 2025 at the earliest.
- **Adopting local policies will result in increased community resilience sooner than relying on state or federal mandates.** Factoring projections of sea level rise and precipitation change into planning, engineering, and design through local adopted policies and practices will reduce risk and damage from flooding and storm surge.
- **A regional approach can reduce the costs of developing and implementing standards.** It can also provide a strong statement of support for state and federal action to support local resilience initiatives.

Related Efforts

Several similar and related efforts are currently underway at the local, state, and federal government levels to develop new models, tools, and policies that account for current and future flood risk. These guidelines are based in part on several of these efforts. Examples of federal models and tools include the North Atlantic Coast Comprehensive Study and Federal Emergency Management Agency Flood Insurance Studies and supporting products (USACE, 2015). At the state level, examples include the Virginia Coastal Resilience Master Plan and Virginia Institute of Marine Science Sea Level Rise Report Cards (Virginia Department of Conservation and Recreation, 2021; Virginia Institute of Marine Science, 2024). Examples of local initiatives in Hampton Roads include Sea Level Wise in Virginia Beach and Resilient Hampton (City of Virginia Beach, 2020; City of Hampton, n.d.). Research efforts include tools such as the MARISA Projected Intensity-Duration-Frequency (IDF) Curve Data Tool for the Chesapeake Bay Watershed and Virginia (Miro, et al., 2021). Examples of policies that factor in future conditions such as sea level rise or increased rainfall include the Federal Flood Risk Management Standard, Virginia Beach's Public Works Design Standards Manual, and the Virginia Department of Transportation Structure and Bridge Division Design Guidelines (National Climate Task Force Flood Resilience Interagency Working Group, 2024; City of Virginia Beach, 2022; Virginia Department of Transportation, 2025). Specific sources used for each recommendation are included in the relevant sections.

Summary of Recommendations

The Regional Resilient Design Guidelines for Hampton Roads include recommendations for sea level rise, tailwater, precipitation, and joint design storms. These recommendations are summarized below.

Sea Level Rise

- Hampton Roads localities should incorporate the following sea level rise projections into their plans (comprehensive plans, hazard mitigation plans, etc.) and policies (public works standards, stormwater ordinances, zoning ordinances, etc.).
    - 1.5 feet of sea level rise by 2050 (relative to the 1983-2001 National Tidal Datum Epoch)
    - 3.0 feet of sea level rise by 2080
    - 4.5 feet of sea level rise by 2100
- For projects with longer lifespans, Hampton Roads localities should calculate project-appropriate sea level rise projections based on the 2022 Global and Regional Sea Level Rise Scenarios for the United States using a tool such as the NASA Sea Level Projection Tool or NOAA Sea Level Calculator.

Tailwater Elevations

- Hampton Roads localities should incorporate watershed-specific tailwater elevations into their stormwater design standards. These elevations should account for sea level rise based on project lifespan.

Precipitation

- Hampton Roads localities should adopt standards requiring the use of future precipitation levels that account for projected climate change. Hampton Roads localities should adopt a standard that increases NOAA Atlas 14 values by a minimum of 10%.

Joint Tidal/Rainfall Design Storms

- Hampton Roads localities should adopt design storm requirements that account for both tidal elevations and rainfall and incorporate projected future conditions from sea level rise and increased rainfall.

Project Lifespan and Criticality

Incorporating climate change impacts into project design and implementation requires both estimating what future conditions may apply and level of protection or performance should be required. Underestimating a project's lifespan by planning for a smaller amount of sea level rise may result in frequent flooding in the future, lessening the value that project provides or requiring costly maintenance. Similarly, lowering the level of protection required may cost less, but it will result in additional risk that the project may fail or otherwise be negatively affected by flooding or sea level rise. Conversely, overestimating a project's lifespan or criticality may add substantially to a project's costs without providing the benefits to justify such an expense. Localities should consider adopting specific standards for different categories of projects. Table 1 provides below provides some examples for project categories with lifespans that correspond to the HRPDC regional sea level rise planning scenarios. These are based on the New York City Climate Resiliency Design Guidelines and Climate Ready DC Resilient Design Guidelines (District of Columbia Department of Energy & Environment, 2020; NYC Mayor's Office of Climate & Environmental Justice, 2020).

In some cases, communities may wish to apply higher standards or requirements for critical or essential facilities. The 2022 Hampton Roads Hazard Mitigation Plan defines essential facilities and infrastructure as "those facilities or systems whose incapacity or destruction would present an immediate threat to life, public health, and safety or have a debilitating effect on the economic security of the region" (HRPDC, 2022). In addition, several localities, including Chesapeake, Gloucester County, Norfolk, and Virginia Beach, have officially designated critical facilities in their floodplain ordinance or other policy with additional design and siting requirements (City of Chesapeake, 2013; Gloucester County, 2010; City of Norfolk, 2018; City of Virginia Beach, 2022). Examples of critical facilities include:

- Emergency management or operations centers
- Evacuation routes
- Governmental facilities, such as data and communication centers and key government complexes
- Hazardous material facilities
- Hospitals and other medical facilities
- Fire and rescue stations
- Police stations
- Prisons
- Retirement or nursing homes
- Schols
- Shelters
- Universities
- Utility systems such as water, wastewater, oil, natural gas, electricity, and telecommunications facilities
- Other high potential loss facilities

Table 1: Recommended Project Lifespan Categories

Timeframe *Description*	**Example Projects**
2020-2050 *Temporary or rapidly replaceable components and finishings*	- Interim and deployable flood protection measures - Asphalt pavement, pavers, and other right-of-way finishings - Green infrastructure - Street furniture - Temporary building structures - Storage facilities - Emergent or developing technology (e.g., telecommunications equipment, batteries, solar photovoltaics, fuel cells, etc.)
2050-2080 *Facility improvements and components on a regular replacement cycle*	- Electrical, HVAC, and mechanical components - Most building retrofits (substantial improvements) - Concrete paving - Infrastructure mechanical components (e.g., compressors, lifts, pumps) - Outdoor recreational facilities - On-site/at-site energy equipment (e.g., fuel tanks, conduit, emergency generators) - Stormwater detention systems
2080-2100 *Long-lifespan buildings and infrastructure*	- Most buildings (e.g., public facilities, office/commercial/residential buildings) - Piers, wharfs, and bulkheads - Plazas - Retaining walls - Culverts - On-site energy generation/co-generation plants
Beyond 2100 *Infrastructure or assets that cannot be relocated*	- Major infrastructure projects (e.g., tunnels, bridges, water and wastewater treatment plants, etc.) - Monumental buildings - Road reconstruction - Subgrade sewer infrastructure (e.g., sewers, catch basins, outfalls)

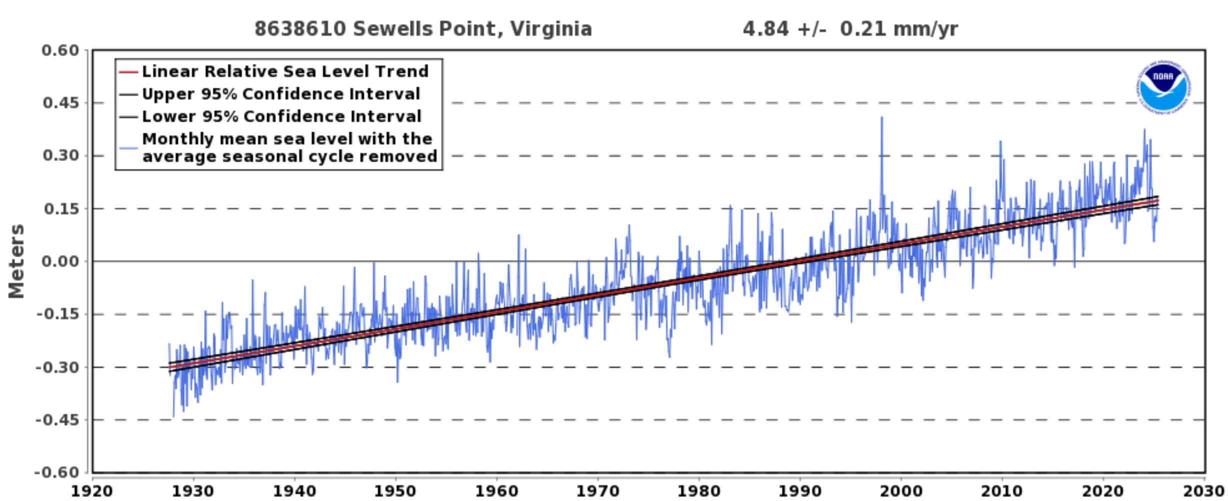
Climate Observations and Projections

Observational data forms the foundation for understanding the region's recent weather patterns and how those patterns are changing over time. Data from authoritative sources such as the National Oceanic and Atmospheric Administration, the Virginia Institute of Marine Science, and other federal and state entities provide both a record of what has already occurred and serve as inputs for climate models to project future conditions. Data for tides and sea level trends is available from NOAA's Center for Operational Oceanographic Products and Services (CO-OPS) (NOAA, 2024). Precipitation data is available from NIAA's National Centers for Environmental Information (NCEI) (NOAA, 2024).

Sea Level Rise

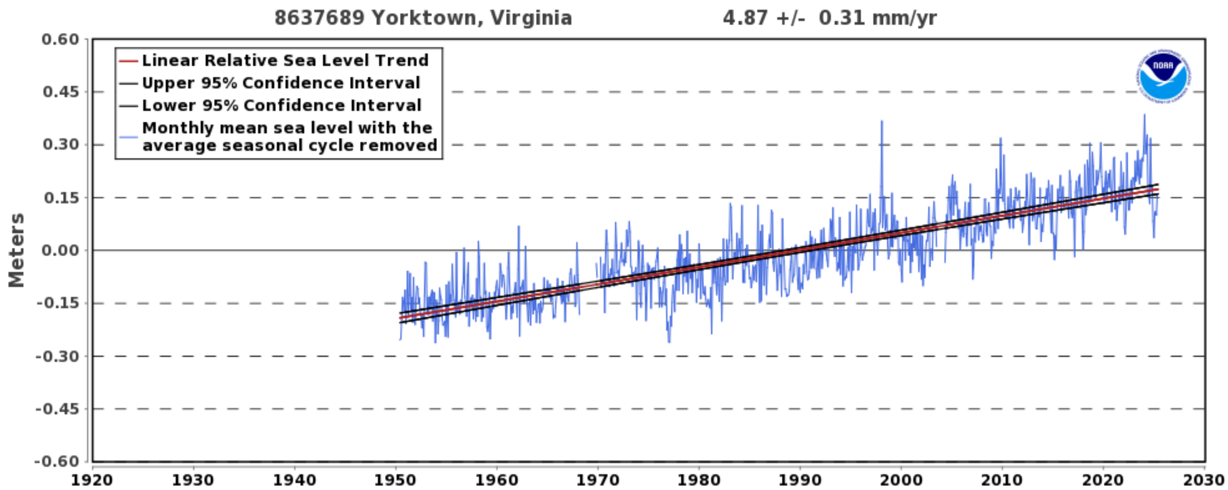
Sea level rise is already having significant impacts on Hampton Roads communities, and these impacts are expected to increase in the future due to further sea level rise resulting from climate change. Ongoing and future impacts from sea level rise include loss of tidal wetlands and other shoreline areas due to permanent inundation, more frequent tidal flooding of riparian areas, increased extent of flooding from high tides and storm surge, and more frequent and wider spread inland flooding in some areas. According to the U.S. Interagency Sea Level Task Force, mean sea level increased by approximately 12 inches at the Sewell's Point tide gauge in Norfolk, Virginia, between 1970 and the present, and it is projected to increase by a further 12 inches between 2020 and 2050 under the 2022 Intermediate Sea Level Rise Scenario (U.S. Interagency Sea Level Task Force, 2024). The HRPDC regional sea level rise planning scenarios originally adopted in 2018 and recommended again in these guidelines are based on observations at the Sewell's Point tide gauge, near-term projections based on statistical analysis of the observation record, and regional sea level rise projections based on global climate scenarios (Hampton Roads Planning District Commission, 2018). The continuous long-term record at the Sewell's Point gauge extends from 1928 to the present and shows an annual average rate of sea level rise of 4.84 millimeters per year, or approximately 1.59 feet per hundred years, as shown in Figure 1 below (NOAA, 2025).

Figure 1: Relative Sea Level Trend for Sewell's Point Tide Gauge, Norfolk, Virginia



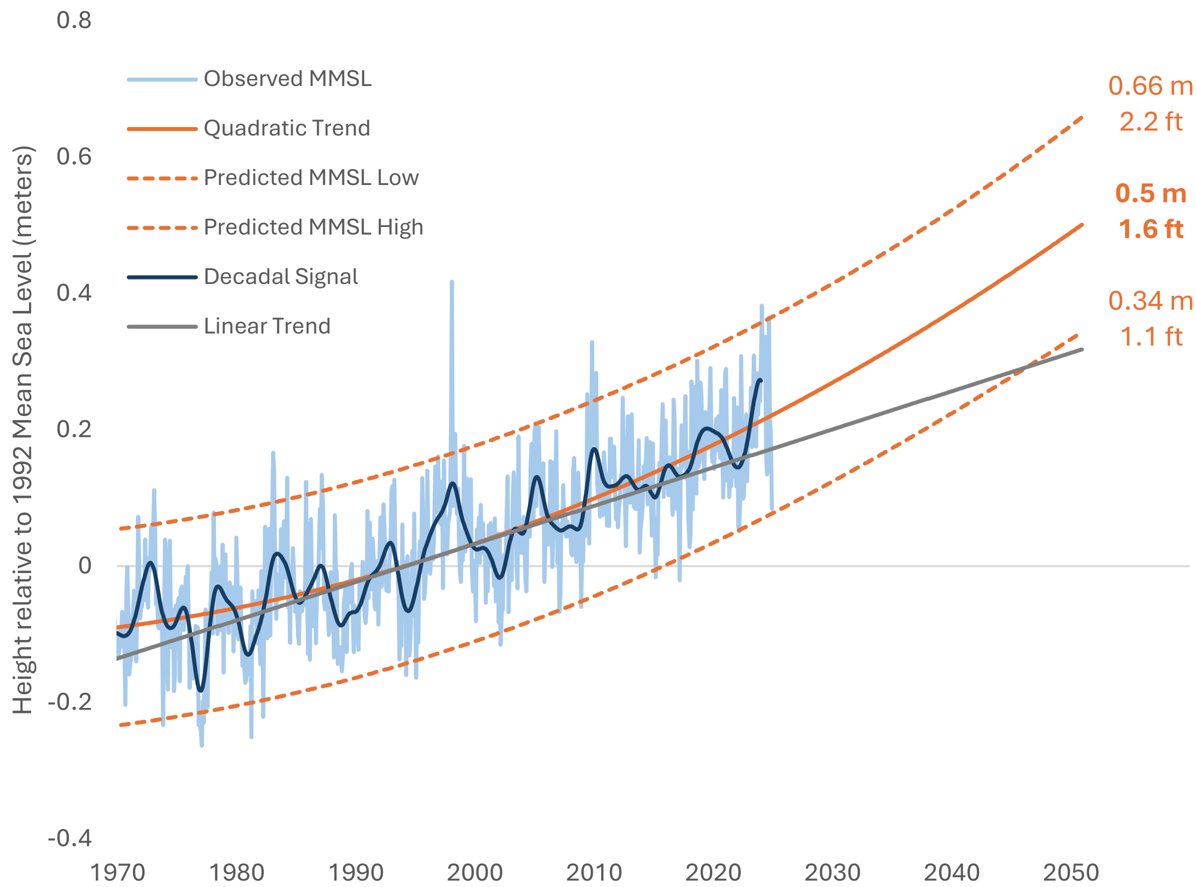
The long-term record for the Yorktown gauge extends from 1950 to the present and shows an annual average rate of sea level rise of 4.87 millimeters per year, or approximately 1.60 feet per hundred years, as shown in Figure 2 (NOAA, 2025).

Figure 2: Relative Sea Level Trend for Yorktown, Virginia



The long-term record is a critical tool, but, depending on the length of the record, it can downplay changes to the average trend. Recent research from the Virginia Institute of Marine Science has found evidence of accelerating sea level rise beginning in 1987 (Boon, Evidence of Sea Level Acceleration at U.S. and Canadian Tide Stations, Atlantic Coast, North America, 2012). Additional research published in 2018 reinforced this finding (Boon, Mitchell, Loftis, & Malmquist, 2018). Based on this work, VIMS publishes Sea Level Rise Report Cards for thirty-two locations along the U.S. East, Gulf, West, and Alaskan coasts, including Norfolk (Virginia Institute of Marine Science, 2024). These report cards include recent observational data (mean monthly sea level or MMSL), projections of future sea level in 2050, and a summary of how different drivers are affecting sea level trends for each location. For example, sea level rise in the Norfolk area is significantly affected by changing ocean dynamics and glacial ice melt, but less affected by groundwater withdrawals (Virginia Institute of Marine Science, 2024).

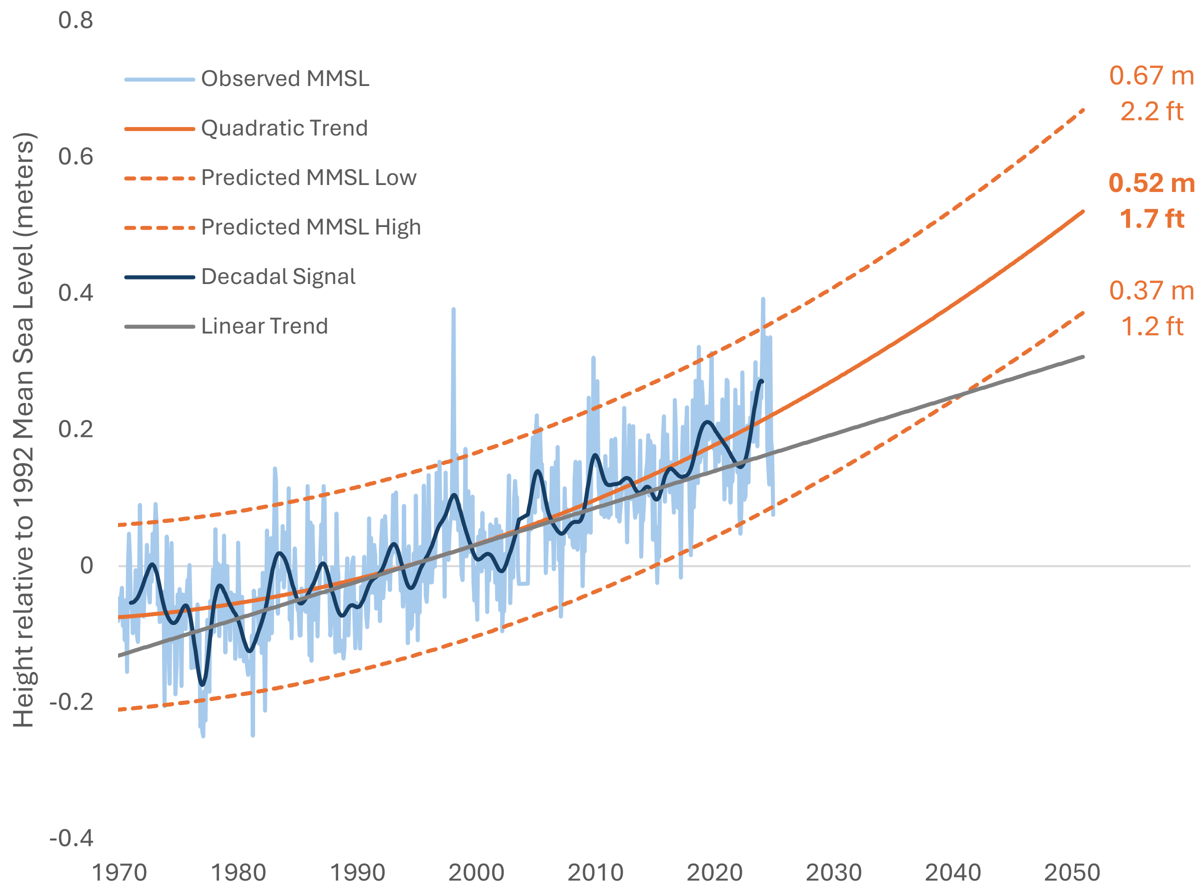
Figure 3: VIMS 2050 Sea Level Rise Projection for Norfolk, Virginia[2]



The VIMS Sea Level Rise Report Card for Norfolk (Figure 3) projects that sea level will rise 0.5 meters or 1.64 feet above 1992 mean sea level, with a 95% chance that mean sea level in 2050 will rise between 0.34 and 0.66 meters (1.1 feet to 2.2 feet). This confidence interval accounts for interannual and decadal variations in mean sea level. 1992 is used as the benchmark because it is the midpoint of the current 1983-2001 National Tidal Datum Epoch (NOAA, 2024).

[2] Data from VIMS U.S. Sea-Level Report Cards analysis. 2025. https://www.vims.edu/research/products/slrc/. Water level data from NOAA/NOS/CO-OPS tide gauge. https://tidesandcurrents.noaa.gov/stationhome.html?id=8638610. All data in meters relative to the tidal datum centered on 1992.

Figure 4: VIMS 2050 Sea Level Rise Projection for Yorktown, Virginia[3]



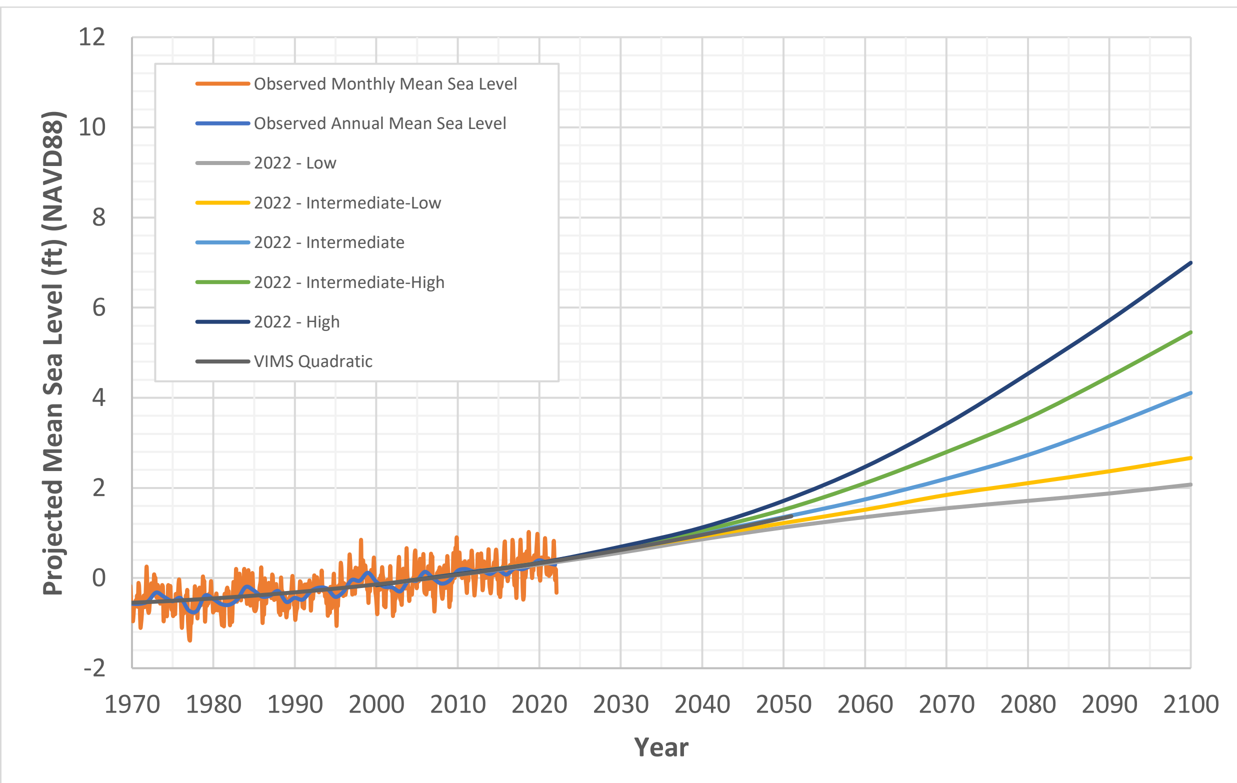
The VIMS Sea Level Rise Report Card for Yorktown (Figure 4) projects that sea level will rise 0.52 meters or 1.71 feet above 1992 mean sea level, with a 95% chance that mean sea level in 2050 will rise between 0.37 and 0.67 meters (1.2 feet to 2.2 feet).

The VIMS projections end in 2050 because uncertainty grows significantly beyond that timeframe using a statistical analysis approach. For longer-term projections, a scenario-based approach that uses various sets of socio-economic conditions is used to develop a range of possible outcomes. This is the approach used by both the Intergovernmental Panel on Climate and the U.S. Interagency Sea Level Task Force. In 2022, the National Oceanic and Atmospheric Agency, in partnership with the U.S. Interagency Sea Level Task Force, Rutgers University, and the Florida International University Institute of Environment, published *Global and Regional Sea Level Rise Scenarios for the United States: Updated Mean Projections and Extreme Water Level Probabilities Along U.S.*

[3] Data from VIMS U.S. Sea-Level Report Cards analysis. 2025. https://www.vims.edu/research/products/slrc/. Water level data from NOAA/NOS/CO-OPS tide gauge. https://tidesandcurrents.noaa.gov/stationhome.html?id=8637689. All data in meters relative to the tidal datum centered on 1992.

Coastlines (Sweet, et al., 2022). This report incorporates updated science, including the statistical approach used by VIMS, and additional observations of sea level change and various drivers to produce five sea level rise scenarios that have been downscaled to develop regional estimates. These estimates account for global sea level rise drivers, such as ocean thermal expansion, glacial ice melt, ice sheet instability, and changes in the Earth's gravitational field, along with regional and local drivers such as vertical land movement (e.g., land subsidence caused groundwater withdrawals) and changes in ocean currents. This new analysis projects between 2.2 feet of sea level rise in Hampton Roads between 2000 and 2100 under the low scenario and 7.2 feet of sea level rise by 2100 under the high scenario (Figure 5). The intermediate scenario projects 4.3 feet of sea level rise between 2000 and 2100. The observational trend roughly aligns with the intermediate scenario to date.

Figure 5: Observed and Projected Mean Sea Level Change in Norfolk, Virginia Sewells Point Tide Gauge, VA 1970-2100 (2022 NOAA Sea Level Rise Scenarios)[4]

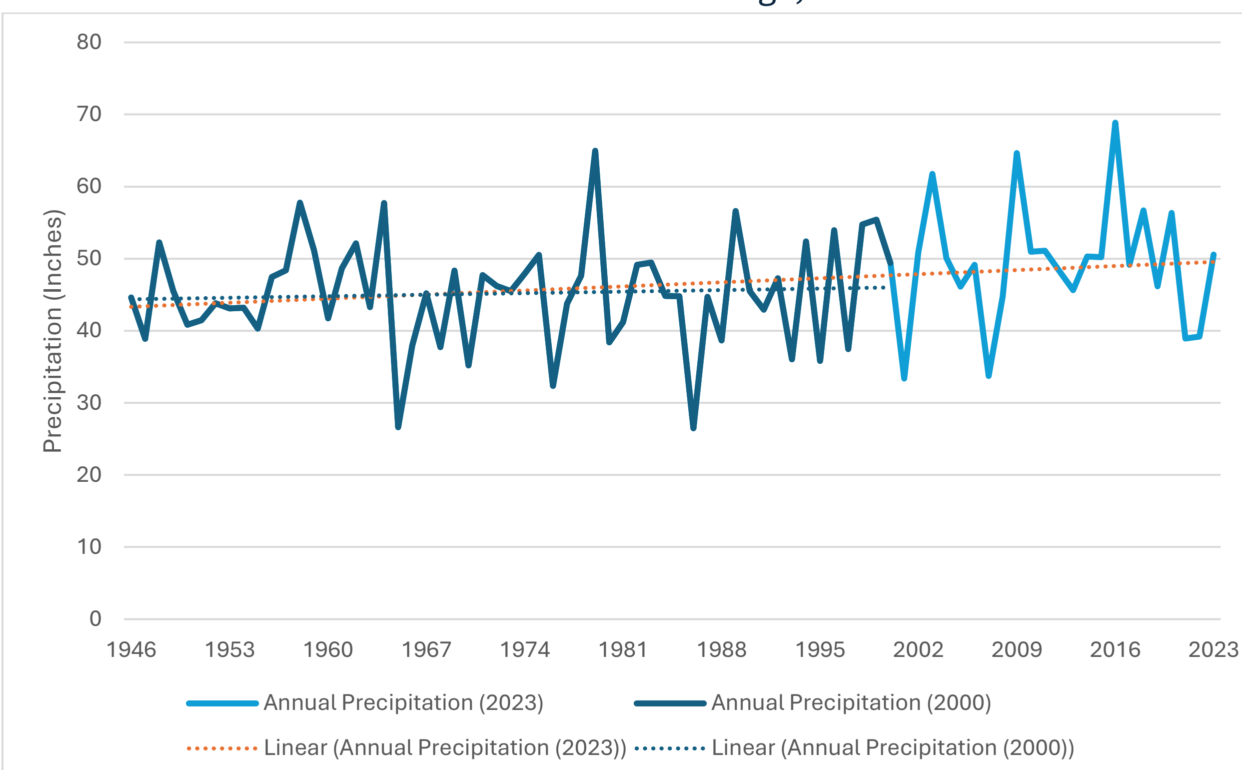


[4] **Note:** This chart uses 2000 as the baseline year to align with the 2022 NOAA sea level rise report.

Precipitation

Increasing rainfall will have a significant impact on community infrastructure. Stormwater flooding is becoming more of a concern as rainfall intensifies and as sea level rise reduces stormwater system capacity during high tides. Generally, stormwater management facilities in Hampton Roads have been constructed based on design depths from NOAA Atlas 14, Volume 2, which is the most recent precipitation atlas for Virginia (Bonnin G. M., et al., 2006). However, this atlas only includes data through December 2000, and analyses of recent data by Virginia Beach and others suggest that rainfall has continued to increase at an accelerated rate. Between 1946 and 2000, annual precipitation at the rain gauge located at Norfolk International Airport increased approximately 3.7%, from 44.3 inches in 1946 to 45.9 inches in 2000, based on the linear trend. Including data from 2000 to 2023 results in a much larger increase of approximately 10.1% between 1946 to 2000 and 14.3% from 1946 to 2023. This trend is shown in Figure 6.

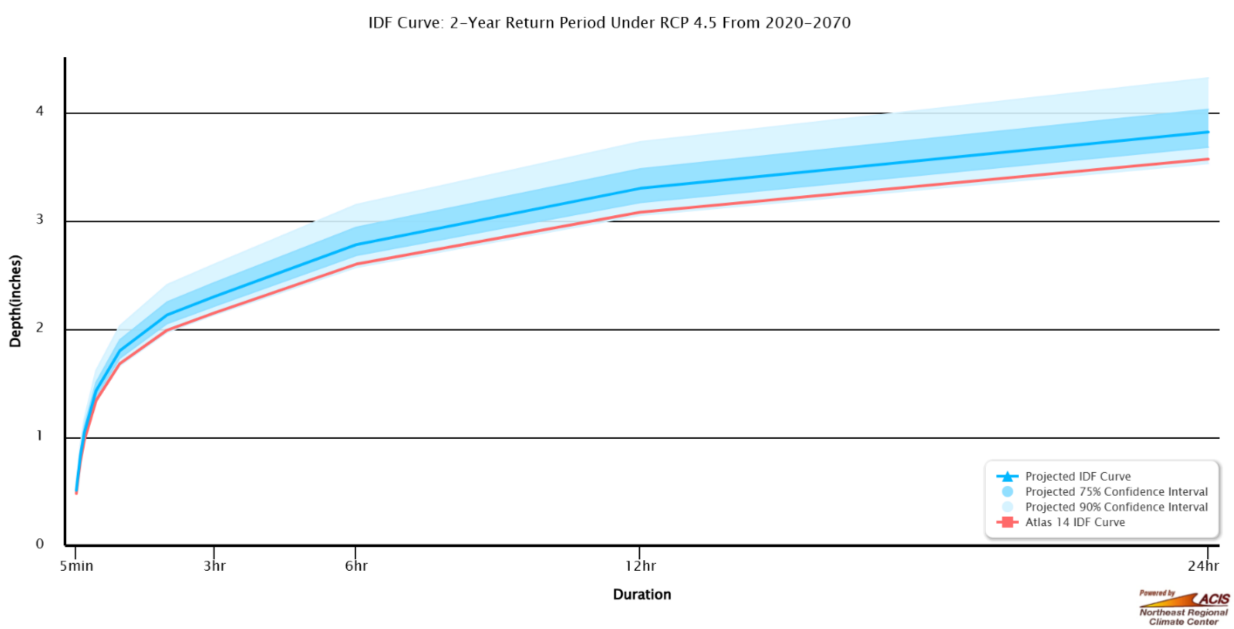
Figure 6: Annual Precipitation in Norfolk, Virginia - 1946-2023
Sewells Point Tide Gauge, VA



While updating the dataset to include observations since 2000 is important for understanding current rainfall patterns, it is also important to take into account projected changes in precipitation due to climate change. Recent projects completed separately by the City of Virginia Beach and the Mid-Atlantic Regional Integrated Sciences and Assessments (MARISA) program have shown that rainfall will increase significantly in future years due to climate change (Miro, et al., 2021). The

MARISA project, completed in partnership with RAND and the Chesapeake Bay Program, used available precipitation data and downscaled climate models to project future precipitation levels and intensity-duration-frequency (IDF) curves for various combinations of climate scenarios, time periods, and recurrence intervals. For example, Figure 7 below shows the adjusted IDF curve from the MARISA/RAND tool for the 2-year storm under Representative Concentration Pathway 4.5 for 2020-2070 at Norfolk International Airport (Miro, et al., 2021). Averaging both climate scenarios and all return periods for the 2020-2070 time period resulted in median projected increases between 4% and 13% above Atlas 14 for Hampton Roads localities, while using the 75th percentile resulted in median projected increases between 13% and 22%. More information on this analysis is available in Appendix C.

Figure 7: Project IDF Curve for Norfolk International Airport



Recommended Design Guidelines

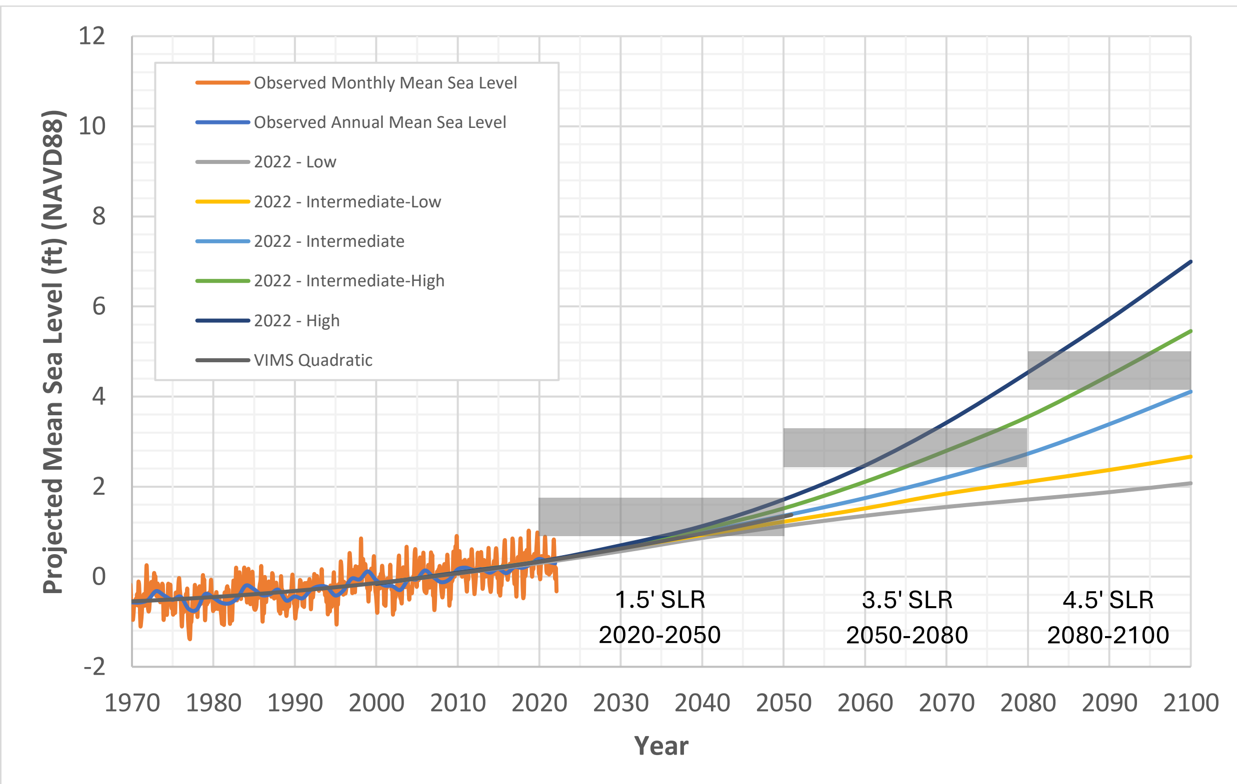
Sea Level Rise

Given the uncertainty in how much sea level rise will occur over the 21st century, it is important for localities to use robust planning values that are relevant across multiple scenarios. Regional sea level rise planning values for Hampton Roads should be based on a combination of the observational record, near-term projections based on observed trends, and long-term climate scenarios. Based on the regional tide gauge record, VIMS projections, and 2022 NOAA sea level rise report, the HRPDC recommends that Hampton Roads localities use the following scenarios for sea level rise planning at the local and regional level (Figure 8):

- 1.5' of sea level rise between 1992 and 2050
- 3.0' of sea level rise between 1992 and 2080
- 4.5' of sea level rise between 1992 and 2100

For projects with longer lifespans, Hampton Roads localities should calculate project-appropriate sea level rise projections based on the 2022 Global and Regional Sea Level Rise Scenarios for the United States using a tool such as the NASA Sea Level Projection Tool or NOAA Sea Level Calculator (Sweet, et al., 2022; NASA, 2024; NOAA, 2024). These scenarios should be incorporated into local plans (e.g., comprehensive plans, hazard mitigation plans) and policies (e.g., stormwater ordinances, public works/facilities manuals) as well as regional plans (e.g., the regional hazard mitigation plan or regional long-range transportation plan).

Figure 8: Regional Sea Level Rise Scenarios[5]



Design Tidal Elevations

Tailwater elevations are used as boundary conditions for stormwater management calculations based on specified design storms or other standards. The VDOT Drainage Manual requires the use of actual water elevations corresponding to either the specified design storm or to mean high water

[5] **Note:** This chart uses 2000 as the baseline year to align with the 2022 NOAA sea level rise report.

if those values are known; if not, the standard is to use an elevation equal to 0.8 times the diameter of the outlet pipe (Virginia Department of Transportation, 2025). Several localities, including Chesapeake, Norfolk, and Virginia Beach, have specific elevations in their ordinances. Other communities in Hampton Roads currently rely on the VDOT Drainage Manual. Since stormwater infrastructure is generally intended to be long-lived, it is important that the design criteria used should account for expected future conditions, including sea level rise. The HRPDC recommends that Hampton Roads localities incorporate watershed-specific tailwater elevations into their stormwater design standards. These elevations should account for sea level rise based on the project's projected lifespan. A proposed methodology for calculating these values is included in Appendix A. Design tidal elevations based on this methodology for each Hampton Roads locality are included in Appendix B.

Design Rainfall Depths

Rainfall depths are key inputs into stormwater management calculations, with different design storms used for different regulatory or other requirements. Virginia's current stormwater management regulations reference NOAA Atlas 14. Updated and new NOAA precipitation products are anticipated to be available in 2025 or 2026. However, the delivery timeline for these products is uncertain. The HRPDC recommends that Hampton Roads localities should adopt standards requiring the use of future precipitation levels that account for projected climate change. Hampton Roads localities should consider adopting a standard that increases NOAA Atlas 14 values by a minimum of 10%. A proposed methodology for determining design rainfall depths is included in Appendix C. Recommended design rainfall depths for each Hampton Roads locality are included in Appendix D.

Joint Probability Events

As part of its broader sea level rise planning program, in 2017 the City of Virginia Beach and Dewberry completed a report assessing the interaction between tidal and rainfall events. The report, "Joint Occurrence and Probabilities of Tides and Rainfall," documents correlation and joint probability analyses used to develop coastal tailwater conditions for tidal waterbodies in Virginia Beach and accompanying rainfall depths to be used together in implementing the city's stormwater management program in coastal areas (Sreetharan, et al., 2017). The design storm pairs listed in Table 2 are based on the joint probability pairs included in the City of Virginia Beach's Public Works Design Standards Manual (City of Virginia Beach, 2022). Accounting for both conditions will enable the design of more robust stormwater systems in areas where capacity may be limited during high tides or storm tides. The HRPDC recommends that Hampton Roads localities should adopt design storm requirements that account for both tidal elevations and rainfall and incorporate projected future conditions from sea level rise and increased rainfall.

Table 2: Recommended Joint Tidal/Rainfall Design Storms

Design Storm	Tidal Elevation	Rainfall
1-Year	10-Year	1-Year
2-Year	5-Year	2-Year
10-Year	1-Year	10-Year
25-Year	2-Year	25-Year
50-Year	2-Year	50-Year
100-Year	3-Year	100-Year

Future Policy Recommendations

Climate trends are continuously monitored and updated by both federal (e.g., NOAA, USGS) and state (e.g., VIMS) entities. In addition, research and analysis into how climate change will alter sea level rise dynamics and precipitation patterns continue to progress. Several efforts underway, including updates to NOAA Atlas 14, the development of NOAA Atlas 15, regional Coastal Storm Risk Management Plans, Phase 2 of the Virginia Coastal Resilience Master Plan, and the Virginia Flood Protection Master Plan, will have direct relevance to the policies recommended in this document. The HRPDC recommends that the HRPDC staff and Hampton Roads local governments evaluate and update these guidelines, as appropriate, based on new information as it becomes available.

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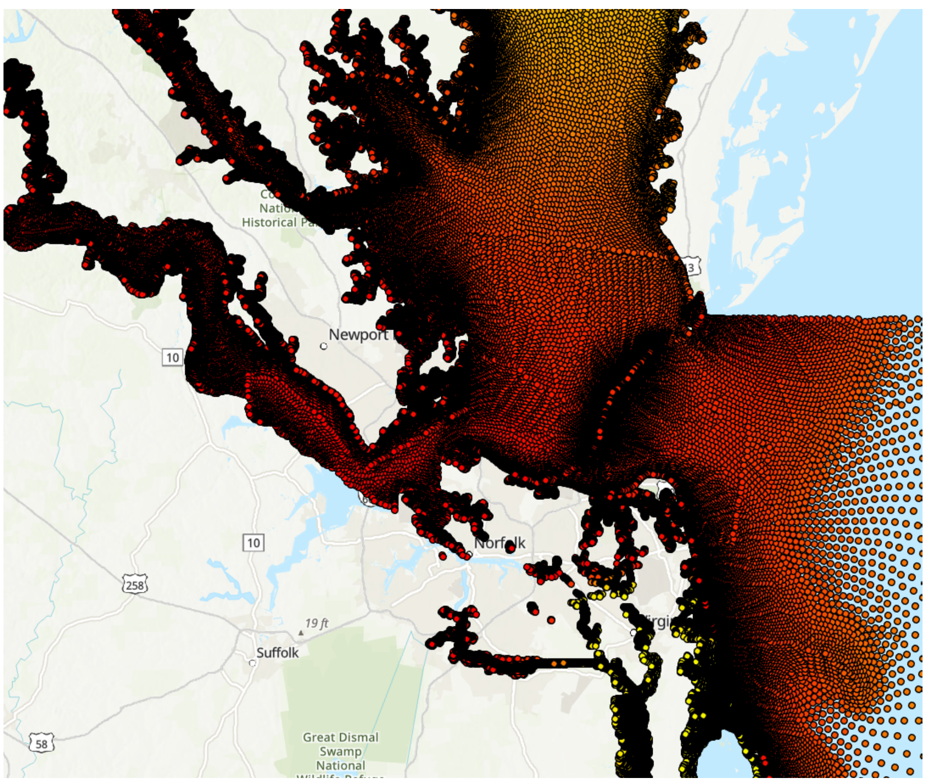
Appendix A – Design Tidal Elevations Methodology

The goal of this effort is to develop design tidal elevations for communities in Hampton Roads that incorporate future sea level rise. These design tidal elevations are intended for use as input tailwater conditions for stormwater management calculations using design storms based on specific recurrence intervals for individual tidal subwatersheds (12-digit Hydrologic Unit Code) throughout Hampton Roads. This analysis builds on two previous studies conducted by the U.S. Army Corps of Engineers: the FEMA Region III Storm Surge Study[6] and the North Atlantic Coast Comprehensive Study.[7] The FEMA Region III Storm Surge Study (FEMA Study) was used in the development of the most recent flood insurance studies and corresponding flood insurance rate maps for coastal Hampton Roads localities. As part of the FEMA Study, the Advanced Circulation Model for Oceanic, Coastal and Estuarine Waters (ADCIRC) model was used to develop a two-dimensional, unstructured grid of storm surge stillwater (not including waves) elevations for six return periods: 10-year, 25-year, 50-year, 100-year, 500-year, and 1000-year (Figure 1). This dataset provided the baseline storm surge values used for the analysis.

Figure A-1: ADCIRC Grid from FEMA Region III Storm Surge Study



[6] Hanson, Jeffrey L., Michael F. Forte, Brian Blanton, Mark Gravens, and Peter Vickery. FEMA Region III Storm Surge Study Coastal Storm Surge Analysis: Storm Surge Results. US. Army Corps of Engineers Engineer Research and Development Center. November 2013.

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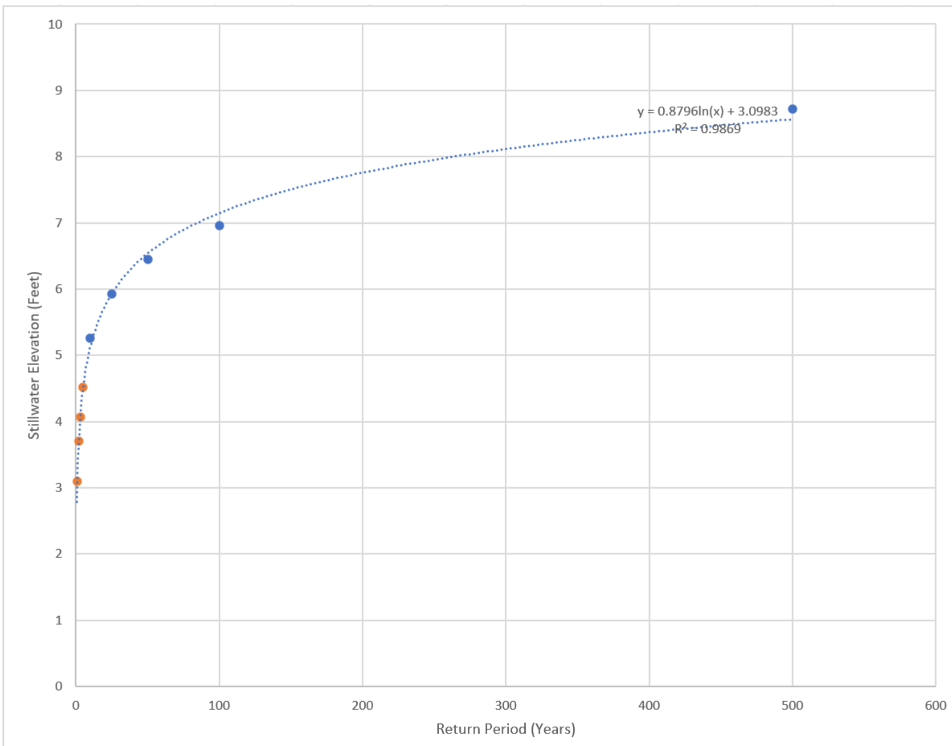
HRPDC staff developed representative tidal elevations for individual watersheds by calculating the 95th- percentile for each HUC-12 geography. A log-linear analysis was run on these values to calculated values for the 1-year, 2-year, 3-year, and 5-year return periods for each watershed. Figure 2 shows an example of this approach. Blue dots represent the 95th-percentile values calculated from the original dataset. Orange dots represent the values calculated using the log-linear analysis.

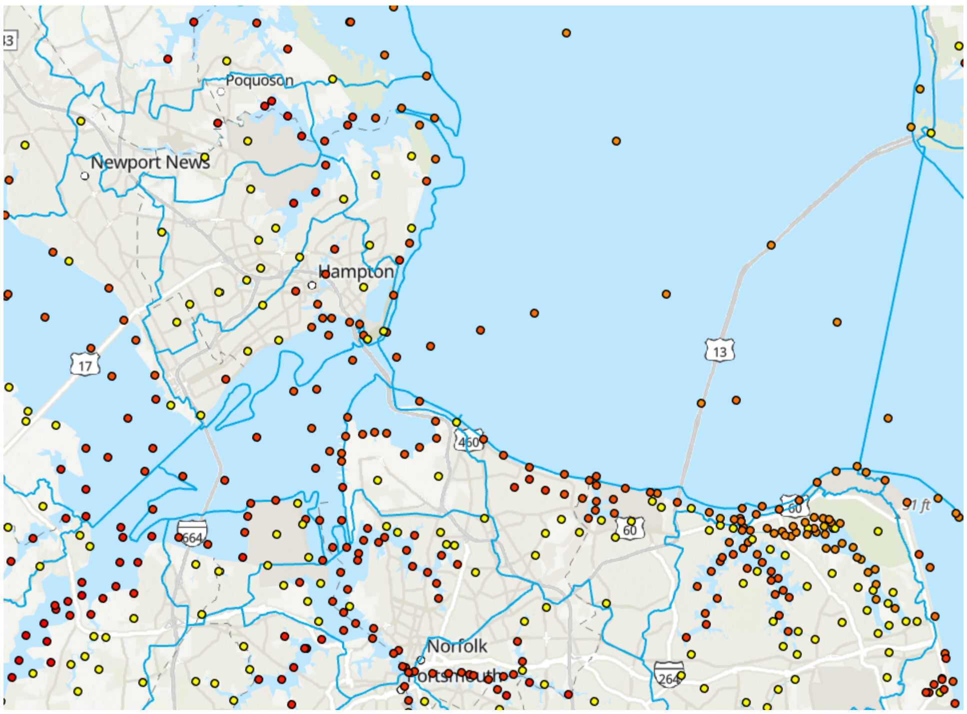
Figure A-2: Chart Showing Results of Log-Linear Analysis of 1-, 2-, 3-, and 5-Year Return Periods



Separately, estimates of non-linear effects of sea level rise were calculated by comparing storm surge elevations from the North Atlantic Coast Comprehensive Study (NACCS) with and without sea level rise (Figure 3). This approach described here for calculating non-linearity factors is based on the methodology used by the City of Virginia Beach and Dewberry to develop design tidal elevations for the city's Public Works Design Standards Manual (June 2020). As part of the NACCS, the US. Army Corps of Engineers modeled storm surge under present conditions and with one meter of sea level rise. The results showed that storm surge in many areas was higher than simply adding one meter to the baseline value. This difference can be accounted for by using non-linearity factors, which are multipliers used to convert baseline values to future values.

For this analysis, non-linearity factors for all HUC-10 and HUC-12 watersheds in Hampton Roads were calculated by averaging factors for each NACCS grid point and return period (10-year, 20-year, 50-year, 100-year, and 500-year). HUC-10 watershed values were calculated for use when the NACCS did not include points within a given HUC-10. Design tidal elevations with sea level rise were then calculated by adding the three regional sea level rise scenarios (1.5', 3', and 4.5') to the calculated elevations. The non-linearity factors derived from the NACCS were then used to develop design tidal elevations for the 3' and 4.5' sea level rise scenarios. The Virginia Beach study found that non-linearity did not occur with 1.5' of sea level rise, so for that scenario the amount of sea level rise was just added to the baseline tidal elevation. Non-linearity factors for all watersheds included in this analysis are listed in Table 1.

Figure A-3: NACCS Storm Surge and Sea Level Rise Analysis Grid Points



Methodology for Design Tidal Elevations:

1. Spatially join Region III Storm Surge points to HUC-12 watersheds (Figure 4)
2. Export spatially joined table and convert to Excel format
3. Calculate 95th-percentile for 10-year, 25-year, 50-year, 100-year, 500-year, and 1000-year return periods for each HUC-12 watershed
4. Calculate SLOPE and INTERCEPT values for each watershed
5. Calculate values for 1-year, 2-year, 3-year, and 5-year return periods using log-linear model
6. (For 1.5' SLR) Add 1.5' to each baseline return period value
7. (For 3' and 4.5' SLR):

Future Design Tidal Elevation = *(Baseline Tidal Elevation + SLR Scenario) x Non-Linearity Factor*

Calculation of Non-Linearity Factors

$$\text{Non-Linearity Factor} = \frac{\text{(USACE Modeled Storm Surge Elevation with SLR)}}{\text{(USACE Baseline Storm Surge Elevation + SLR)}}$$

Figure A-4: HUC-12 Watersheds Used for Tidal Elevation Analysis

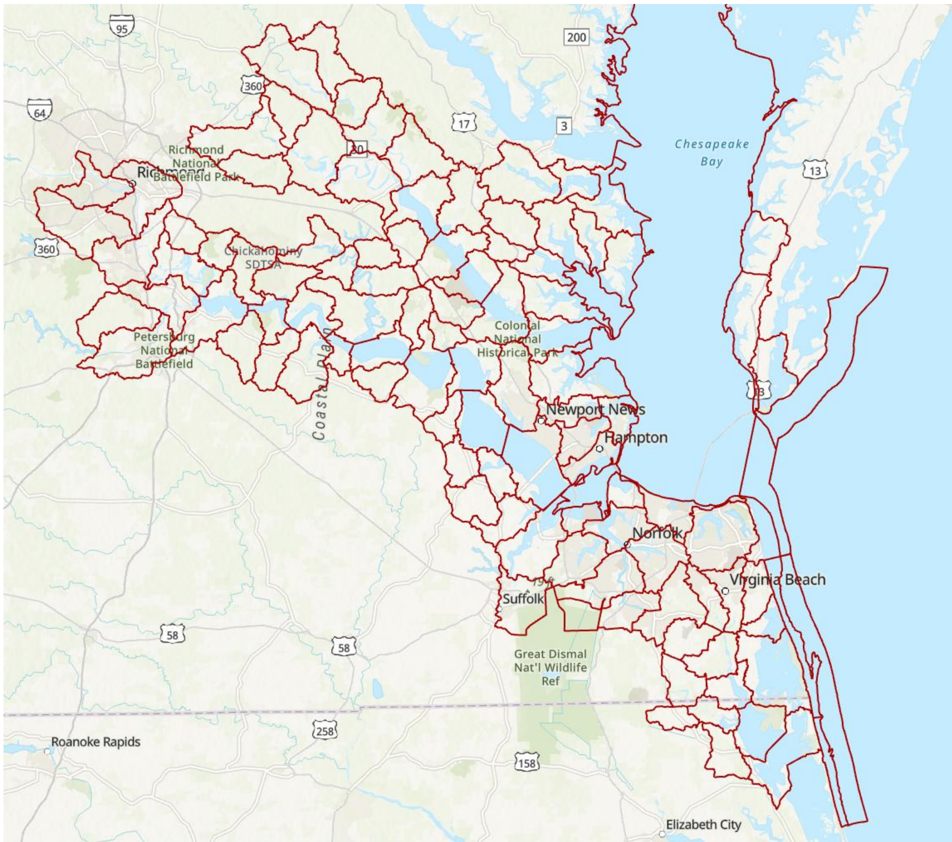


Table A-1: Non-Linearity Factors for Hampton Roads Tidal Watersheds

HUC12	Name	Non-Linearity Factor
020403040304	Smith Island Inlet-The Thorofare	1.07
020403040404	Lower Eastern Shore-Atlantic Ocean	1.09
020403040501	Rudee Inlet-Atlantic Ocean	1.07
020403040502	020403040502-Atlantic Ocean	1.08
020801010000	Lower Chesapeake Bay	1.03
020801020301	Carvers Creek-Piankatank River	1.00
020801020302	Hills Bay-Piankatank River	1.03
020801020303	Milford Haven-Lower Chesapeake Bay	1.01
020801020401	Beaverdam Swamp	1.03*
020801020402	Crany Creek-Fox Mill Run	1.01
020801020403	Ware River	1.02
020801020404	North River	1.03
020801020405	East River	1.04
020801020406	Winter Harbor-Lower Chesapeake Bay	1.02
020801020407	Severn River	1.02
020801020408	Monday Creek-Mobjack Bay	1.03
020801050504	Aylett Creek-Mattaponi River	1.03
020801050601	Garnetts Creek	1.04*
020801050602	Courthouse Creek-Mattaponi River	1.05
020801050603	Heartquake Creek-Mattaponi River	1.04
020801050604	Cabin Creek-Mattaponi River	1.04
020801061003	Black Creek	1.10*
020801061004	Montague Creek-Pamunkey River	1.10
020801061005	Jacks Creek	1.10*
020801061101	Cohoke Mill Creek-Pamunkey River	1.11
020801061102	Mill Creek-Pamunkey River	1.04
020801070101	Ware Creek	1.04*
020801070102	Philbates Creek-York River	1.03
020801070103	Poropotank River	1.09
020801070104	Skimino Creek-York River	1.05
020801070201	Jones Creek-York River	1.03
020801070202	Queen Creek	1.03
020801070203	Carter Creek-York River	1.03
020801070204	Sarah Creek-York River	1.02
020801080101	Poquoson River-Lower Chesapeake Bay	1.02
020801080102	Northwest Branch Back River	1.02
020801080103	Southwest Branch Back River	1.01
020801080104	Back River-Lower Chesapeake Bay	1.03
020801080201	Lynnhaven River	1.03
020801080202	Little Creek-Lower Chesapeake Bay	1.03
020801110901	Hungars Creek-Lower Chesapeake Bay	1.03
020801110902	Cherrystone Inlet-Lower Chesapeake Bay	1.04

HUC12	Name	Non-Linearity Factor
020802050607	Little Westham Creek-James River	2.73
020802060101	Almond Creek-James River	2.54
020802060102	Falling Creek	1.85*
020802060103	Proctors Creek-James River	2.09
020802060104	Fourmile Creek	1.85*
020802060105	Turkey Island Creek	1.85*
020802060106	Curles Creek-James River	1.48
020802060201	Bailey Creek-James River	1.12
020802060202	Powell Creek	1.11
020802060203	Herring Creek	1.12*
020802060204	Courthouse Creek-Queens Creek	1.12*
020802060205	Flowerdew Hundred Creek-James River	1.09
020802060301	Wards Creek	1.07*
020802060302	Kittewan Creek-James River	1.07
020802060303	Upper Chippokes Creek	1.10
020802060304	Sunken Meadow Pond-James River	1.06
020802060506	Big Swamp-Chickahominy River	1.04
020802060601	Barrows Creek-Chickahominy River	1.04
020802060603	Mill Creek-Diascund Creek	1.05*
020802060604	Yarmouth Creek-Chickahominy River	1.05
020802060605	Morris Creek-Chickahominy River	1.05
020802060701	Broad Swamp-James River	1.05
020802060702	Powhatan Creek	1.05
020802060703	Grays Creek	1.05
020802060704	Lower Chippokes Creek-James River	1.04
020802060801	College Creek	1.04*
020802060802	Skiffes Creek-James River	1.04
020802060803	Lawnes Creek	1.04*
020802060804	Morrisons Creek-James River	1.04
020802060901	Warwick River	1.07
020802060902	Warren Creek-Pagan River	1.03*
020802060903	Cypress Creek	1.03*
020802060904	Jones Creek-Pagan River	1.02
020802060905	Chuckatuck Creek	1.01
020802060906	Cooper Creek-James River	1.03
020802070904	Franks Branch-Swift Creek	1.15
020802071001	Oldtown Creek-Appomattox River	1.14
020802071002	Ashton Creek-Appomattox River	1.14
020802080105	Cedar Lake-Nansemond River	1.05
020802080106	Bennett Creek-Nansemond River	1.02
020802080201	New Mill Creek-Southern Branch Elizabeth River	0.99
020802080202	Big Entry Ditch-Dismal Swamp	1.01*
020802080203	Deep Creek-Southern Branch Elizabeth River	1.00
020802080204	Eastern Branch Elizabeth River	1.02

HUC12	**Name**	**Non-Linearity Factor**
020802080205	Western Branch Elizabeth River	1.02
020802080206	Elizabeth River	1.02
020802080301	Streeter Creek-Hampton Roads	1.03
020802080302	Willoughby Bay	1.02
020802080303	Hampton River-Hampton Roads	1.03
020802080304	Hampton Roads Channel	1.03
030102051104	Indian Creek-Northwest River	1.04
030102051105	Moyock Run	1.04*
030102051107	Tull Creek	1.04*
030102051108	Tull Bay-Northwest River	1.04
030102051201	Chesapeake Canal	1.00
030102051202	West Neck Creek	1.04*
030102051203	Upper North Landing River	1.04
030102051204	Pocaty River	1.04*
030102051205	Blackwater Creek-North Landing River	1.03
030102051206	Milldam Creek-North Landing River	1.03
030102051207	Town of Currituck-North Landing River	1.06
030102051301	Ashville Bridge Creek	1.07*
030102051302	North Bay-Shipps Bay	1.08
030102051303	Back Bay	1.09
030102051304	Coinjock Bay-Currituck Sound	1.05
030102051701	Sand Ridge-Atlantic Ocean	1.09
030102051702	Town of Corolla-Oceanside Seashore	1.12
030102051706	030102051706-Atlantic Ocean	1.10

* Non-Linearity Factor for corresponding HUC-10 watershed

Appendix B – Design Tidal Elevations for Hampton Roads Localities

Notes:

1. Sea level rise scenarios are based on HRPDC Sea Level Rise Planning Policy and Approach (2018) and HRPDC Regional Resilient Design Guidelines (2024).
2. Except where noted, all elevations sourced from statistical analysis of the distribution of water elevations in each watershed from the FEMA Region III Storm Surge Study conducted by the U.S. Army Corps of Engineers Engineer Research and Development Center (2013).
3. Conditions related to the 3-ft sea level rise design level include non-linear increases derived from numerical modeling completed by the U.S. Army Corps of Engineers as part of the North Atlantic Coast Comprehensive Study.
4. Non-linearity factors for HUC-10 watersheds used in cases where HUC-12 watersheds had no data points to calculate non-linearity factors.

Design Tidal Elevations – Chesapeake

Table B-1: Design Tidal Elevation Values for Chesapeake, Virginia

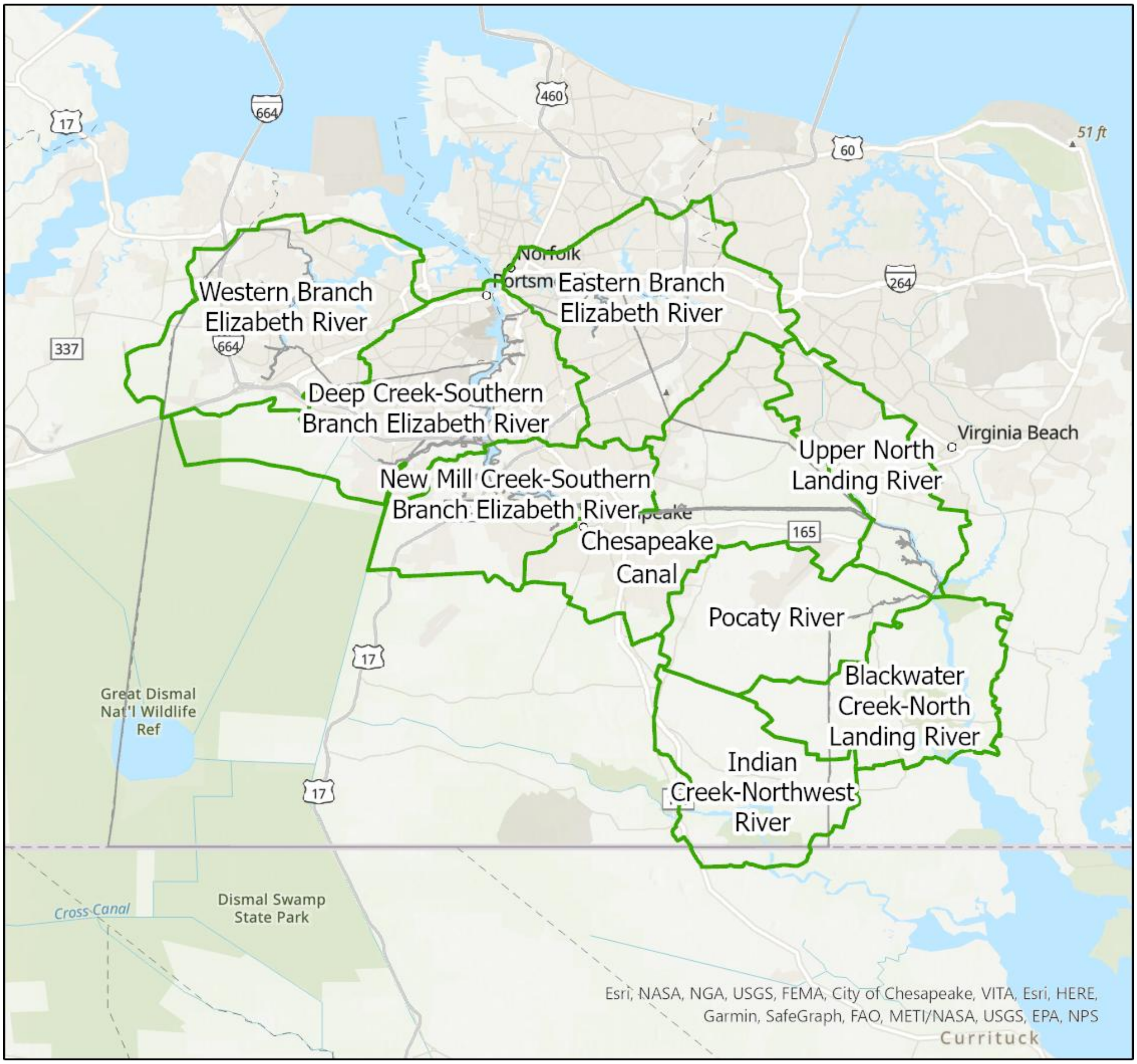
Note: All elevations in feet relative to the North American Vertical Datum (NAVD) of 1988

HUC12	Watershed	Design Level	1-Year	2-Year	3-Year	5-Year	10-Year	25-Year	50-Year	100-Year	500-Year
020802080201	New Mill Creek-Southern Branch Elizabeth River	Current	3.9	4.5	4.8	5.2	5.8	6.6	7.2	7.8	9.2
		1.5 ft SLR	5.4	6.0	6.3	6.7	7.3	8.1	8.7	9.3	10.7
		3.0 ft SLR	6.9	7.5	7.8	8.2	8.8	9.6	10.2	10.8	12.2
020802080203	Deep Creek-Southern Branch Elizabeth River	Current	3.4	4.1	4.5	5.1	5.9	6.7	7.3	8.0	10.0
		1.5 ft SLR	4.9	5.6	6.0	6.6	7.4	8.2	8.8	9.5	11.5
		3.0 ft SLR	6.4	7.1	7.5	8.1	8.9	9.7	10.3	11.0	13.0
020802080204	Eastern Branch Elizabeth River	Current	2.9	3.7	4.2	4.8	5.9	6.6	7.3	8.0	10.4
		1.5 ft SLR	4.4	5.2	5.7	6.3	7.4	8.1	8.8	9.5	11.9
		3.0 ft SLR	6.0	6.8	7.3	7.9	9.1	9.8	10.5	11.2	13.6
020802080205	Western Branch Elizabeth River	Current	3.7	4.5	4.9	5.4	6.1	7.0	7.9	8.6	10.3
		1.5 ft SLR	5.2	6.0	6.4	6.9	7.6	8.5	9.4	10.1	11.8
		3.0 ft SLR	6.9	7.7	8.1	8.6	9.3	10.2	11.2	11.9	13.6
030102051104	Indian Creek-Northwest River	Current	-	-	-	-	-	2.0	2.4	2.8	3.8
		1.5 ft SLR	-	-	-	-	-	3.5	3.9	4.3	5.3
		3.0 ft SLR	-	-	-	-	-	5.2	5.6	6.0	7.1
030102051201	Chesapeake Canal	Current	3.0	3.6	4.0	4.4	5.0	5.8	6.4	7.0	8.4
		1.5 ft SLR	4.5	5.1	5.5	5.9	6.5	7.3	7.9	8.5	9.9
		3.0 ft SLR	6.0	6.6	7.0	7.4	8.0	8.8	9.4	10.0	11.4
030102051203 030102051204 030102051205	North Landing River	Current	-	-	-	-	-	2.8	3.4	3.9	4.9
		1.5 ft SLR	-	-	-	-	-	4.3	4.9	5.4	6.4
		3.0 ft SLR	-	-	-	-	-	6.3	6.9	7.5	8.5

Notes:

1. North Landing River watershed includes Upper North Landing River, Pocaty River, and Blackwater Creek-North Landing River watersheds. Sourced from Virginia Beach Public Works Design Standards Manual, June 2020.
2. Due to recurring wind tides, it is recommended to use the 25-year design tidal elevations for 1-year to 10-year return periods for the Indian Creek-Northwest River and North Landing River watersheds.

Figure B-1: Watershed Boundaries for Design Tidal Elevations – Chesapeake



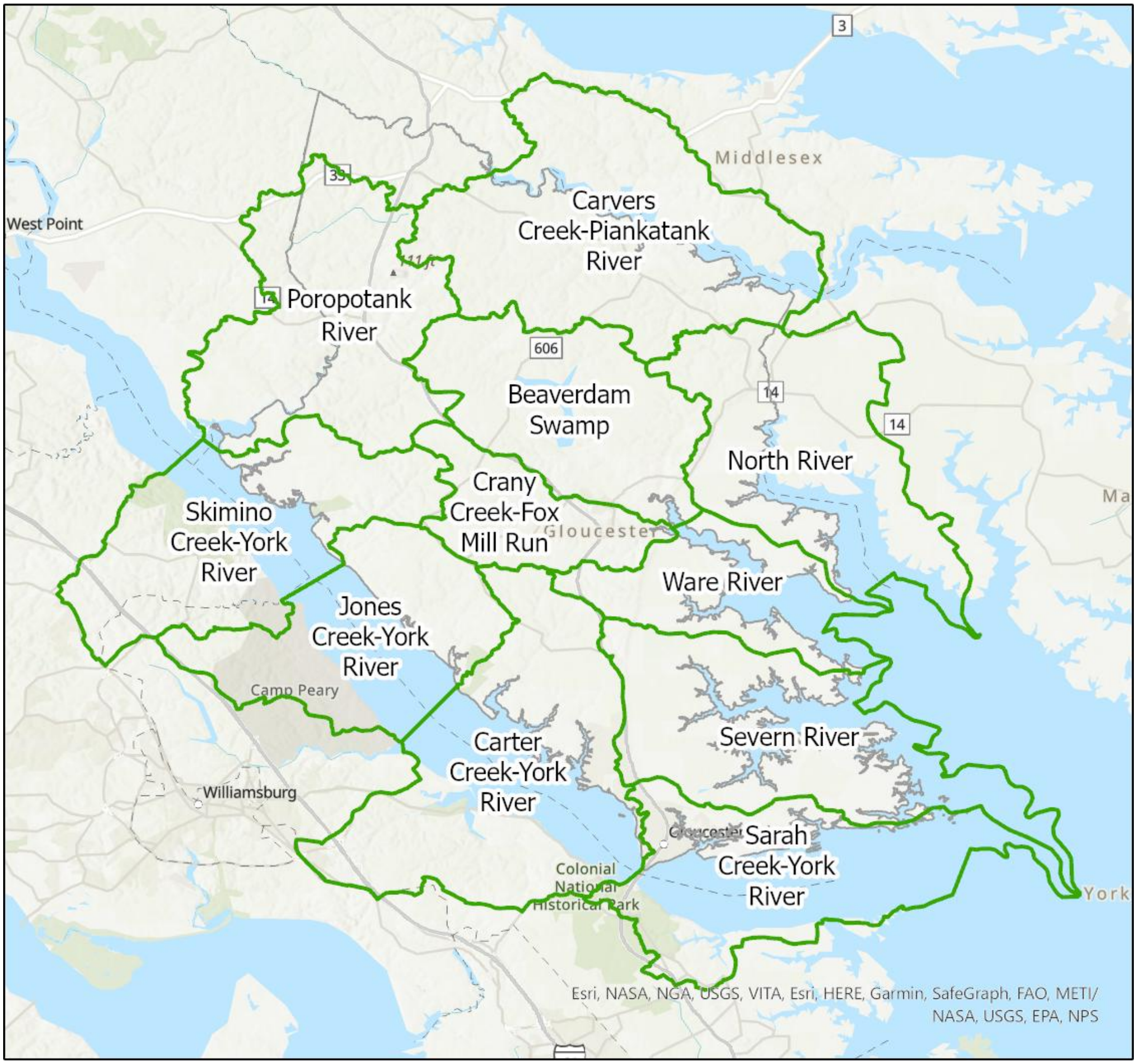
Design Tidal Elevations – Gloucester County

Table B-2: Design Tidal Elevation Values for Gloucester County, Virginia

Note: All elevations in feet relative to the North American Vertical Datum (NAVD) of 1988

HUC12	Watershed	Design Level	1-Year	2-Year	3-Year	5-Year	10-Year	25-Year	50-Year	100-Year	500-Year
020801020301	Carvers Creek-Piankatank River	Current	1.8	2.5	2.9	3.4	4.2	5.0	5.3	5.9	7.8
		1.5 ft SLR	3.3	4.0	4.4	4.9	5.7	6.5	6.8	7.4	9.3
		3.0 ft SLR	4.8	5.5	5.9	6.4	7.2	8.0	8.3	8.9	10.8
020801020401	Beaverdam Swamp	Current	1.2	2.2	2.7	3.4	4.9	5.6	6.1	6.9	10.0
		1.5 ft SLR	2.7	3.7	4.2	4.9	6.4	7.1	7.6	8.4	11.5
		3.0 ft SLR	4.3	5.4	5.9	6.6	8.1	8.9	9.4	10.2	13.4
020801020402	Crany Creek-Fox Mill Run	Current	1.6	2.5	3.0	3.6	4.9	5.6	6.1	6.8	9.6
		1.5 ft SLR	3.1	4.0	4.5	5.1	6.4	7.1	7.6	8.3	11.1
		3.0 ft SLR	4.7	5.6	6.1	6.7	8.0	8.7	9.2	9.9	12.8
020801020403	Ware River	Current	1.8	2.6	3.1	3.7	4.9	5.6	6.0	6.6	9.3
		1.5 ft SLR	3.3	4.1	4.6	5.2	6.4	7.1	7.5	8.1	10.8
		3.0 ft SLR	4.9	5.7	6.2	6.8	8.1	8.8	9.2	9.8	12.5
020801020404	North River	Current	1.5	2.3	2.8	3.5	4.8	5.4	5.9	6.6	9.4
		1.5 ft SLR	3.0	3.8	4.3	5.0	6.3	6.9	7.4	8.1	10.9
		3.0 ft SLR	4.6	5.5	6.0	6.7	8.1	8.7	9.2	9.9	12.8
020801020407	Severn River	Current	2.6	3.2	3.6	4.1	4.9	5.7	6.0	6.5	8.5
		1.5 ft SLR	4.1	4.7	5.1	5.6	6.4	7.2	7.5	8.0	10.0
		3.0 ft SLR	5.7	6.3	6.8	7.3	8.1	8.9	9.2	9.7	11.8
020801070103	Poropotank River	Current	2.7	3.4	3.9	4.4	5.4	6.1	6.5	6.9	9.2
		1.5 ft SLR	4.2	4.9	5.4	5.9	6.9	7.6	8.0	8.4	10.7
		3.0 ft SLR	6.2	7.0	7.5	8.0	9.1	9.9	10.3	10.8	13.3
020801070104	Skimino Creek-York River	Current	3.0	3.6	4.0	4.5	5.3	6.1	6.4	6.9	8.8
		1.5 ft SLR	4.5	5.1	5.5	6.0	6.8	7.6	7.9	8.4	10.3
		3.0 ft SLR	6.3	6.9	7.3	7.9	8.7	9.5	9.8	10.4	12.4
020801070201	Jones Creek-York River	Current	3.2	3.8	4.1	4.6	5.2	6.0	6.4	6.8	8.5
		1.5 ft SLR	4.7	5.3	5.6	6.1	6.7	7.5	7.9	8.3	10.0
		3.0 ft SLR	6.4	7.0	7.3	7.8	8.5	9.3	9.7	10.1	11.9
020801070203	Carter Creek-York River	Current	3.1	3.7	4.0	4.5	5.1	5.8	6.3	6.8	8.3
		1.5 ft SLR	4.6	5.2	5.5	6.0	6.6	7.3	7.8	8.3	9.8
		3.0 ft SLR	6.3	6.9	7.2	7.7	8.3	9.1	9.6	10.1	11.6
020801070204	Sarah Creek-York River	Current	3.0	3.6	3.9	4.3	4.9	5.5	6.1	6.6	7.9
		1.5 ft SLR	4.5	5.1	5.4	5.8	6.4	7.0	7.6	8.1	9.4
		3.0 ft SLR	6.1	6.7	7.1	7.5	8.1	8.7	9.3	9.8	11.1

Figure B-2: Watershed Boundaries for Design Tidal Elevations – Gloucester County



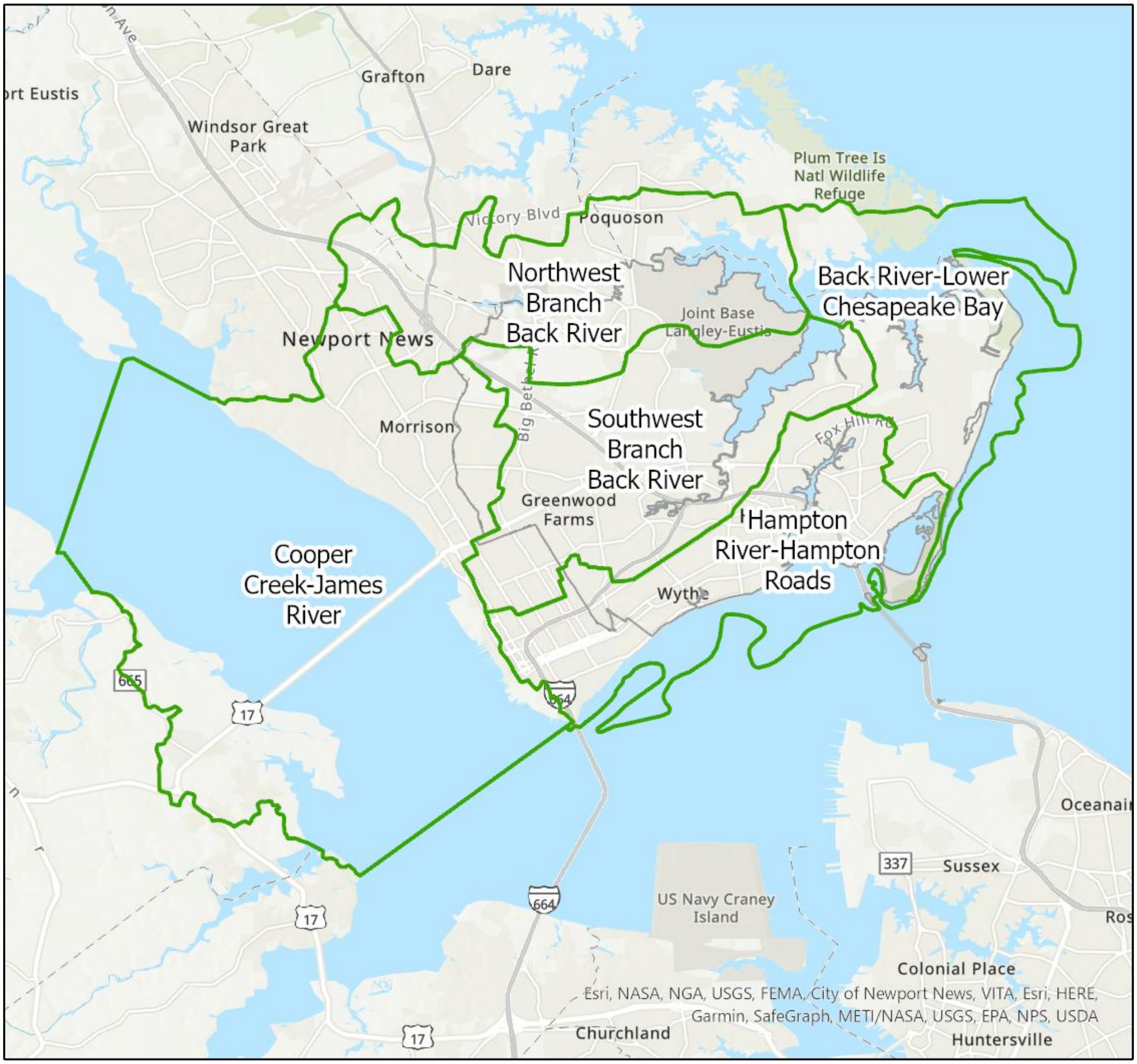
Design Tidal Elevations – Hampton

Table B-3: Design Tidal Elevation Values for Hampton, Virginia

Note: All elevations in feet relative to the North American Vertical Datum (NAVD) of 1988

HUC12	Watershed	Design Level	1-Year	2-Year	3-Year	5-Year	10-Year	25-Year	50-Year	100-Year	500-Year
020801080102	Northwest Branch Back River	Current	3.2	3.9	4.3	4.9	5.6	6.4	7.2	7.9	9.6
		1.5 ft SLR	4.7	5.4	5.8	6.4	7.1	7.9	8.7	9.4	11.1
		3.0 ft SLR	6.4	7.1	7.5	8.1	8.8	9.6	10.5	11.2	12.9
020801080103	Southwest Branch Back River	Current	3.3	4.0	4.4	5.0	5.6	6.5	7.4	8.1	9.7
		1.5 ft SLR	4.8	5.5	5.9	6.5	7.1	8.0	8.9	9.6	11.2
		3.0 ft SLR	6.4	7.1	7.5	8.1	8.7	9.6	10.5	11.3	12.9
020801080104	Back River-Lower Chesapeake Bay	Current	3.2	3.9	4.3	4.7	5.4	6.1	6.8	7.5	9.0
		1.5 ft SLR	4.7	5.4	5.8	6.2	6.9	7.6	8.3	9.0	10.5
		3.0 ft SLR	6.4	7.1	7.5	7.9	8.6	9.3	10.1	10.8	12.3
020802060906	Cooper Creek-James River	Current	3.7	4.4	4.8	5.2	5.8	6.7	7.5	8.1	9.6
		1.5 ft SLR	5.2	5.9	6.3	6.7	7.3	8.2	9.0	9.6	11.1
		3.0 ft SLR	6.9	7.6	8.0	8.4	9.1	10.0	10.8	11.4	13.0
020802080303	Hampton River-Hampton Roads	Current	3.5	4.1	4.4	4.9	5.4	6.2	7.0	7.6	8.9
		1.5 ft SLR	5.0	5.6	5.9	6.4	6.9	7.7	8.5	9.1	10.4
		3.0 ft SLR	6.7	7.3	7.6	8.1	8.6	9.5	10.3	10.9	12.2

Figure B-3: Watershed Boundaries for Design Tidal Elevations - Hampton



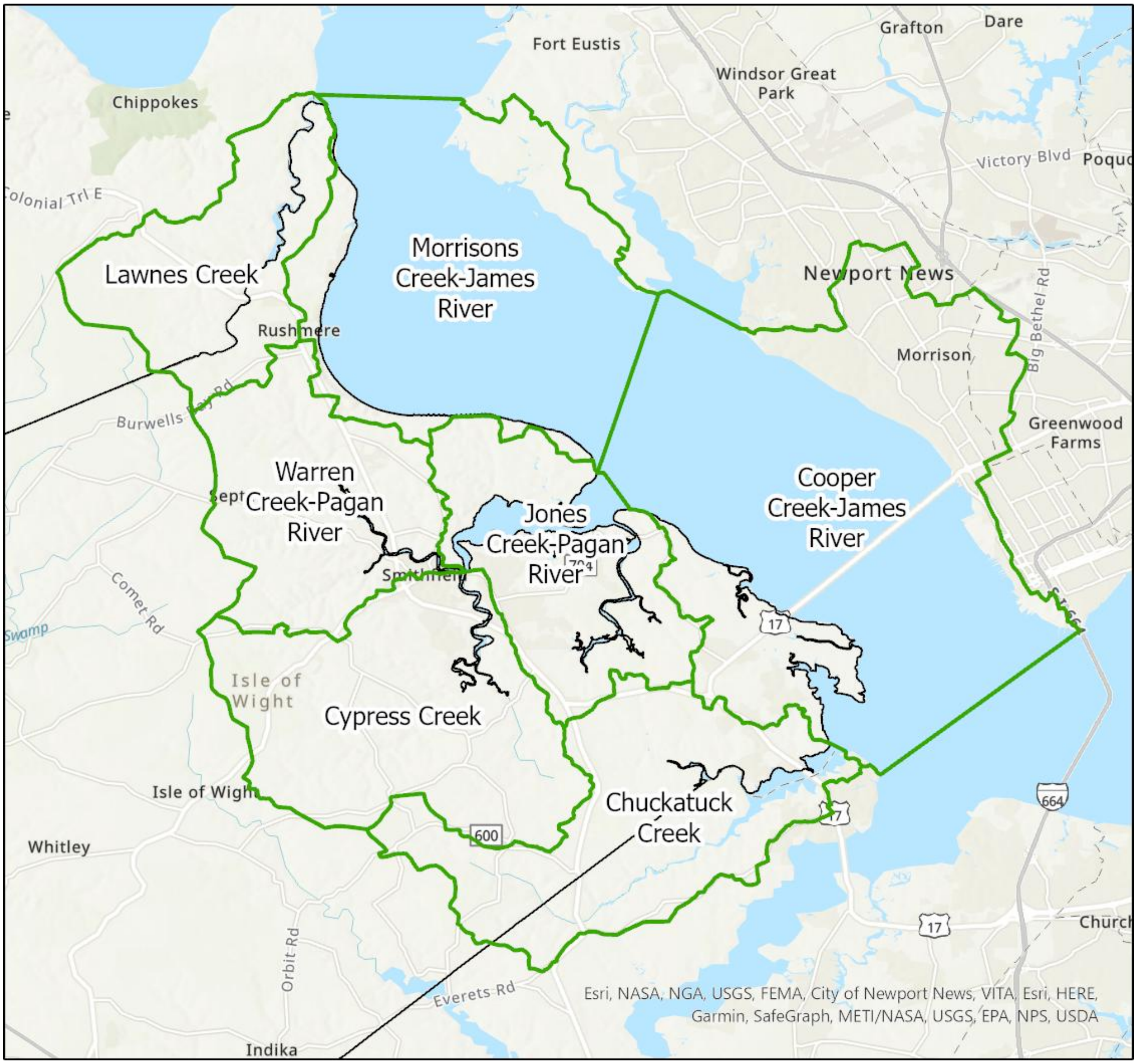
Design Tidal Elevations – Isle of Wight County

Table B-4: Design Tidal Elevation Values for Isle of Wight County, Virginia

Note: All elevations in feet relative to the North American Vertical Datum (NAVD) of 1988

HUC12	Watershed	Design Level	1-Year	2-Year	3-Year	5-Year	10-Year	25-Year	50-Year	100-Year	500-Year
020802060803	Lawnes Creek	Current	4.0	4.5	4.8	5.2	5.6	6.4	6.8	7.3	8.4
		1.5 ft SLR	5.5	6.0	6.3	6.7	7.1	7.9	8.3	8.8	9.9
		3.0 ft SLR	7.3	7.8	8.1	8.5	8.9	9.8	10.2	10.7	11.9
020802060804	Morrisons Creek-James River	Current	4.0	4.6	4.9	5.3	5.7	6.5	7.1	7.6	8.7
		1.5 ft SLR	5.5	6.1	6.4	6.8	7.2	8.0	8.6	9.1	10.2
		3.0 ft SLR	7.2	7.9	8.2	8.6	9.0	9.8	10.5	11.0	12.1
020802060902	Warren Creek-Pagan River	Current	4.0	4.6	5.0	5.5	6.0	6.9	7.8	8.4	9.7
		1.5 ft SLR	5.5	6.1	6.5	7.0	7.5	8.4	9.3	9.9	11.2
		3.0 ft SLR	7.2	7.8	8.2	8.8	9.3	10.2	11.1	11.7	13.1
020802060903	Cypress Creek	Current	3.9	4.6	5.0	5.5	6.0	6.9	7.8	8.5	9.8
		1.5 ft SLR	5.4	6.1	6.5	7.0	7.5	8.4	9.3	10.0	11.3
		3.0 ft SLR	7.1	7.8	8.2	8.8	9.3	10.2	11.1	11.8	13.2
020802060904	Jones Creek-Pagan River	Current	3.9	4.6	5.0	5.4	5.9	6.8	7.6	8.3	9.5
		1.5 ft SLR	5.4	6.1	6.5	6.9	7.4	8.3	9.1	9.8	11.0
		3.0 ft SLR	7.0	7.8	8.2	8.6	9.1	10.0	10.8	11.5	12.8
020802060905	Chuckatuck Creek	Current	4.0	4.7	5.1	5.7	6.2	7.3	8.2	8.9	10.4
		1.5 ft SLR	5.5	6.2	6.6	7.2	7.7	8.8	9.7	10.4	11.9
		3.0 ft SLR	7.1	7.8	8.2	8.8	9.3	10.5	11.4	12.1	13.6
020802060906	Cooper Creek-James River	Current	3.7	4.4	4.8	5.2	5.8	6.7	7.5	8.1	9.6
		1.5 ft SLR	5.2	5.9	6.3	6.7	7.3	8.2	9.0	9.6	11.1
		3.0 ft SLR	6.9	7.6	8.0	8.4	9.1	10.0	10.8	11.4	13.0

Figure B-4: Watershed Boundaries for Design Tidal Elevations – Isle of Wight County



Design Tidal Elevations – James City County

Table B-5: Design Tidal Elevation Values for James City County, Virginia

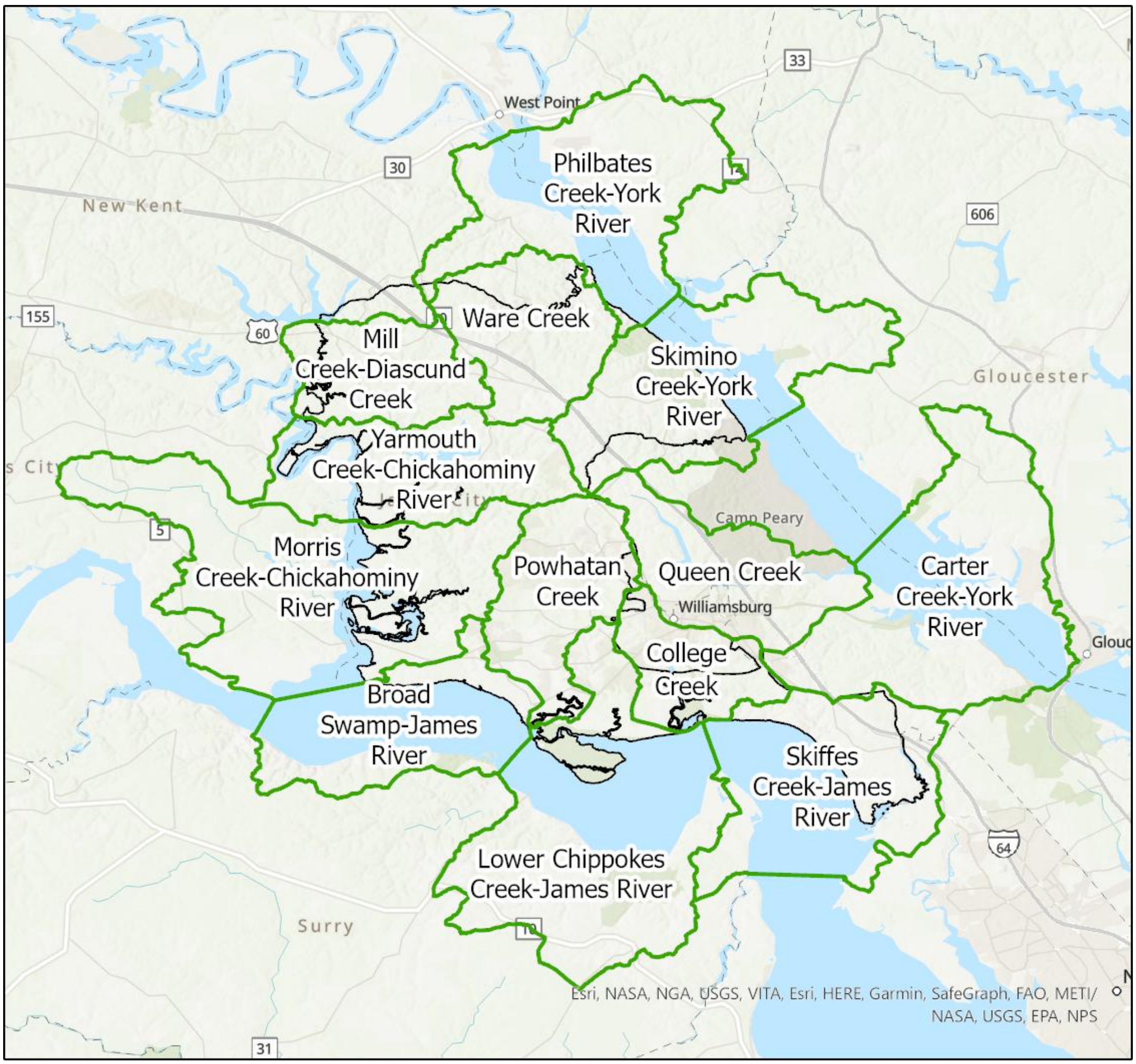
Note: All elevations in feet relative to the North American Vertical Datum (NAVD) of 1988

HUC12	Watershed	Design Level	1-Year	2-Year	3-Year	5-Year	10-Year	25-Year	50-Year	100-Year	500-Year
020801070101	Ware Creek	Current	2.8	3.5	3.9	4.5	5.5	6.2	6.6	7.1	9.3
		1.5 ft SLR	4.3	5.0	5.4	6.0	7.0	7.7	8.1	8.6	10.8
		3.0 ft SLR	6.0	6.8	7.2	7.8	8.8	9.6	10.0	10.5	12.8
020801070102	Philbates Creek-York River	Current	2.1	3.0	3.5	4.2	5.5	6.3	6.6	7.2	10.2
		1.5 ft SLR	3.6	4.5	5.0	5.7	7.0	7.8	8.1	8.7	11.7
		3.0 ft SLR	5.3	6.2	6.7	7.4	8.8	9.6	9.9	10.6	13.7
020801070104	Skimino Creek-York River	Current	3.0	3.6	4.0	4.5	5.3	6.1	6.4	6.9	8.8
		1.5 ft SLR	4.5	5.1	5.5	6.0	6.8	7.6	7.9	8.4	10.3
		3.0 ft SLR	6.3	6.9	7.3	7.9	8.7	9.5	9.8	10.4	12.4
020801070202	Queen Creek	Current	2.9	3.5	3.9	4.4	5.1	5.9	6.3	6.8	8.6
		1.5 ft SLR	4.4	5.0	5.4	5.9	6.6	7.4	7.8	8.3	10.1
		3.0 ft SLR	6.1	6.7	7.1	7.6	8.4	9.2	9.6	10.1	12.0
020801070203	Carter Creek-York River	Current	3.1	3.7	4.0	4.5	5.1	5.8	6.3	6.8	8.3
		1.5 ft SLR	4.6	5.2	5.5	6.0	6.6	7.3	7.8	8.3	9.8
		3.0 ft SLR	6.3	6.9	7.2	7.7	8.3	9.1	9.6	10.1	11.6
020802060603	Mill Creek-Descend Creek	Current	4.0	4.6	4.9	5.3	5.9	6.6	7.0	7.3	8.7
		1.5 ft SLR	5.5	6.1	6.4	6.8	7.4	8.1	8.5	8.8	10.2
		3.0 ft SLR	7.4	8.0	8.3	8.7	9.3	10.1	10.5	10.8	12.3
020802060604	Yarmouth Creek-Chickahominy River	Current	3.8	4.4	4.7	5.2	5.9	6.6	7.0	7.3	8.9
		1.5 ft SLR	5.3	5.9	6.2	6.7	7.4	8.1	8.5	8.8	10.4
		3.0 ft SLR	7.1	7.7	8.1	8.6	9.3	10.1	10.5	10.8	12.5
020802060605	Morris Creek-Chickahominy River	Current	3.8	4.4	4.7	5.2	5.9	6.7	7.0	7.4	9.0
		1.5 ft SLR	5.3	5.9	6.2	6.7	7.4	8.2	8.5	8.9	10.5
		3.0 ft SLR	7.2	7.8	8.1	8.6	9.4	10.2	10.5	11.0	12.6
020802060701	Broad Swamp-James River	Current	4.0	4.6	4.9	5.3	5.8	6.7	7.1	7.4	8.8
		1.5 ft SLR	5.5	6.1	6.4	6.8	7.3	8.2	8.6	8.9	10.3
		3.0 ft SLR	7.3	8.0	8.3	8.7	9.2	10.2	10.6	10.9	12.4
020802060702	Powhatan Creek	Current	3.7	4.3	4.6	5.0	5.6	6.3	6.7	7.0	8.5
		1.5 ft SLR	5.2	5.8	6.1	6.5	7.1	7.8	8.2	8.5	10.0
		3.0 ft SLR	7.0	7.6	8.0	8.4	9.0	9.7	10.2	10.5	12.0
020802060704	Lower Chippokes Creek-James River	Current	3.9	4.5	4.8	5.2	5.7	6.5	6.9	7.3	8.6
		1.5 ft SLR	5.4	6.0	6.3	6.7	7.2	8.0	8.4	8.8	10.1
		3.0 ft SLR	7.2	7.8	8.1	8.5	9.1	9.9	10.3	10.7	12.1
020802060801	College Creek	Current	3.3	3.9	4.3	4.8	5.6	6.3	6.7	7.1	9.0
		1.5 ft SLR	4.8	5.4	5.8	6.3	7.1	7.8	8.2	8.6	10.5
		3.0 ft SLR	6.6	7.2	7.6	8.1	8.9	9.7	10.1	10.5	12.5

Table B-5: Design Tidal Elevation Values for James City County, Virginia (continued)

HUC12	Watershed	Design Level	1-Year	2-Year	3-Year	5-Year	10-Year	25-Year	50-Year	100-Year	500-Year
020802060802	Skiffes Creek-James River	Current	3.6	4.2	4.5	4.9	5.6	6.3	6.7	7.1	8.6
		1.5 ft SLR	5.1	5.7	6.0	6.4	7.1	7.8	8.2	8.6	10.1
		3.0 ft SLR	6.9	7.5	7.8	8.2	8.9	9.7	10.1	10.5	12.1

Figure B-5: Watershed Boundaries for Design Tidal Elevations – James City County



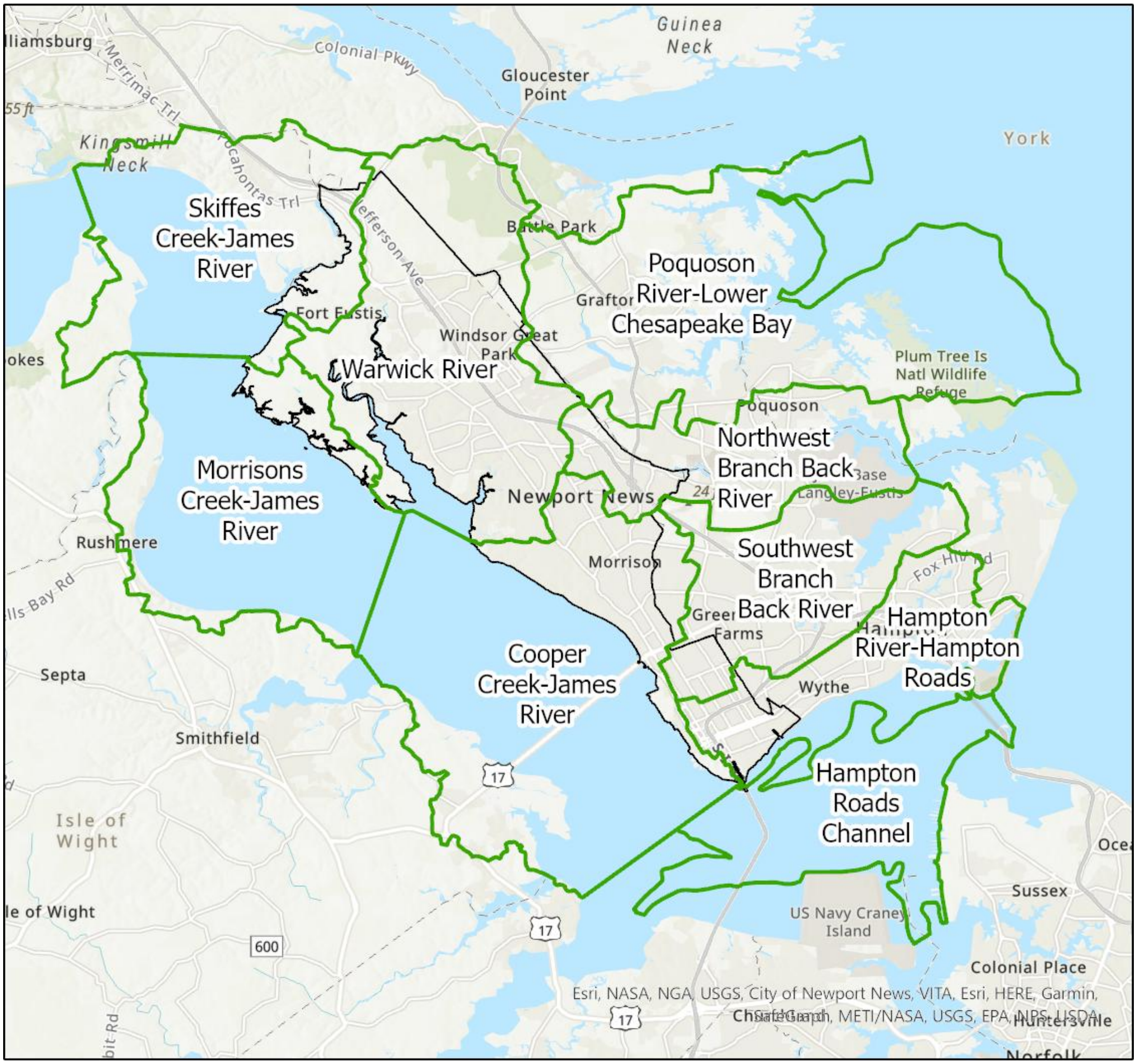
Design Tidal Elevations – Newport News

Table B-6: Design Tidal Elevation Values for Newport News, Virginia

Note: All elevations in feet relative to the North American Vertical Datum (NAVD) of 1988

HUC12	Watershed	Design Level	1-Year	2-Year	3-Year	5-Year	10-Year	25-Year	50-Year	100-Year	500-Year
020801080101	Poquoson River-Lower Chesapeake Bay	Current	2.8	3.5	3.9	4.4	5.1	5.9	6.8	7.4	9.0
		1.5 ft SLR	4.3	5.0	5.4	5.9	6.6	7.4	8.3	8.9	10.5
		3.0 ft SLR	5.9	6.6	7.0	7.5	8.3	9.1	10.0	10.6	12.2
020801080102	Northwest Branch Back River	Current	3.2	3.9	4.3	4.9	5.6	6.4	7.2	7.9	9.6
		1.5 ft SLR	4.7	5.4	5.8	6.4	7.1	7.9	8.7	9.4	11.1
		3.0 ft SLR	6.4	7.1	7.5	8.1	8.8	9.6	10.5	11.2	12.9
020801080103	Southwest Branch Back River	Current	3.3	4.0	4.4	5.0	5.6	6.5	7.4	8.1	9.7
		1.5 ft SLR	4.8	5.5	5.9	6.5	7.1	8.0	8.9	9.6	11.2
		3.0 ft SLR	6.4	7.1	7.5	8.1	8.7	9.6	10.5	11.3	12.9
020802060802	Skiffes Creek-James River	Current	3.6	4.2	4.5	4.9	5.6	6.3	6.7	7.1	8.6
		1.5 ft SLR	5.1	5.7	6.0	6.4	7.1	7.8	8.2	8.6	10.1
		3.0 ft SLR	6.9	7.5	7.8	8.2	8.9	9.7	10.1	10.5	12.1
020802060804	Morrisons Creek-James River	Current	4.0	4.6	4.9	5.3	5.7	6.5	7.1	7.6	8.7
		1.5 ft SLR	5.5	6.1	6.4	6.8	7.2	8.0	8.6	9.1	10.2
		3.0 ft SLR	7.2	7.9	8.2	8.6	9.0	9.8	10.5	11.0	12.1
020802060901	Warwick River	Current	3.7	4.2	4.6	5.0	5.6	6.3	6.8	7.2	8.7
		1.5 ft SLR	5.2	5.7	6.1	6.5	7.1	7.8	8.3	8.7	10.2
		3.0 ft SLR	7.1	7.7	8.1	8.5	9.2	9.9	10.4	10.9	12.5
020802060906	Cooper Creek-James River	Current	3.7	4.4	4.8	5.2	5.8	6.7	7.5	8.1	9.6
		1.5 ft SLR	5.2	5.9	6.3	6.7	7.3	8.2	9.0	9.6	11.1
		3.0 ft SLR	6.9	7.6	8.0	8.4	9.1	10.0	10.8	11.4	13.0
020802080303	Hampton River-Hampton Roads	Current	3.5	4.1	4.4	4.9	5.4	6.2	7.0	7.6	8.9
		1.5 ft SLR	5.0	5.6	5.9	6.4	6.9	7.7	8.5	9.1	10.4
		3.0 ft SLR	6.7	7.3	7.6	8.1	8.6	9.5	10.3	10.9	12.2
020802080304	Hampton Roads Channel	Current	3.3	4.0	4.4	4.9	5.5	6.4	7.1	7.8	9.4
		1.5 ft SLR	4.8	5.5	5.9	6.4	7.0	7.9	8.6	9.3	10.9
		3.0 ft SLR	6.5	7.2	7.6	8.1	8.7	9.6	10.4	11.1	12.7

Figure B-6: Watershed Boundaries for Design Tidal Elevations – Newport News



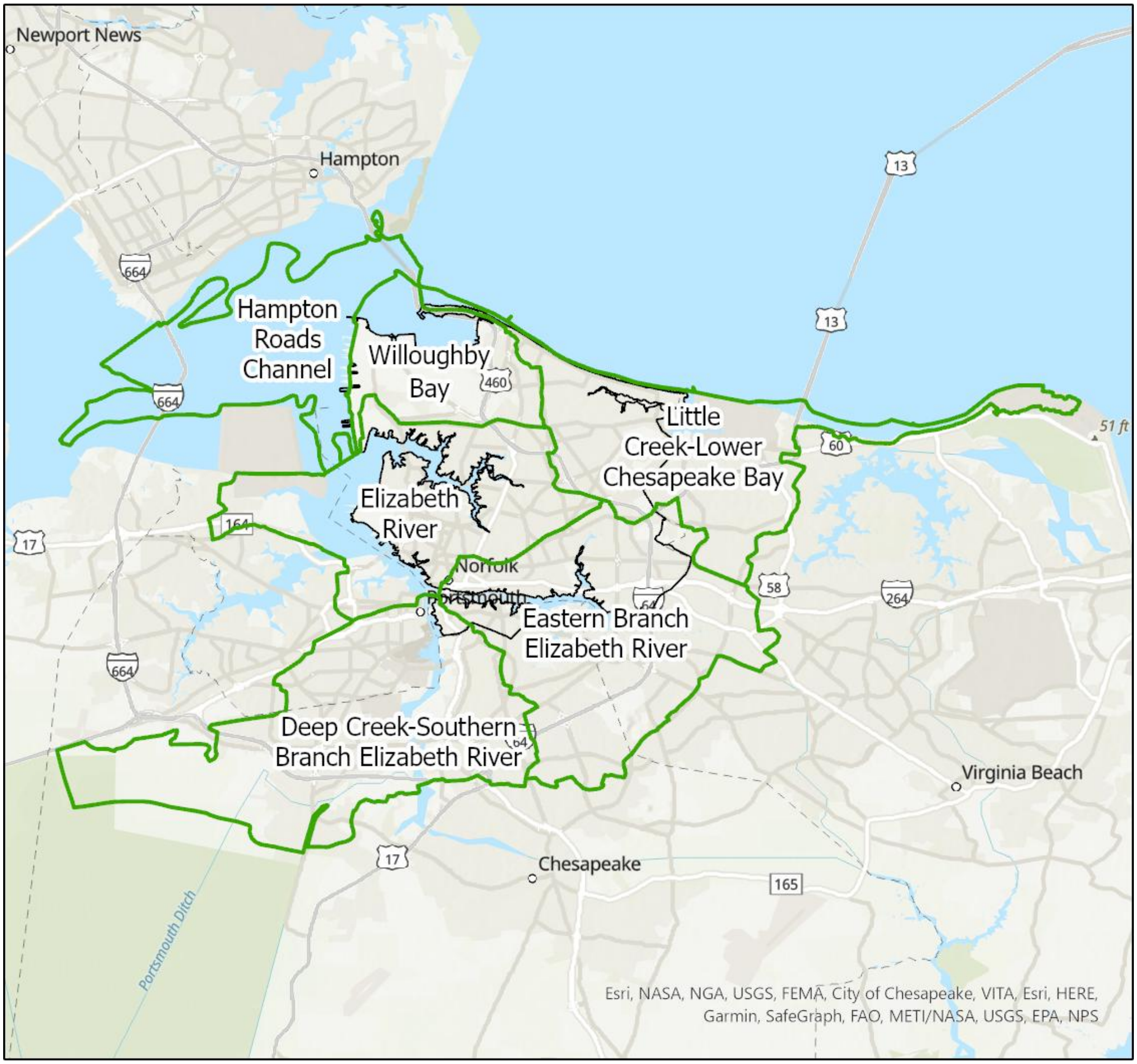
Design Tidal Elevations – Norfolk

Table B-7: Design Tidal Elevation Values for Norfolk, Virginia

Note: All elevations in feet relative to the North American Vertical Datum (NAVD) of 1988

HUC12	Watershed	Design Level	1-Year	2-Year	3-Year	5-Year	10-Year	25-Year	50-Year	100-Year	500-Year
020801080202	Little Creek-Lower Chesapeake Bay	Current	3.2	3.8	4.2	4.7	5.3	6.1	6.8	7.4	8.9
		1.5 ft SLR	4.7	5.3	5.7	6.2	6.8	7.6	8.3	8.9	10.4
		3.0 ft SLR	6.4	7.0	7.4	8.0	8.6	9.4	10.1	10.7	12.3
020802080203	Deep Creek-Southern Branch Elizabeth River	Current	3.4	4.1	4.5	5.1	5.9	6.7	7.3	8.0	10.0
		1.5 ft SLR	4.9	5.6	6.0	6.6	7.4	8.2	8.8	9.5	11.5
		3.0 ft SLR	6.4	7.1	7.5	8.1	8.9	9.7	10.3	11.0	13.0
020802080204	Eastern Branch Elizabeth River	Current	2.9	3.7	4.2	4.8	5.9	6.6	7.3	8.0	10.4
		1.5 ft SLR	4.4	5.2	5.7	6.3	7.4	8.1	8.8	9.5	11.9
		3.0 ft SLR	6.0	6.8	7.3	7.9	9.1	9.8	10.5	11.2	13.6
020802080206	Elizabeth River	Current	3.2	3.9	4.4	4.9	5.8	6.5	7.3	7.9	9.9
		1.5 ft SLR	4.7	5.4	5.9	6.4	7.3	8.0	8.8	9.4	11.4
		3.0 ft SLR	6.3	7.1	7.6	8.1	9.0	9.7	10.5	11.2	13.2
020802080302	Willoughby Bay	Current	3.2	3.8	4.2	4.7	5.4	6.2	6.9	7.6	9.2
		1.5 ft SLR	4.7	5.3	5.7	6.2	6.9	7.7	8.4	9.1	10.7
		3.0 ft SLR	6.3	6.9	7.3	7.8	8.6	9.4	10.1	10.8	12.4
020802080304	Hampton Roads Channel	Current	3.3	4.0	4.4	4.9	5.5	6.4	7.1	7.8	9.4
		1.5 ft SLR	4.8	5.5	5.9	6.4	7.0	7.9	8.6	9.3	10.9
		3.0 ft SLR	6.5	7.2	7.6	8.1	8.7	9.6	10.4	11.1	12.7

Figure B-7: Watershed Boundaries for Design Tidal Elevations – Norfolk



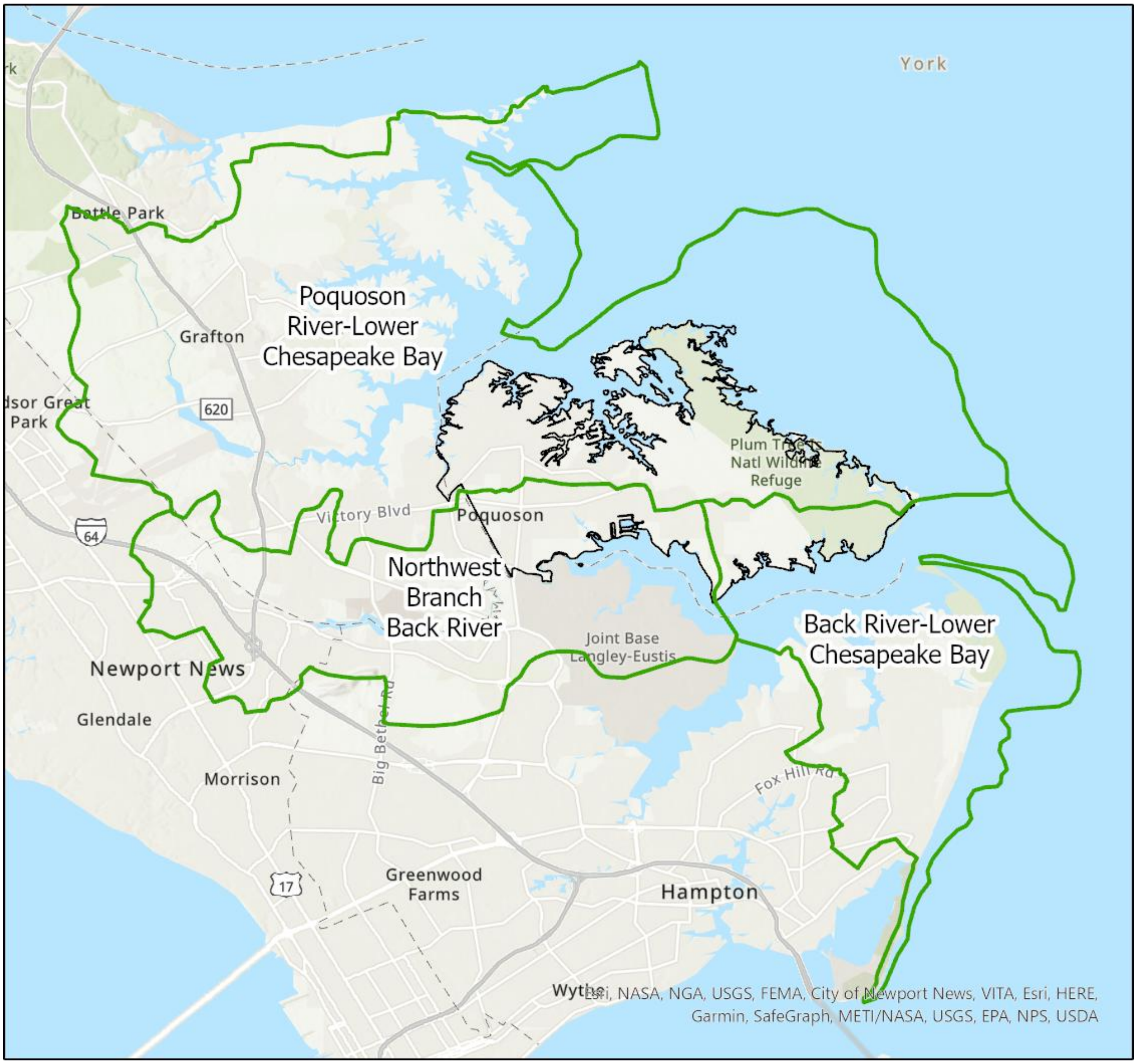
Design Tidal Elevations – Poquoson

Table B-8: Design Tidal Elevation Values for Poquoson, Virginia

Note: All elevations in feet relative to the North American Vertical Datum (NAVD) of 1988

HUC12	Watershed	Design Level	1-Year	2-Year	3-Year	5-Year	10-Year	25-Year	50-Year	100-Year	500-Year
020801080101	Poquoson River-Lower Chesapeake Bay	Current	2.8	3.5	3.9	4.4	5.1	5.9	6.8	7.4	9.0
		1.5 ft SLR	4.3	5.0	5.4	5.9	6.6	7.4	8.3	8.9	10.5
		3.0 ft SLR	5.9	6.6	7.0	7.5	8.3	9.1	10.0	10.6	12.2
020801080102	Northwest Branch Back River	Current	3.2	3.9	4.3	4.9	5.6	6.4	7.2	7.9	9.6
		1.5 ft SLR	4.7	5.4	5.8	6.4	7.1	7.9	8.7	9.4	11.1
		3.0 ft SLR	6.4	7.1	7.5	8.1	8.8	9.6	10.5	11.2	12.9
020801080104	Back River-Lower Chesapeake Bay	Current	3.2	3.9	4.3	4.7	5.4	6.1	6.8	7.5	9.0
		1.5 ft SLR	4.7	5.4	5.8	6.2	6.9	7.6	8.3	9.0	10.5
		3.0 ft SLR	6.4	7.1	7.5	7.9	8.6	9.3	10.1	10.8	12.3

Figure B-8: Watershed Boundaries for Design Tidal Elevations - Poquoson



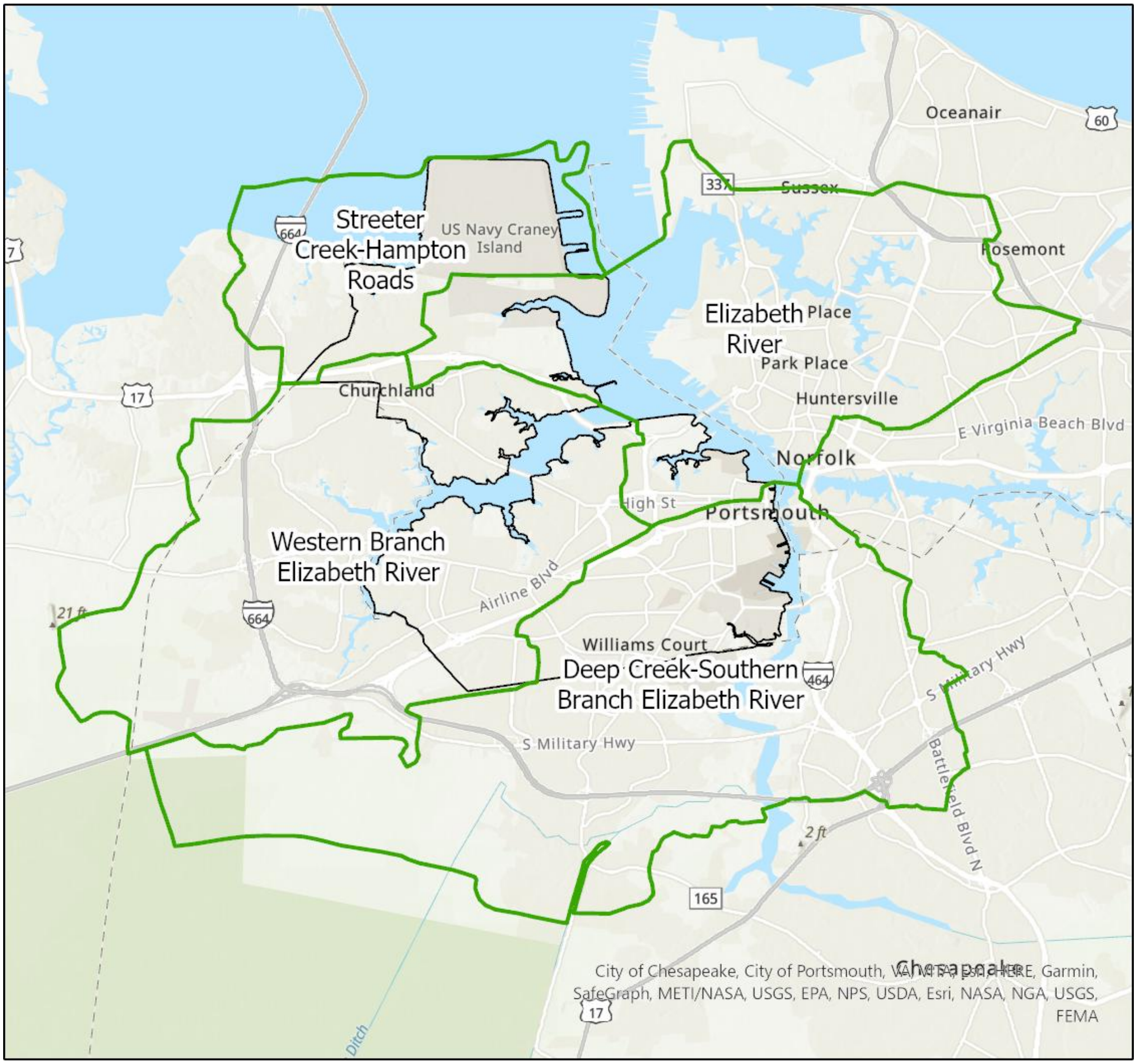
Design Tidal Elevations – Portsmouth

Table B-9: Design Tidal Elevation Values for Portsmouth, Virginia

Note: All elevations in feet relative to the North American Vertical Datum (NAVD) of 1988

HUC12	Watershed	Design Level	1-Year	2-Year	3-Year	5-Year	10-Year	25-Year	50-Year	100-Year	500-Year
020802080203	Deep Creek-Southern Branch Elizabeth River	Current	3.4	4.1	4.5	5.1	5.9	6.7	7.3	8.0	10.0
		1.5 ft SLR	4.9	5.6	6.0	6.6	7.4	8.2	8.8	9.5	11.5
		3.0 ft SLR	6.4	7.1	7.5	8.1	8.9	9.7	10.3	11.0	13.0
020802080205	Western Branch Elizabeth River	Current	3.7	4.5	4.9	5.4	6.1	7.0	7.9	8.6	10.3
		1.5 ft SLR	5.2	6.0	6.4	6.9	7.6	8.5	9.4	10.1	11.8
		3.0 ft SLR	6.9	7.7	8.1	8.6	9.3	10.2	11.2	11.9	13.6
020802080206	Elizabeth River	Current	3.2	3.9	4.4	4.9	5.8	6.5	7.3	7.9	9.9
		1.5 ft SLR	4.7	5.4	5.9	6.4	7.3	8.0	8.8	9.4	11.4
		3.0 ft SLR	6.3	7.1	7.6	8.1	9.0	9.7	10.5	11.2	13.2
020802080301	Streeter Creek-Hampton Roads	Current	3.3	4.0	4.5	5.0	5.7	6.6	7.4	8.1	9.9
		1.5 ft SLR	4.8	5.5	6.0	6.5	7.2	8.1	8.9	9.6	11.4
		3.0 ft SLR	6.5	7.2	7.7	8.2	8.9	9.9	10.7	11.4	13.2

Figure B-9: Watershed Boundaries for Design Tidal Elevations – Portsmouth



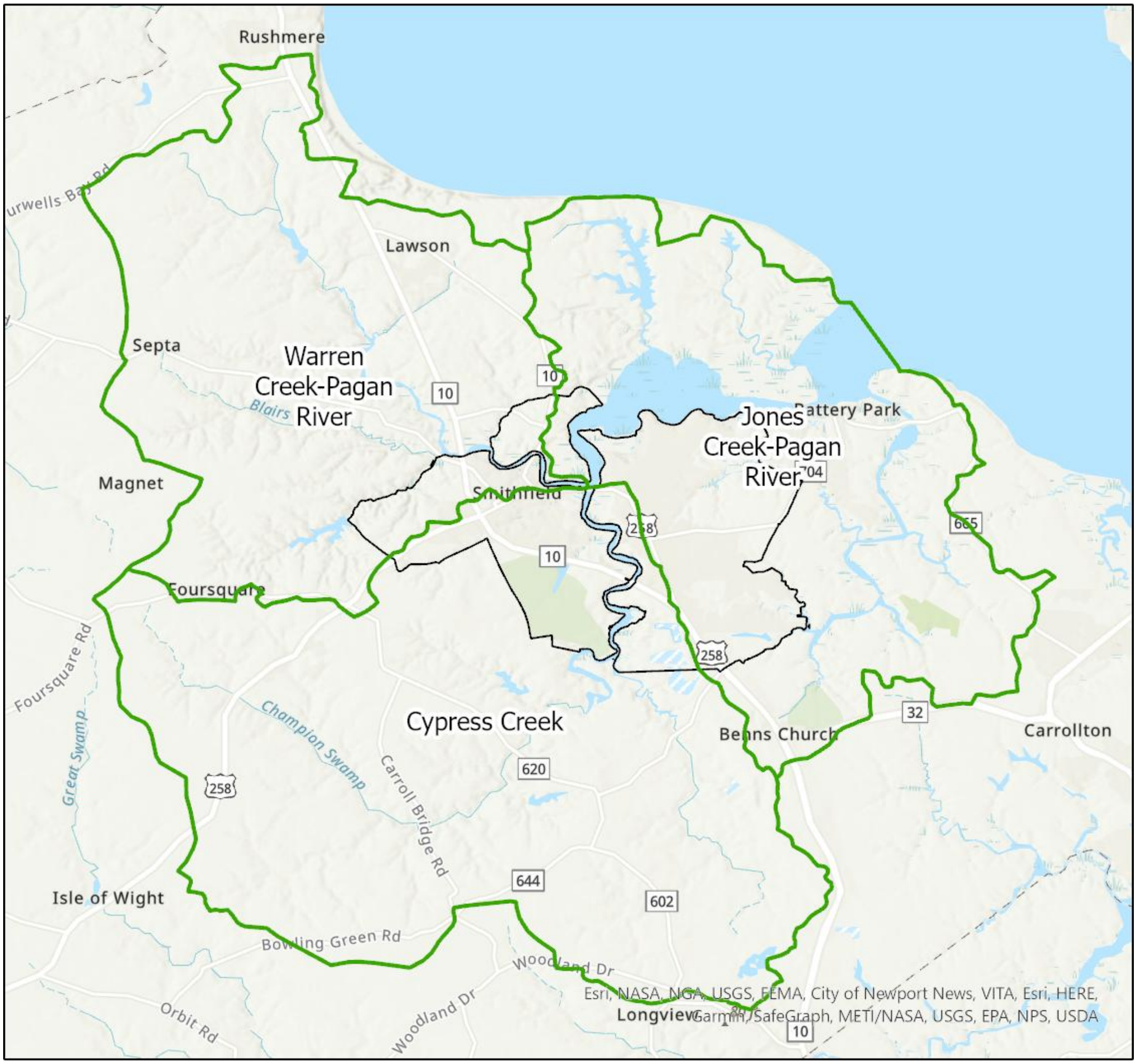
Design Tidal Elevations – Smithfield

Table B-10: Design Tidal Elevation Values for Smithfield, Virginia

Note: All elevations in feet relative to the North American Vertical Datum (NAVD) of 1988

HUC12	Watershed	Design Level	1-Year	2-Year	3-Year	5-Year	10-Year	25-Year	50-Year	100-Year	500-Year
020802060902	Warren Creek-Pagan River	Current	4.0	4.6	5.0	5.5	6.0	6.9	7.8	8.4	9.7
		1.5 ft SLR	5.5	6.1	6.5	7.0	7.5	8.4	9.3	9.9	11.2
		3.0 ft SLR	7.2	7.8	8.2	8.8	9.3	10.2	11.1	11.7	13.1
020802060903	Cypress Creek	Current	3.9	4.6	5.0	5.5	6.0	6.9	7.8	8.5	9.8
		1.5 ft SLR	5.4	6.1	6.5	7.0	7.5	8.4	9.3	10.0	11.3
		3.0 ft SLR	7.1	7.8	8.2	8.8	9.3	10.2	11.1	11.8	13.2
020802060904	Jones Creek-Pagan River	Current	3.9	4.6	5.0	5.4	5.9	6.8	7.6	8.3	9.5
		1.5 ft SLR	5.4	6.1	6.5	6.9	7.4	8.3	9.1	9.8	11.0
		3.0 ft SLR	7.0	7.8	8.2	8.6	9.1	10.0	10.8	11.5	12.8

Figure B-10: Watershed Boundaries for Design Tidal Elevations - Smithfield



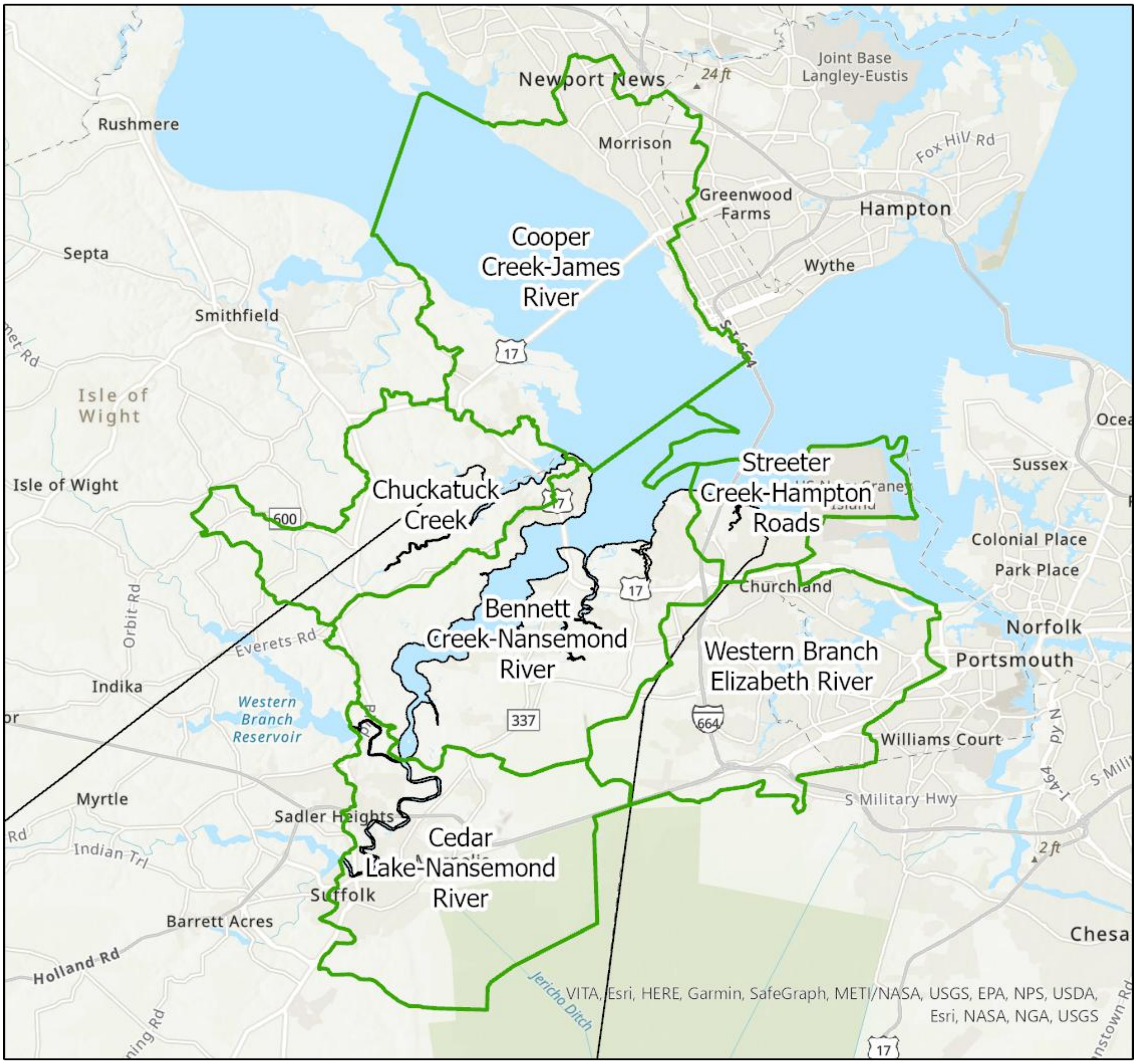
Design Tidal Elevations – Suffolk

Table B-11: Design Tidal Elevation Values for Suffolk, Virginia

Note: All elevations in feet relative to the North American Vertical Datum (NAVD) of 1988

HUC12	Watershed	Design Level	1-Year	2-Year	3-Year	5-Year	10-Year	25-Year	50-Year	100-Year	500-Year
020802060905	Chuckatuck Creek	Current	4.0	4.7	5.1	5.7	6.2	7.3	8.2	8.9	10.4
		1.5 ft SLR	5.5	6.2	6.6	7.2	7.7	8.8	9.7	10.4	11.9
		3.0 ft SLR	7.1	7.8	8.2	8.8	9.3	10.5	11.4	12.1	13.6
020802060906	Cooper Creek-James River	Current	3.7	4.4	4.8	5.2	5.8	6.7	7.5	8.1	9.6
		1.5 ft SLR	5.2	5.9	6.3	6.7	7.3	8.2	9.0	9.6	11.1
		3.0 ft SLR	6.9	7.6	8.0	8.4	9.1	10.0	10.8	11.4	13.0
020802080105	Cedar Lake-Nansemond River	Current	4.0	4.9	5.4	6.1	6.9	8.0	9.1	9.9	12.0
		1.5 ft SLR	5.5	6.4	6.9	7.6	8.4	9.5	10.6	11.4	13.5
		3.0 ft SLR	7.4	8.3	8.8	9.6	10.4	11.6	12.7	13.6	15.8
020802080106	Bennett Creek-Nansemond River	Current	4.0	4.9	5.4	6.0	6.8	7.9	8.9	9.8	11.7
		1.5 ft SLR	5.5	6.4	6.9	7.5	8.3	9.4	10.4	11.3	13.2
		3.0 ft SLR	7.1	8.1	8.6	9.2	10.0	11.1	12.2	13.1	15.0
020802080205	Western Branch Elizabeth River	Current	3.7	4.5	4.9	5.4	6.1	7.0	7.9	8.6	10.3
		1.5 ft SLR	5.2	6.0	6.4	6.9	7.6	8.5	9.4	10.1	11.8
		3.0 ft SLR	6.9	7.7	8.1	8.6	9.3	10.2	11.2	11.9	13.6
020802080301	Streeter Creek-Hampton Roads	Current	3.3	4.0	4.5	5.0	5.7	6.6	7.4	8.1	9.9
		1.5 ft SLR	4.8	5.5	6.0	6.5	7.2	8.1	8.9	9.6	11.4
		3.0 ft SLR	6.5	7.2	7.7	8.2	8.9	9.9	10.7	11.4	13.2

Figure B-11: Watershed Boundaries for Design Tidal Elevations - Suffolk



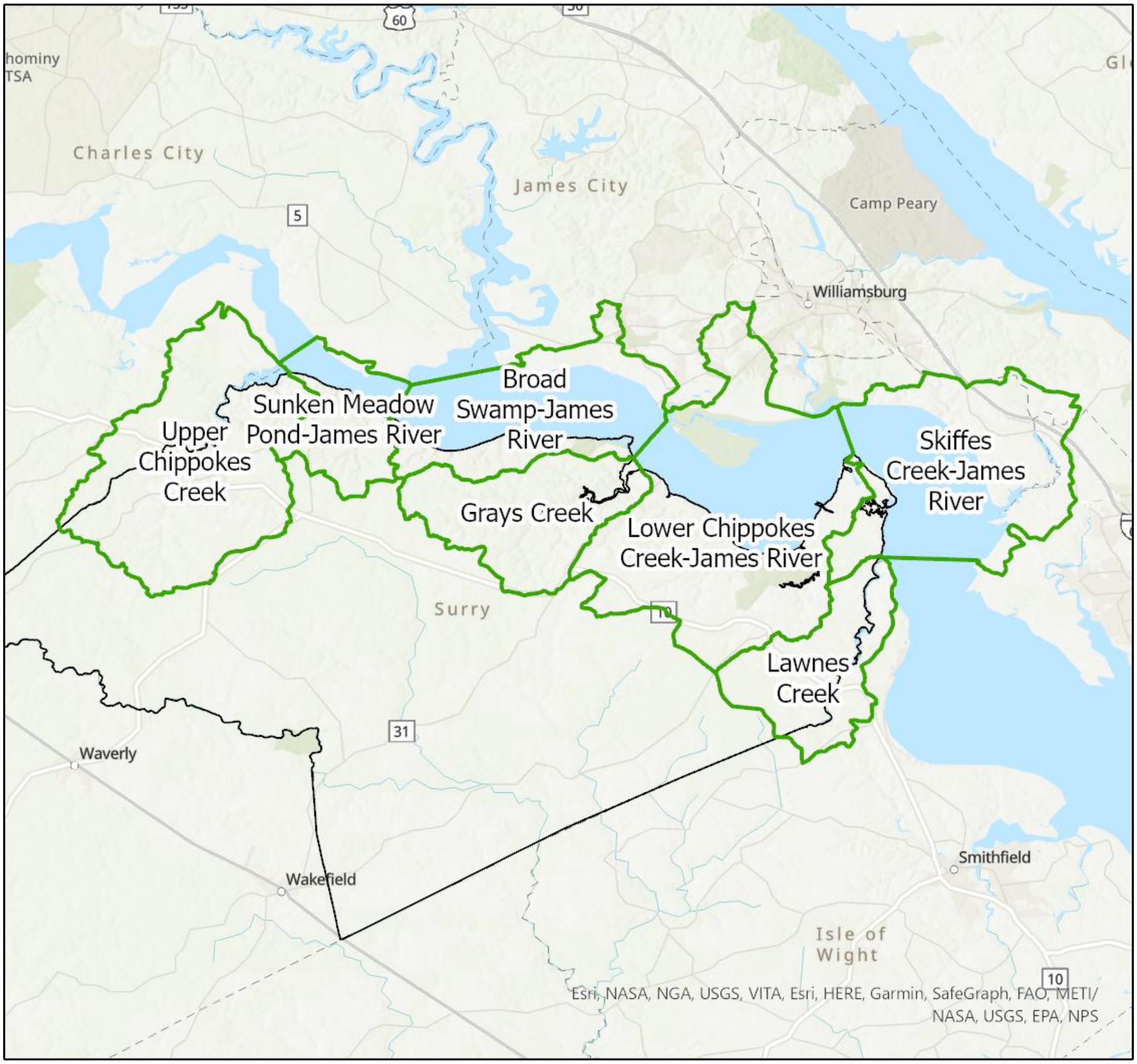
Design Tidal Elevations – Surry County

Table B-12: Design Tidal Elevation Values for Surry County, Virginia

Note: All elevations in feet relative to the North American Vertical Datum (NAVD) of 1988

HUC12	Watershed	Design Level	1-Year	2-Year	3-Year	5-Year	10-Year	25-Year	50-Year	100-Year	500-Year
020802060303	Upper Chippokes Creek	Current	4.2	4.8	5.1	5.5	6.0	7.0	7.3	7.6	9.0
		1.5 ft SLR	5.7	6.3	6.6	7.0	7.5	8.5	8.8	9.1	10.5
		3.0 ft SLR	7.9	8.6	8.9	9.4	9.9	11.0	11.4	11.7	13.2
020802060304	Sunken Meadow Pond-James River	Current	4.0	4.5	4.9	5.3	5.9	6.8	7.2	7.5	9.0
		1.5 ft SLR	5.5	6.0	6.4	6.8	7.4	8.3	8.7	9.0	10.5
		3.0 ft SLR	7.4	7.9	8.4	8.8	9.4	10.4	10.8	11.1	12.7
020802060701	Broad Swamp-James River	Current	4.0	4.6	4.9	5.3	5.8	6.7	7.1	7.4	8.8
		1.5 ft SLR	5.5	6.1	6.4	6.8	7.3	8.2	8.6	8.9	10.3
		3.0 ft SLR	7.3	8.0	8.3	8.7	9.2	10.2	10.6	10.9	12.4
020802060703	Grays Creek	Current	4.1	4.6	4.9	5.3	5.7	6.6	7.0	7.3	8.5
		1.5 ft SLR	5.6	6.1	6.4	6.8	7.2	8.1	8.5	8.8	10.0
		3.0 ft SLR	7.5	8.0	8.3	8.7	9.2	10.1	10.5	10.8	12.1
020802060704	Lower Chippokes Creek-James River	Current	3.9	4.5	4.8	5.2	5.7	6.5	6.9	7.3	8.6
		1.5 ft SLR	5.4	6.0	6.3	6.7	7.2	8.0	8.4	8.8	10.1
		3.0 ft SLR	7.2	7.8	8.1	8.5	9.1	9.9	10.3	10.7	12.1
020802060802	Skiffes Creek-James River	Current	3.6	4.2	4.5	4.9	5.6	6.3	6.7	7.1	8.6
		1.5 ft SLR	5.1	5.7	6.0	6.4	7.1	7.8	8.2	8.6	10.1
		3.0 ft SLR	6.9	7.5	7.8	8.2	8.9	9.7	10.1	10.5	12.1
020802060803	Lawnes Creek	Current	4.0	4.5	4.8	5.2	5.6	6.4	6.8	7.3	8.4
		1.5 ft SLR	5.5	6.0	6.3	6.7	7.1	7.9	8.3	8.8	9.9
		3.0 ft SLR	7.3	7.8	8.1	8.5	8.9	9.8	10.2	10.7	11.9

Figure B-12: Watershed Boundaries for Design Tidal Elevations – Surry County



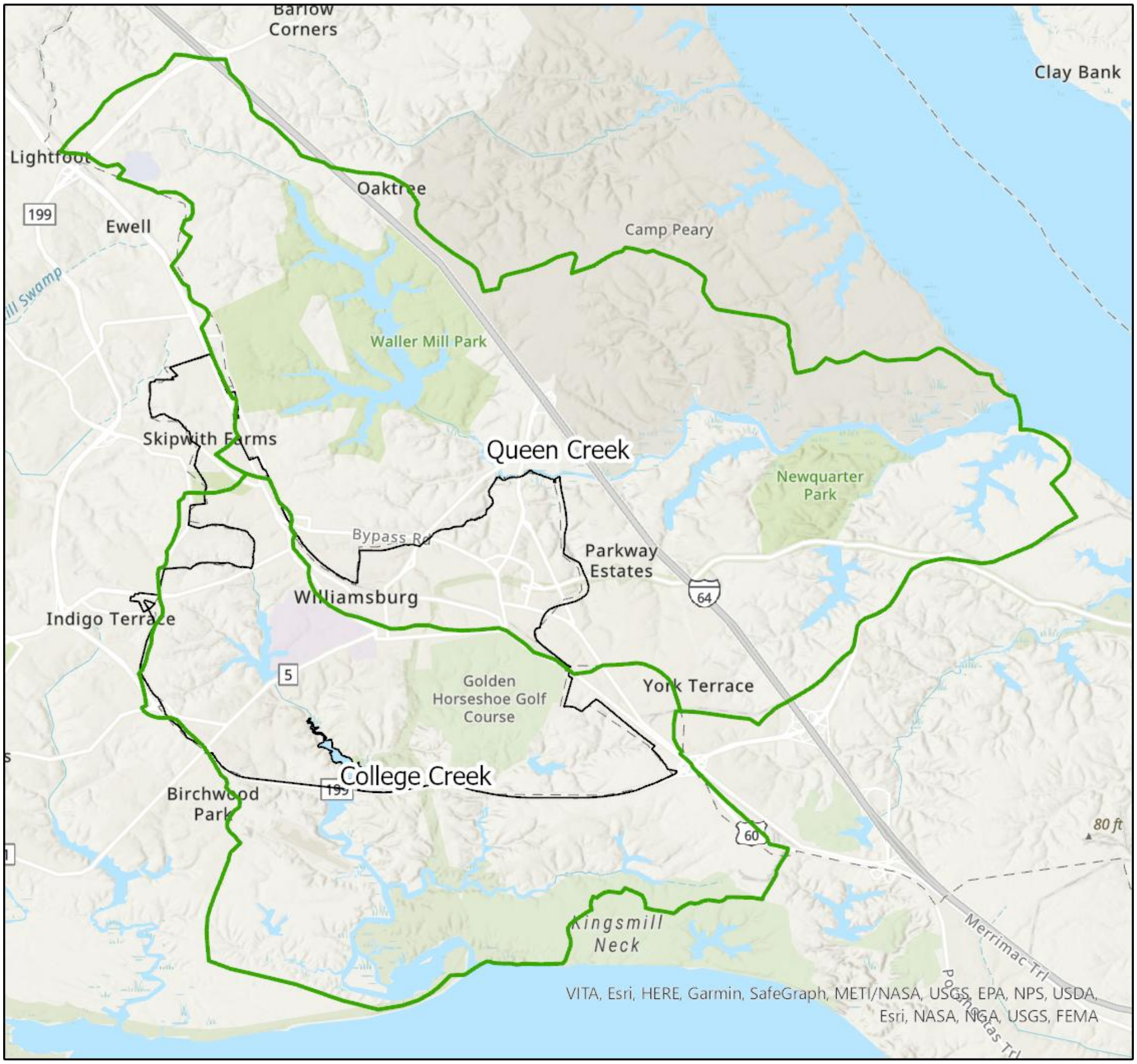
Design Tidal Elevations – Williamsburg

Table B-13: Design Tidal Elevation Values for Williamsburg, Virginia

Note: All elevations in feet relative to the North American Vertical Datum (NAVD) of 1988

HUC12	Watershed	Design Level	1-Year	2-Year	3-Year	5-Year	10-Year	25-Year	50-Year	100-Year	500-Year
020801070202	Queen Creek	Current	2.9	3.5	3.9	4.4	5.1	5.9	6.3	6.8	8.6
		1.5 ft SLR	4.4	5.0	5.4	5.9	6.6	7.4	7.8	8.3	10.1
		3.0 ft SLR	6.1	6.7	7.1	7.6	8.4	9.2	9.6	10.1	12.0
020802060801	College Creek	Current	3.3	3.9	4.3	4.8	5.6	6.3	6.7	7.1	9.0
		1.5 ft SLR	4.8	5.4	5.8	6.3	7.1	7.8	8.2	8.6	10.5
		3.0 ft SLR	6.6	7.2	7.6	8.1	8.9	9.7	10.1	10.5	12.5

Figure B-13: Watershed Boundaries for Design Tidal Elevations - Williamsburg



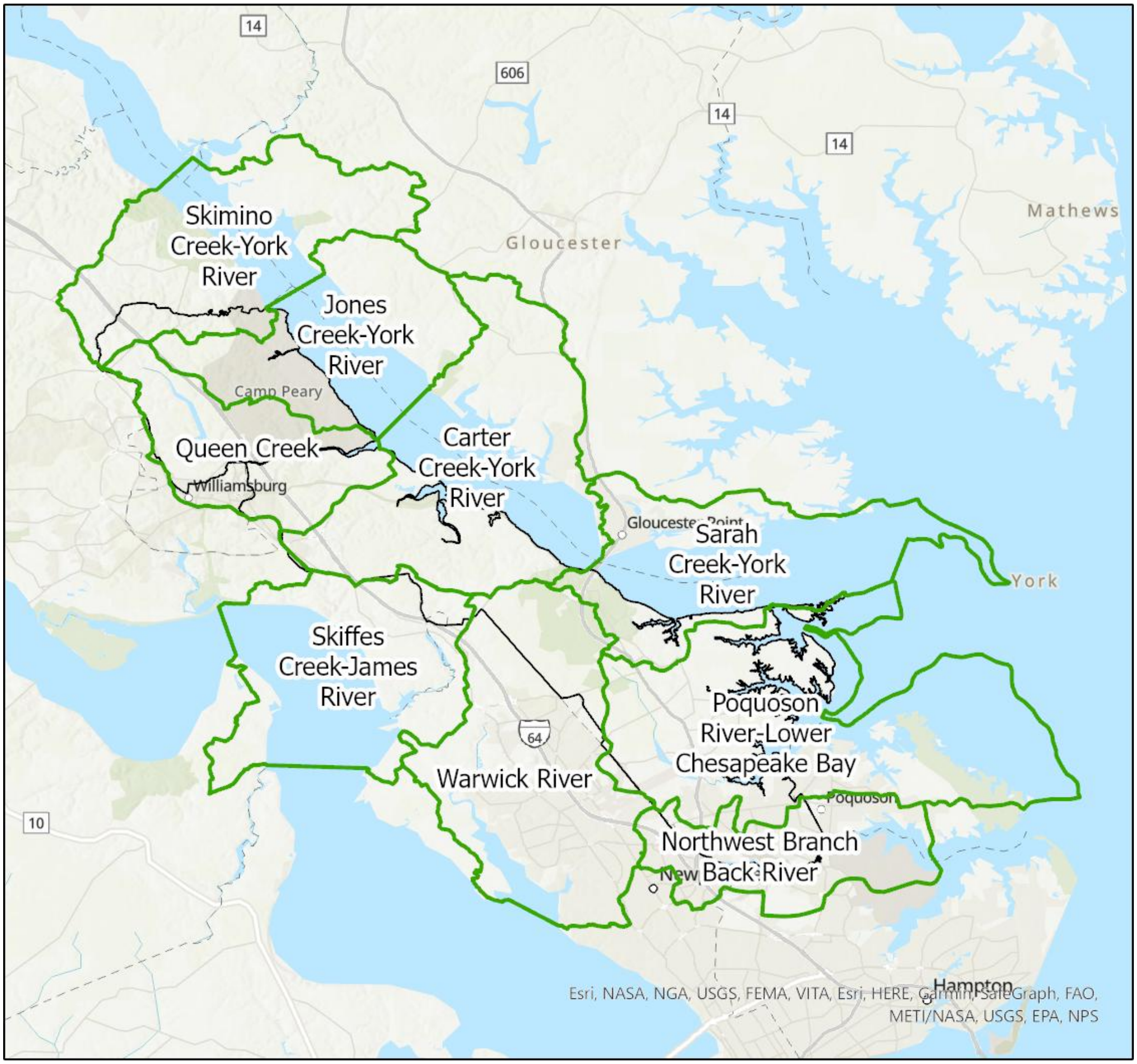
Design Tidal Elevations – York County

Table B-14: Design Tidal Elevation Values for York County, Virginia

Note: All elevations in feet relative to the North American Vertical Datum (NAVD) of 1988

HUC12	Watershed	Design Level	1-Year	2-Year	3-Year	5-Year	10-Year	25-Year	50-Year	100-Year	500-Year
020801070104	Skimino Creek-York River	Current	3.0	3.6	4.0	4.5	5.3	6.1	6.4	6.9	8.8
		1.5 ft SLR	4.5	5.1	5.5	6.0	6.8	7.6	7.9	8.4	10.3
		3.0 ft SLR	6.3	6.9	7.3	7.9	8.7	9.5	9.8	10.4	12.4
020801070201	Jones Creek-York River	Current	3.2	3.8	4.1	4.6	5.2	6.0	6.4	6.8	8.5
		1.5 ft SLR	4.7	5.3	5.6	6.1	6.7	7.5	7.9	8.3	10.0
		3.0 ft SLR	6.4	7.0	7.3	7.8	8.5	9.3	9.7	10.1	11.9
020801070202	Queen Creek	Current	2.9	3.5	3.9	4.4	5.1	5.9	6.3	6.8	8.6
		1.5 ft SLR	4.4	5.0	5.4	5.9	6.6	7.4	7.8	8.3	10.1
		3.0 ft SLR	6.1	6.7	7.1	7.6	8.4	9.2	9.6	10.1	12.0
020801070203	Carter Creek-York River	Current	3.1	3.7	4.0	4.5	5.1	5.8	6.3	6.8	8.3
		1.5 ft SLR	4.6	5.2	5.5	6.0	6.6	7.3	7.8	8.3	9.8
		3.0 ft SLR	6.3	6.9	7.2	7.7	8.3	9.1	9.6	10.1	11.6
020801070204	Sarah Creek-York River	Current	3.0	3.6	3.9	4.3	4.9	5.5	6.1	6.6	7.9
		1.5 ft SLR	4.5	5.1	5.4	5.8	6.4	7.0	7.6	8.1	9.4
		3.0 ft SLR	6.1	6.7	7.1	7.5	8.1	8.7	9.3	9.8	11.1
020801080101	Poquoson River-Lower Chesapeake Bay	Current	2.8	3.5	3.9	4.4	5.1	5.9	6.8	7.4	9.0
		1.5 ft SLR	4.3	5.0	5.4	5.9	6.6	7.4	8.3	8.9	10.5
		3.0 ft SLR	5.9	6.6	7.0	7.5	8.3	9.1	10.0	10.6	12.2
020801080102	Northwest Branch Back River	Current	3.2	3.9	4.3	4.9	5.6	6.4	7.2	7.9	9.6
		1.5 ft SLR	4.7	5.4	5.8	6.4	7.1	7.9	8.7	9.4	11.1
		3.0 ft SLR	6.4	7.1	7.5	8.1	8.8	9.6	10.5	11.2	12.9
020802060802	Skiffes Creek-James River	Current	3.6	4.2	4.5	4.9	5.6	6.3	6.7	7.1	8.6
		1.5 ft SLR	5.1	5.7	6.0	6.4	7.1	7.8	8.2	8.6	10.1
		3.0 ft SLR	6.9	7.5	7.8	8.2	8.9	9.7	10.1	10.5	12.1
020802060901	Warwick River	Current	3.7	4.2	4.6	5.0	5.6	6.3	6.8	7.2	8.7
		1.5 ft SLR	5.2	5.7	6.1	6.5	7.1	7.8	8.3	8.7	10.2
		3.0 ft SLR	7.1	7.7	8.1	8.5	9.2	9.9	10.4	10.9	12.5

Figure B-14: Watershed Boundaries for Design Tidal Elevations – York County



Appendix C – Design Rainfall Depths – Methodology

The goal of this effort is to develop design rainfall depths for communities in Hampton Roads that account for project climate change for use as inputs for stormwater management calculations. Design rainfall depths are commonly based on the NOAA Atlas 14 Precipitation-Frequency Atlas for the United States. Virginia is included in Volume 2, which covers the states in and around the Ohio River basin. Volume 2 was last published in 2004 and revised in 2006. It only includes data through 2000, so does not account for observed changes in precipitation patterns since then, nor does it account for future climate change.

This analysis is based on two previous projects. The first was conducted by the City of Virginia Beach to help inform the development of the city's revised public facilities manual. The second was completed by RAND and the Mid-Atlantic Regional Integrated Sciences and Assessments (MARISA) program to develop a Chesapeake Bay watershed-wide tool for the Chesapeake Bay Program. Both efforts use NOAA's Atlas 14[8] precipitation data as a starting point along with multiple downscaled climate projections to generate future precipitation values.

The primary deliverable from the RAND study was the development of change factors for individual counties and county-equivalent units (e.g., independent cities in Virginia) in the Chesapeake Bay watershed and all of Virginia (Figure 5). Change factors are multipliers applied to values from the current NOAA Atlas 14 volume to generate estimates that correspond to future climate conditions.

Future Precipitation = *NOAA Atlas 14 Precipitation x Change Factor*

Change factors were developed for different combinations of climate scenarios, time periods, and recurrence intervals. For example, a change factor would be calculated for the 2-year recurrence interval for 2020-2069 under representative concentration pathway 4.5.

- Climate scenarios: representative concentration pathways (RCPs) 4.5 and 8.5[9]
- Time periods: 2020-2069 and 2050-2099 (baseline time period is 1950-2000)
- Recurrence intervals: 2-year, 5-year, 10-year, 25-year, 50-year, and 100-year

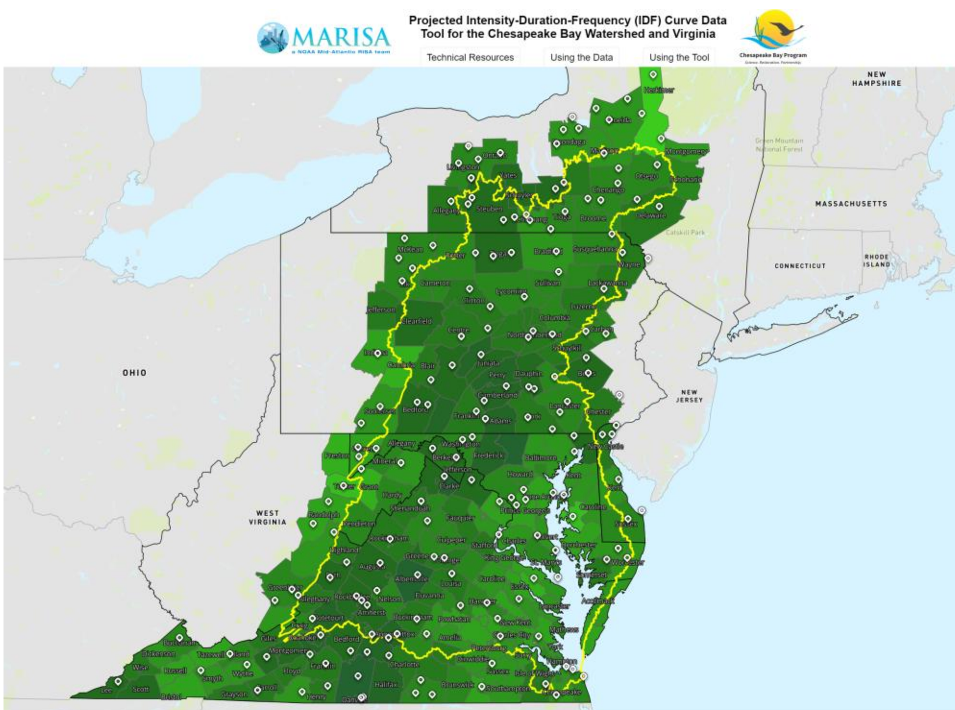
In order to account for uncertainty, the RAND/MARISA team calculated multiple values for each factor, including the 10th-percentile, 25th-percentile, 50th-percentile, 75th-percentile, and 90th-percentile, in addition to minimum and maximum values.

[8] NOAA Atlas 14 Precipitation-Frequency Atlas of the United States, Volume 2 (2006) https://www.weather.gov/media/owp/oh/hdsc/docs/Atlas14_Volume2.pdf

[9] Representative concentration pathways (RCPs) are greenhouse gas emissions scenarios based on different assumptions about energy usage and economic activity in the future. RCP 4.5 represents a decline in emissions around 2045. RCP 8.5 represents increasing emissions through the 21st century.

The Virginia Beach study[10] included both a statistical analysis of rainfall data after the cutoff for NOAA Atlas 14 and projections of future rainfall with climate change. The analysis found that the current 10-year event was approximately 10% larger in the Hampton Roads region than what is in NOAA Atlas 14. The climate analysis also considered both climate scenarios RCP 4.5 and RCP 8.5. The Virginia Beach study included mid-term (2045) and long-term (2075) estimates for the 24-hour rainfall duration for the 1-year, 2-year, 5-year, 10-year, 20-year, 50-year, and 100-year return periods. The study also modeled historical values to compare with NOAA Atlas 14. The change between the modeled historical value and the future projected value ranged from 11% to 23% for the mid-term and from 19% to 36% for the long-term. Although the Virginia Beach study provided both mid-term and long-term estimates of future rainfall depths for each return period, the final recommendation was for the city to apply a 20% increase above NOAA Atlas 14 values for all return periods instead of using the individual calculated values.

Figure C-1: Screenshot of MARISA IDF Curve Data Tool Showing Median County Change Factors[11]



For these guidelines, the results of the MARISA tool were used in conjunction with the approach used by Virginia Beach to calculate an average multiplier for each locality. For each locality, all median values for all 2020-2070 scenarios (2-year through 100-year storm events, RCP 4.5 and RCP

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[10] "Analysis of Historical and Future Heavy Precipitation," March 26, 2018 (CIP 7-030, PWCN-15-0014, Work Order 9A) https://www.vbgov.com/government/departments/public-works/comp-sea-level-rise/Documents/anaylsis-hist-and-future-hvy-precip-4-2-18.pdf

[11] Projected Intensity-Duration-Frequency (IDF) Curve Data Tool for the Chesapeake Bay Watershed and Virginia (https://midatlantic-idf.rcc-acis.org/)

8.5) were averaged to calculate a single median multiplier. The same was done for all 75th percentile values for each locality. The average median and 75th percentile change factors for each locality are listed below. The final recommended multiplier for each locality was then selected from either the average of the median values or the average of the 75th percentile values based on existing impervious cover. The methodology for calculating impervious cover is described below.

Table C-1: Average Median and 75th Percentile Change Factors for Hampton Roads Localities

Locality	Median	75th Percentile
Chesapeake	1.10	1.21
Franklin	1.12	1.21
Gloucester County	1.06	1.14
Hampton	1.08	1.18
Isle of Wight County	1.12	1.20
James City County	1.05	1.13
Newport News	1.08	1.17
Norfolk	1.09	1.22
Poquoson	1.07	1.18
Portsmouth	1.09	1.21
Southampton County	1.09	1.19
Suffolk	1.13	1.21
Surry County	1.08	1.16
Virginia Beach	1.10	1.20
Williamsburg	1.04	1.13
York County	1.06	1.14

Impervious Cover Calculations

Impervious cover for each locality was calculated using the best available one-meter resolution land cover data. For Franklin, Smithfield, and Southampton County, the source of the data was the 2013-2014 land cover data developed by Worldview Solutions and the Virginia Geographic Information Network. For all other localities, draft data from the 2018 Chesapeake Bay High Resolution Land Cover was acquired from the Chesapeake Conservancy and used instead. Data from the 2013-2014 is available online at the Chesapeake Conservancy website.[12] Data from the 2018 update is expected to be available for download through the same website in early 2022.

To calculate the percentage of impervious cover using the 2013-2014 data, locality boundaries for all seventeen jurisdictions were clipped using a shoreline file to remove major tidal water bodies. Federal properties such as Department of Defense installations and Department of the Interior facilities were then removed to identify those areas within each locality that are under local

[12] https://www.chesapeakeconservancy.org/conservation-innovation-center/high-resolution-data/land-cover-data-project/

authority. The 2013-2014 land cover data is divided into twelve classifications.[13] For the 2013-2014 data, the percentage of impervious cover was calculated using the following function.

$$\text{Impervious Cover Percentage} = \frac{\text{(Impervious (Extracted) + Impervious (Local))}}{\text{(All Land Cover Classifications minus Hydro)}}$$

The 2018 data was only provided in tabular format. The 2018 land cover data is divided into eleven classifications.[14] For the 2018 data, the percentage of impervious cover was calculated using the following function.

$$\text{Impervious Cover Percentage} = \frac{\text{(Impervious Structures + Other Impervious + Impervious Roads)}}{\text{(All Land Cover Classifications minus Water)}}$$

Impervious cover percentages for Hampton Roads localities range from less than two percent in Southampton County and Surry County to over fifty percent in Norfolk. The results of this analysis are listed below.

Table C-2: Impervious Cover Percentages for Hampton Roads Localities

Locality	2013-2014	2018
Chesapeake	11.78%	10.82%
Franklin	14.89%	N/A*
Gloucester County	3.23%	4.33%
Hampton	36.89%	40.07%
Isle of Wight County	3.93%	4.28%
James City County	9.71%	10.37%
Newport News	38.98%	38.49%
Norfolk	48.59%	52.07%
Poquoson	14.91%	12.21%
Portsmouth	44.13%	41.40%
Smithfield	17.72%	N/A**
Southampton County	1.42%	N/A*
Suffolk	6.40%	5.70%
Surry County	1.41%	1.82%
Virginia Beach	22.54%	19.41%
Williamsburg	19.98%	24.16%
York County	14.91%	14.06%

[13] Hydro, Impervious (extracted), Impervious (local), Barren, Forest, Tree, Scrub/Shrub, Harvested/Disturbed, Turf Grass, Pasture, Cropland, Woody Wetlands

[14] Water, Tree Canopy, Scrub/Shrub, Herbaceous, Barren, Impervious Structures, Other Impervious, Impervious Roads, Tree Canopy over Impervious Structures, Tree Canopy over Other Impervious, Tree Canopy over Impervious Roads

* 2018 land cover data for Franklin and Southampton County is not expected to be developed, since both localities are outside of the Chesapeake Bay watershed.
** 2018 land cover data for Smithfield is expected to become available once the data is released in raster format.

Development of Recommended Multipliers

Recommended multipliers for each locality were calculated based on either the average median or average 75th percentile for 2020-2070. For localities with less than 10% impervious cover, the average median value was used, while the average 75th percentile value was used for localities with greater than 10% impervious cover. For ease of use, these average multipliers were rounded to the nearest 0.05, with a minimum multiplier of 1.10 (10% increase above NOAA Atlas 14). The recommended multipliers Hampton Roads localities are listed below. Recommended precipitation values for each locality are included in the individual locality summaries.

Table C-3: Recommended Multipliers for Hampton Roads Localities

Locality	Recommended Multiplier
Chesapeake	1.2
Franklin	1.2
Gloucester County	1.1
Hampton	1.2
Isle of Wight County	1.1
James City County	1.15
Newport News	1.15
Norfolk	1.2
Poquoson	1.2
Portsmouth	1.2
Smithfield*	1.2
Southampton County	1.1
Suffolk	1.15
Surry County	1.1
Virginia Beach	1.2
Williamsburg	1.15
York County	1.15

* The recommended multiplier for Smithfield is based on the 75th percentile value for Isle of Wight County due to the town's impervious cover percentage.

Methodology for Design Rainfall Depths[15]

1. Calculate centroid of locality in ArcGIS using Convert Feature To Point

[15] This methodology is used for all localities except for Virginia Beach, which establish a separate representative point as part of adopting the city's Public Works Design Standards Manual in June 2020.

2. Use Extract Multi Values to Points to append NOAA Atlas 14 rainfall depths[16] to Locality Centroid Feature
3. Export Feature and convert to Excel format
4. Multiply NOAA Atlas 14 rainfall depths for locality centroids by recommended change factor to calculate future rainfall depths for 2020-2070

[16] NOAA Atlas 14 GIS data was obtained from NOAA's Precipitation Frequency Data Server (PF Data Server-PFDS/HDSC/OWP (noaa.gov))

Appendix D – Design Rainfall Depths for Hampton Roads Localities

Notes:

1. All values are in inches.
2. All values are for the 24-hour duration event.
3. Atlas 14 values are for the centroid of each locality unless otherwise noted.

Recommended Design Rainfall Depths - Chesapeake

Table D-1: NOAA Atlas 14 (Vol. 2) Precipitation Values for Chesapeake, Virginia

Design Storm	Minimum	Maximum	Mean	Median	90th Percentile	Centroid
1-Year	2.95	3.08	3.03	3.03	3.07	3.04
2-Year	3.59	3.75	3.69	3.69	3.74	3.70
5-Year	4.64	4.84	4.76	4.76	4.82	4.78
10-Year	5.53	5.76	5.67	5.67	5.74	5.69
25-Year	6.85	7.12	7.01	7.01	7.10	7.04
50-Year	7.98	8.29	8.17	8.17	8.26	8.19
100-Year	9.23	9.58	9.44	9.44	9.54	9.47

Table D-2: Recommended Design Rainfall Depths for Chesapeake, Virginia

Design Storm Frequency	NOAA Atlas 14 Rainfall (24-Hour Duration)	Design Rainfall (NOAA Atlas 14 * Multiplier)	CBP Median Rainfall Depth (RCP 4.5)	CBP Median Rainfall Depth (RCP 8.5)
1-Year	3.04	**3.65**	-	-
2-Year	3.70	**4.44**	3.96	4.11
5-Year	4.78	**5.73**	5.20	5.25
10-Year	5.69	**6.83**	6.20	6.31
25-Year	7.04	**8.44**	7.67	7.81
50-Year	8.19	**9.83**	8.93	9.26
100-Year	9.47	**11.36**	10.51	10.70

Notes:

1. All values are in inches.
2. All values are for the 24-hour duration event.
3. NOAA Atlas 14 rainfall values for Recommended Design Rainfall Depths are based on the centroid of the city (latitude 36.6793761, longitude -76.3017883).
4. CBP Median Rainfall Depths are not available for the 1-Year event.

Recommended Design Rainfall Depths - Franklin

Table D-3: NOAA Atlas 14 (Vol. 2) Precipitation Values for Franklin, Virginia

Design Storm	Minimum	Maximum	Mean	Median	90th Percentile	Centroid
1-Year	2.94	2.96	2.95	2.95	2.96	2.95
2-Year	3.57	3.60	3.59	3.59	3.59	3.59
5-Year	4.61	4.64	4.62	4.62	4.64	4.63
10-Year	5.48	5.52	5.50	5.50	5.52	5.50
25-Year	6.76	6.81	6.79	6.79	6.81	6.79
50-Year	7.86	7.92	7.89	7.90	7.92	7.90
100-Year	9.07	9.13	9.10	9.11	9.13	9.11

Table D-4: Recommended Design Rainfall Depths for Franklin, Virginia

Design Storm Frequency	NOAA Atlas 14 Rainfall (24-Hour Duration)	Design Rainfall (NOAA Atlas 14 * Multiplier)	CBP Median Rainfall Depth (RCP 4.5)	CBP Median Rainfall Depth (RCP 8.5)
1-Year	2.95	**3.54**	**-**	**-**
2-Year	3.59	**4.31**	3.88	3.98
5-Year	4.63	**5.55**	5.09	5.09
10-Year	5.50	**6.6**	6.05	6.05
25-Year	6.79	**8.15**	7.67	7.61
50-Year	7.90	**9.48**	9.00	8.92
100-Year	9.11	**10.93**	10.48	10.29

Notes:

1. All values are in inches.
2. All values are for the 24-hour duration event.
3. NOAA Atlas 14 rainfall values for Recommended Design Rainfall Depths are based on the centroid of the city (latitude 36.6840142, longitude -76.9413955).
4. CBP Median Rainfall Depths are not available for the 1-Year event.

Recommended Design Rainfall Depths – Gloucester County

Table D-5: NOAA Atlas 14 (Vol. 2) Precipitation Values for Gloucester County, Virginia

Design Storm	Minimum	Maximum	Mean	Median	90th Percentile	Centroid
1-Year	2.78	2.92	2.86	2.86	2.91	2.87
2-Year	3.38	3.55	3.48	3.48	3.53	3.49
5-Year	4.38	4.60	4.51	4.52	4.58	4.52
10-Year	5.24	5.49	5.39	5.40	5.47	5.41
25-Year	6.54	6.83	6.72	6.73	6.81	6.74
50-Year	7.67	7.99	7.88	7.89	7.97	7.90
100-Year	8.93	9.28	9.17	9.18	9.26	9.19

Table D-6: Recommended Design Rainfall Depths for Gloucester County, Virginia

Design Storm Frequency	NOAA Atlas 14 Rainfall (24-Hour Duration)	Design Rainfall (NOAA Atlas 14 * Multiplier)	CBP Median Rainfall Depth (RCP 4.5)	CBP Median Rainfall Depth (RCP 8.5)
1-Year	2.87	**3.15**	-	-
2-Year	3.49	**3.84**	3.70	3.80
5-Year	4.52	**4.97**	4.79	4.97
10-Year	5.41	**5.95**	5.68	5.89
25-Year	6.74	**7.41**	6.94	7.27
50-Year	7.90	**8.69**	7.98	8.53
100-Year	9.19	**10.11**	9.10	9.93

Notes:

1. All values are in inches.
2. All values are for the 24-hour duration event.
3. NOAA Atlas 14 rainfall values for Recommended Design Rainfall Depths are based on the centroid of the county (latitude 37.4035413, longitude -76.523505).
4. CBP Median Rainfall Depths are not available for the 1-Year event.

Recommended Design Rainfall Depths - Hampton

Table D-7: NOAA Atlas 14 (Vol. 2) Precipitation Values for Hampton, Virginia

Design Storm	Minimum	Maximum	Mean	Median	90th Percentile	Centroid
1-Year	2.92	2.95	2.94	2.94	2.94	2.94
2-Year	3.56	3.59	3.57	3.57	3.58	3.58
5-Year	4.61	4.64	4.63	4.63	4.64	4.63
10-Year	5.50	5.54	5.53	5.53	5.54	5.53
25-Year	6.82	6.89	6.87	6.87	6.88	6.88
50-Year	7.97	8.07	8.04	8.04	8.06	8.05
100-Year	9.23	9.38	9.33	9.33	9.36	9.35

Table D-8: Recommended Design Rainfall Depths for Hampton, Virginia

Design Storm Frequency	NOAA Atlas 14 Rainfall (24-Hour Duration)	Design Rainfall (NOAA Atlas 14 * Multiplier)	CBP Median Rainfall Depth (RCP 4.5)	CBP Median Rainfall Depth (RCP 8.5)
1-Year	2.94	**3.52**	-	-
2-Year	3.58	**4.29**	3.86	3.90
5-Year	4.63	**5.56**	4.91	5.05
10-Year	5.53	**6.64**	5.81	6.09
25-Year	6.88	**8.26**	7.22	7.57
50-Year	8.05	**9.66**	8.54	8.94
100-Year	9.35	**11.22**	9.91	10.47

Notes:

1. All values are in inches.
2. All values are for the 24-hour duration event.
3. NOAA Atlas 14 rainfall values for Recommended Design Rainfall Depths are based on the centroid of the city (latitude 37.0480302, longitude -76.2971486).
4. CBP Median Rainfall Depths are not available for the 1-Year event.

Recommended Design Rainfall Depths – Isle of Wight County

Table D-9: Atlas 14 (Vol. 2) Precipitation Values for Isle of Wight County, Virginia

Design Storm	Minimum	Maximum	Mean	Median	90th Percentile	Centroid
1-Year	2.92	2.98	2.95	2.96	2.97	2.96
2-Year	3.56	3.62	3.59	3.60	3.61	3.60
5-Year	4.59	4.68	4.64	4.64	4.66	4.65
10-Year	5.47	5.57	5.53	5.53	5.55	5.53
25-Year	6.75	6.88	6.83	6.84	6.87	6.83
50-Year	7.85	8.02	7.95	7.96	8.00	7.95
100-Year	9.06	9.27	9.19	9.19	9.25	9.18

Table D-10: Recommended Design Rainfall Depths for Isle of Wight County, Virginia

Design Storm Frequency	NOAA Atlas 14 Rainfall (24-Hour Duration)	Design Rainfall (NOAA Atlas 14 * Multiplier)	CBP Median Rainfall Depth (RCP 4.5)	CBP Median Rainfall Depth (RCP 8.5)
1-Year	2.96	**3.26**	-	-
2-Year	3.60	**3.96**	3.92	4.00
5-Year	4.65	**5.11**	5.06	5.20
10-Year	5.53	**6.08**	6.03	6.19
25-Year	6.83	**7.52**	7.65	7.72
50-Year	7.95	**8.75**	9.07	9.07
100-Year	9.18	**10.1**	10.56	10.47

Notes:

1. All values are in inches.
2. All values are for the 24-hour duration event.
3. NOAA Atlas 14 rainfall values for Recommended Design Rainfall Depths are based on the centroid of the county (latitude 36.9014184, longitude -76.7075687).
4. CBP Median Rainfall Depths are not available for the 1-Year event.

Recommended Design Rainfall Depths – James City County

Table D-11: Atlas 14 (Vol. 2) Precipitation Values for James City County, Virginia

Design Storm	Minimum	Maximum	Mean	Median	90th Percentile	Centroid
1-Year	2.83	2.94	2.90	2.90	2.94	2.92
2-Year	3.44	3.58	3.52	3.53	3.57	3.55
5-Year	4.44	4.63	4.56	4.56	4.62	4.59
10-Year	5.30	5.52	5.44	5.44	5.51	5.47
25-Year	6.59	6.85	6.74	6.75	6.83	6.78
50-Year	7.71	8.00	7.88	7.89	7.98	7.91
100-Year	8.95	9.29	9.14	9.14	9.24	9.17

Table D-12: Recommended Design Rainfall Depths for James City County, Virginia

Design Storm Frequency	NOAA Atlas 14 Rainfall (24-Hour Duration)	Design Rainfall (NOAA Atlas 14 * Multiplier)	CBP Median Rainfall Depth (RCP 4.5)	CBP Median Rainfall Depth (RCP 8.5)
1-Year	2.92	**3.35**	-	-
2-Year	3.55	**4.08**	3.76	3.79
5-Year	4.59	**5.27**	4.81	4.95
10-Year	5.47	**6.29**	5.69	5.90
25-Year	6.78	**7.79**	6.98	7.18
50-Year	7.91	**9.1**	7.99	8.39
100-Year	9.17	**10.55**	9.17	9.63

Notes:

1. All values are in inches.
2. All values are for the 24-hour duration event.
3. NOAA Atlas 14 rainfall values for Recommended Design Rainfall Depths are based on the centroid of the county (latitude 37.3244273, longitude -76.7783194).
4. CBP Median Rainfall Depths are not available for the 1-Year event.

Recommended Design Rainfall Depths – Newport News

Table D-13: Atlas 14 (Vol. 2) Precipitation Values for Newport News, Virginia

Design Storm	Minimum	Maximum	Mean	Median	90th Percentile	Centroid
1-Year	2.93	2.95	2.94	2.94	2.95	2.94
2-Year	3.57	3.59	3.58	3.58	3.59	3.58
5-Year	4.62	4.65	4.63	4.63	4.64	4.63
10-Year	5.51	5.54	5.53	5.52	5.54	5.53
25-Year	6.84	6.87	6.86	6.86	6.87	6.86
50-Year	7.99	8.04	8.01	8.01	8.02	8.01
100-Year	9.26	9.33	9.29	9.29	9.31	9.30

Table D-14: Recommended Design Rainfall Depths for Newport News, Virginia

Design Storm Frequency	NOAA Atlas 14 Rainfall (24-Hour Duration)	Design Rainfall (NOAA Atlas 14 * Multiplier)	CBP Median Rainfall Depth (RCP 4.5)	CBP Median Rainfall Depth (RCP 8.5)
1-Year	2.94	**3.38**	-	-
2-Year	3.58	**4.11**	3.86	3.93
5-Year	4.63	**5.32**	4.95	5.14
10-Year	5.53	**6.35**	5.86	6.13
25-Year	6.86	**7.89**	7.20	7.61
50-Year	8.01	**9.22**	8.33	8.90
100-Year	9.30	**10.69**	9.76	10.32

Notes:

1. All values are in inches.
2. All values are for the 24-hour duration event.
3. NOAA Atlas 14 rainfall values for Recommended Design Rainfall Depths are based on the centroid of the city (latitude 37.0759783, longitude -76.5217186).
4. CBP Median Rainfall Depths are not available for the 1-Year event.

Recommended Design Rainfall Depths - Norfolk

Table D-15: Atlas 14 (Vol. 2) Precipitation Values for Norfolk, Virginia

Design Storm	Minimum	Maximum	Mean	Median	90th Percentile	Centroid
1-Year	2.92	2.96	2.94	2.93	2.95	2.93
2-Year	3.55	3.60	3.57	3.57	3.59	3.56
5-Year	4.59	4.65	4.62	4.61	4.64	4.60
10-Year	5.47	5.55	5.50	5.50	5.53	5.49
25-Year	6.78	6.87	6.82	6.82	6.85	6.80
50-Year	7.91	8.01	7.95	7.95	7.98	7.93
100-Year	9.16	9.27	9.20	9.20	9.23	9.18

Table D-16: Recommended Design Rainfall Depths for Norfolk, Virginia

Design Storm Frequency	NOAA Atlas 14 Rainfall (24-Hour Duration)	Design Rainfall (NOAA Atlas 14 * Multiplier)	CBP Median Rainfall Depth (RCP 4.5)	CBP Median Rainfall Depth (RCP 8.5)
1-Year	2.93	**3.51**	-	-
2-Year	3.56	**4.28**	3.81	3.88
5-Year	4.60	**5.52**	4.88	5.06
10-Year	5.49	**6.59**	5.82	6.04
25-Year	6.80	**8.16**	7.21	7.55
50-Year	7.93	**9.51**	8.48	8.88
100-Year	9.18	**11.01**	9.91	10.28

Notes:

1. All values are in inches.
2. All values are for the 24-hour duration event.
3. NOAA Atlas 14 rainfall values for Recommended Design Rainfall Depths are based on the centroid of the city (latitude 36.9230148, longitude -76.2446413).
4. CBP Median Rainfall Depths are not available for the 1-Year event.

Recommended Design Rainfall Depths - Poquoson

Table D-17: Atlas 14 (Vol. 2) Precipitation Values for Poquoson, Virginia

Design Storm	Minimum	Maximum	Mean	Median	90th Percentile	Centroid
1-Year	2.92	2.93	2.93	2.93	2.93	2.93
2-Year	3.55	3.57	3.56	3.56	3.57	3.56
5-Year	4.60	4.62	4.61	4.62	4.62	4.62
10-Year	5.50	5.53	5.52	5.52	5.53	5.52
25-Year	6.85	6.88	6.87	6.87	6.88	6.87
50-Year	8.03	8.06	8.05	8.05	8.06	8.05
100-Year	9.33	9.37	9.35	9.36	9.37	9.36

Table D-18: Recommended Design Rainfall Depths for Poquoson, Virginia

Design Storm Frequency	NOAA Atlas 14 Rainfall (24-Hour Duration)	Design Rainfall (NOAA Atlas 14 * Multiplier)	CBP Median Rainfall Depth (RCP 4.5)	CBP Median Rainfall Depth (RCP 8.5)
1-Year	2.93	**3.51**	-	-
2-Year	3.56	**4.27**	3.81	3.88
5-Year	4.62	**5.54**	4.89	5.03
10-Year	5.52	**6.63**	5.80	6.07
25-Year	6.87	**8.25**	7.15	7.49
50-Year	8.05	**9.66**	8.29	8.86
100-Year	9.36	**11.23**	9.64	10.39

Notes:

1. All values are in inches.
2. All values are for the 24-hour duration event.
3. NOAA Atlas 14 rainfall values for Recommended Design Rainfall Depths are based on the centroid of the city (latitude 37.1283599, longitude -76.3035337).
4. CBP Median Rainfall Depths are not available for the 1-Year event.

Recommended Design Rainfall Depths - Portsmouth

Table D-19: Atlas 14 (Vol. 2) Precipitation Values for Portsmouth, Virginia

Design Storm	Minimum	Maximum	Mean	Median	90th Percentile	Centroid
1-Year	2.95	2.99	2.97	2.97	2.98	2.97
2-Year	3.59	3.63	3.61	3.61	3.63	3.61
5-Year	4.64	4.69	4.66	4.66	4.68	4.66
10-Year	5.53	5.59	5.56	5.56	5.58	5.55
25-Year	6.85	6.91	6.88	6.88	6.90	6.88
50-Year	7.99	8.06	8.02	8.02	8.04	8.01
100-Year	9.24	9.31	9.27	9.27	9.30	9.27

Table D-20: Recommended Design Rainfall Depths for Portsmouth, Virginia

Design Storm Frequency	NOAA Atlas 14 Rainfall (24-Hour Duration)	Design Rainfall (NOAA Atlas 14 * Multiplier)	CBP Median Rainfall Depth (RCP 4.5)	CBP Median Rainfall Depth (RCP 8.5)
1-Year	2.97	**3.56**	-	-
2-Year	3.61	**4.33**	3.90	4.00
5-Year	4.66	**5.59**	4.94	5.08
10-Year	5.55	**6.66**	5.83	6.05
25-Year	6.88	**8.25**	7.22	7.63
50-Year	8.01	**9.62**	8.49	9.06
100-Year	9.27	**11.12**	10.10	10.56

Notes:

1. All values are in inches.
2. All values are for the 24-hour duration event.
3. NOAA Atlas 14 rainfall values for Recommended Design Rainfall Depths are based on the centroid of the city (latitude 36.8594298, longitude -76.3562686).
4. CBP Median Rainfall Depths are not available for the 1-Year event.

Recommended Design Rainfall Depths – Smithfield

Table D-21: Atlas 14 (Vol. 2) Precipitation Values for Smithfield, Virginia

Design Storm	Minimum	Maximum	Mean	Median	90th Percentile	Centroid
1-Year	2.95	2.96	2.95	2.95	2.96	2.95
2-Year	3.59	3.60	3.59	3.59	3.60	3.59
5-Year	4.63	4.65	4.64	4.64	4.65	4.64
10-Year	5.52	5.54	5.53	5.53	5.54	5.53
25-Year	6.84	6.86	6.85	6.85	6.86	6.85
50-Year	7.97	8.00	7.99	7.99	8.00	7.98
100-Year	9.21	9.25	9.24	9.24	9.25	9.24

Table D-22: Recommended Design Rainfall Depths for Smithfield, Virginia

Design Storm Frequency	NOAA Atlas 14 Rainfall (24-Hour Duration)	Design Rainfall (NOAA Atlas 14 * Multiplier)	CBP Median Rainfall Depth (RCP 4.5)	CBP Median Rainfall Depth (RCP 8.5)
1-Year	2.95	**3.54**	-	-
2-Year	3.59	**4.31**	3.92	4.00
5-Year	4.64	**5.57**	5.06	5.20
10-Year	5.53	**6.64**	6.03	6.19
25-Year	6.85	**8.22**	7.65	7.72
50-Year	7.98	**9.58**	9.07	9.07
100-Year	9.24	**11.08**	10.56	10.47

Notes:

1. All values are in inches.
2. All values are for the 24-hour duration event.
3. NOAA Atlas 14 rainfall values for Recommended Design Rainfall Depths are based on the centroid of the town (latitude 36.9718727, longitude -76.612997).
4. CBP Median Rainfall Depths are not available for the 1-Year event.
5. CBP Median Values are for Isle of Wight County

Recommended Design Rainfall Depths – Southampton County

Table D-23: Atlas 14 (Vol. 2) Precipitation Values for Southampton County, Virginia

Design Storm	Minimum	Maximum	Mean	Median	90th Percentile	Centroid
1-Year	2.70	2.97	2.87	2.88	2.94	2.87
2-Year	3.28	3.61	3.49	3.50	3.57	3.49
5-Year	4.22	4.65	4.50	4.51	4.61	4.50
10-Year	5.01	5.53	5.34	5.36	5.48	5.34
25-Year	6.16	6.83	6.59	6.60	6.76	6.58
50-Year	7.13	7.94	7.66	7.67	7.86	7.64
100-Year	8.18	9.16	8.82	8.84	9.06	8.79

Table D-24: Recommended Design Rainfall Depths for Southampton County, Virginia

Design Storm Frequency	NOAA Atlas 14 Rainfall (24-Hour Duration)	Design Rainfall (NOAA Atlas 14 * Multiplier)	CBP Median Rainfall Depth (RCP 4.5)	CBP Median Rainfall Depth (RCP 8.5)
1-Year	2.87	**3.16**	-	-
2-Year	3.49	**3.84**	3.73	3.80
5-Year	4.50	**4.95**	4.77	4.95
10-Year	5.34	**5.88**	5.71	5.88
25-Year	6.58	**7.24**	7.11	7.24
50-Year	7.64	**8.4**	8.32	8.55
100-Year	8.79	**9.67**	9.49	10.02

Notes:

1. All values are in inches.
2. All values are for the 24-hour duration event.
3. NOAA Atlas 14 rainfall values for Recommended Design Rainfall Depths are based on the centroid of the county (latitude 36.7201725, longitude -77.1038556).
4. CBP Median Rainfall Depths are not available for the 1-Year event.

Recommended Design Rainfall Depths - Suffolk

Table D-25: Atlas 14 (Vol. 2) Precipitation Values for Suffolk, Virginia

Design Storm	Minimum	Maximum	Mean	Median	90th Percentile	Centroid
1-Year	2.96	3.07	2.99	2.99	3.03	2.99
2-Year	3.60	3.73	3.64	3.63	3.68	3.64
5-Year	4.63	4.81	4.70	4.69	4.75	4.69
10-Year	5.51	5.72	5.59	5.58	5.65	5.59
25-Year	6.80	7.07	6.91	6.89	6.98	6.90
50-Year	7.91	8.23	8.04	8.03	8.13	8.04
100-Year	9.13	9.50	9.28	9.27	9.38	9.28

Table D-26: Recommended Design Rainfall Depths for Suffolk, Virginia

Design Storm Frequency	NOAA Atlas 14 Rainfall (24-Hour Duration)	Design Rainfall (NOAA Atlas 14 * Multiplier)	CBP Median Rainfall Depth (RCP 4.5)	CBP Median Rainfall Depth (RCP 8.5)
1-Year	2.99	**3.44**	-	-
2-Year	3.64	**4.18**	3.97	4.04
5-Year	4.69	**5.4**	5.16	5.26
10-Year	5.59	**6.43**	6.20	6.37
25-Year	6.90	**7.94**	7.73	7.94
50-Year	8.04	**9.24**	9.16	9.40
100-Year	9.28	**10.67**	10.76	10.94

Notes:

1. All values are in inches.
2. All values are for the 24-hour duration event.
3. NOAA Atlas 14 rainfall values for Recommended Design Rainfall Depths are based on the centroid of the city (latitude 36.6971573, longitude -76.6347807).
4. CBP Median Rainfall Depths are not available for the 1-Year event.

Recommended Design Rainfall Depths – Surry County

Table D-27: Atlas 14 (Vol. 2) Precipitation Values for Surry County, Virginia

Design Storm	Minimum	Maximum	Mean	Median	90th Percentile	Centroid
1-Year	2.83	2.93	2.90	2.90	2.93	2.90
2-Year	3.43	3.57	3.52	3.53	3.56	3.52
5-Year	4.42	4.62	4.55	4.56	4.60	4.55
10-Year	5.26	5.51	5.41	5.42	5.49	5.42
25-Year	6.47	6.83	6.69	6.70	6.79	6.70
50-Year	7.51	7.97	7.79	7.80	7.92	7.80
100-Year	8.63	9.24	9.00	9.01	9.16	9.01

Table D-28: Recommended Design Rainfall Depths for Surry County, Virginia

Design Storm Frequency	NOAA Atlas 14 Rainfall (24-Hour Duration)	Design Rainfall (NOAA Atlas 14 * Multiplier)	CBP Median Rainfall Depth (RCP 4.5)	CBP Median Rainfall Depth (RCP 8.5)
1-Year	2.90	**3.19**	-	-
2-Year	3.52	**3.87**	3.77	3.87
5-Year	4.55	**5.00**	4.87	5.00
10-Year	5.42	**5.96**	5.79	5.90
25-Year	6.70	**7.37**	7.03	7.23
50-Year	7.80	**8.58**	8.34	8.34
100-Year	9.01	**9.91**	9.73	9.73

Notes:

1. All values are in inches.
2. All values are for the 24-hour duration event.
3. NOAA Atlas 14 rainfall values for Recommended Design Rainfall Depths are based on the centroid of the county (latitude 37.119761, longitude -76.8801717).
4. CBP Median Rainfall Depths are not available for the 1-Year event.

Recommended Design Rainfall Depths – Virginia Beach

Table D-29: Atlas 14 (Vol. 2) Precipitation Values for Virginia Beach, Virginia

Design Storm	Minimum	Maximum	Mean	Median	90th Percentile	Centroid
1-Year	2.93	3.06	3.01	3.01	3.04	3.01
2-Year	3.57	3.72	3.66	3.66	3.70	3.66
5-Year	4.61	4.81	4.73	4.73	4.77	4.73
10-Year	5.50	5.72	5.64	5.64	5.68	5.64
25-Year	6.82	7.08	6.98	6.99	7.02	6.98
50-Year	7.95	8.24	8.14	8.15	8.18	8.13
100-Year	9.21	9.52	9.42	9.43	9.46	9.40

Table D-30: Recommended Design Rainfall Depths for Virginia Beach, Virginia

Design Storm Frequency	NOAA Atlas 14 Rainfall (24-Hour Duration)	Design Rainfall (NOAA Atlas 14 * Multiplier)	CBP Median Rainfall Depth (RCP 4.5)	CBP Median Rainfall Depth (RCP 8.5)
1-Year	3.00	**3.60**	-	-
2-Year	3.65	**4.38**	3.95	4.06
5-Year	4.73	**5.68**	5.11	5.25
10-Year	5.64	**6.77**	6.14	6.26
25-Year	6.99	**8.39**	7.60	7.81
50-Year	8.16	**9.79**	8.94	9.11
100-Year	9.45	**11.34**	10.34	10.53

Notes:

1. All values are in inches.
2. All values are for the 24-hour duration event.
3. NOAA Atlas 14 rainfall values for Recommended Design Rainfall Depths are based on latitude 36.8201, longitude -76.0756, as incorporated in the city's Public Works Design Standards Manual, adopted June 2020.
4. CBP Median Rainfall Depths are not available for the 1-Year event.

Recommended Design Rainfall Depths - Williamsburg

Table D-31: Atlas 14 (Vol. 2) Precipitation Values for Williamsburg, Virginia

Design Storm	Minimum	Maximum	Mean	Median	90th Percentile	Centroid
1-Year	2.93	2.94	2.94	2.94	2.94	2.94
2-Year	3.57	3.58	3.57	3.58	3.58	3.58
5-Year	4.61	4.63	4.62	4.62	4.63	4.62
10-Year	5.50	5.52	5.51	5.51	5.52	5.51
25-Year	6.82	6.84	6.83	6.83	6.84	6.83
50-Year	7.95	7.99	7.97	7.97	7.98	7.97
100-Year	9.22	9.26	9.24	9.24	9.25	9.24

Table D-32: Recommended Design Rainfall Depths for Williamsburg, Virginia

Design Storm Frequency	NOAA Atlas 14 Rainfall (24-Hour Duration)	Design Rainfall (NOAA Atlas 14 * Multiplier)	CBP Median Rainfall Depth (RCP 4.5)	CBP Median Rainfall Depth (RCP 8.5)
1-Year	2.94	**3.38**	-	-
2-Year	3.58	**4.11**	3.72	3.79
5-Year	4.62	**5.32**	4.81	4.99
10-Year	5.51	**6.34**	5.68	5.90
25-Year	6.83	**7.85**	6.97	7.17
50-Year	7.97	**9.17**	7.97	8.37
100-Year	9.24	**10.62**	9.05	9.61

Notes:

1. All values are in inches.
2. All values are for the 24-hour duration event.
3. NOAA Atlas 14 rainfall values for Recommended Design Rainfall Depths are based on the centroid of the city (latitude 37.2692929, longitude -76.7067172).
4. CBP Median Rainfall Depths are not available for the 1-Year event.

Recommended Design Rainfall Depths – York County

Table D-33: Atlas 14 (Vol. 2) Precipitation Values for York County, Virginia

Design Storm	Minimum	Maximum	Mean	Median	90th Percentile	Centroid
1-Year	2.91	2.94	2.93	2.93	2.94	2.93
2-Year	3.54	3.58	3.56	3.57	3.57	3.57
5-Year	4.58	4.63	4.61	4.62	4.62	4.61
10-Year	5.46	5.53	5.51	5.51	5.52	5.51
25-Year	6.78	6.88	6.84	6.84	6.86	6.84
50-Year	7.92	8.06	8.00	8.00	8.03	8.00
100-Year	9.19	9.36	9.28	9.29	9.32	9.29

Table D-34: Recommended Design Rainfall Depths for York County, Virginia

Design Storm Frequency	NOAA Atlas 14 Rainfall (24-Hour Duration)	Design Rainfall (NOAA Atlas 14 * Multiplier)	CBP Median Rainfall Depth (RCP 4.5)	CBP Median Rainfall Depth (RCP 8.5)
1-Year	2.93	**3.37**	-	-
2-Year	3.57	**4.1**	3.81	3.89
5-Year	4.61	**5.31**	4.84	5.03
10-Year	5.51	**6.34**	5.73	6.01
25-Year	6.84	**7.87**	7.05	7.46
50-Year	8.00	**9.2**	8.24	8.64
100-Year	9.29	**10.68**	9.47	9.94

Notes:

1. All values are in inches.
2. All values are for the 24-hour duration event.
3. NOAA Atlas 14 rainfall values for Recommended Design Rainfall Depths are based on the centroid of the county (latitude 37.2209138, longitude -76.3955329).
4. CBP Median Rainfall Depths are not available for the 1-Year event.