Recommendations for Freeboard Standards for State-Owned Buildings in the Commonwealth of Virginia

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Version 1.5

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Executive Summary

This report responds to a joint request from The Secretary of Natural Resources and Special Assistant to the Governor for Coastal Adaptation and Protection to assist with meeting the Executive Order Number Twenty-Four (2018), *Increasing Virginia's Resilience to Sea Level Rise and Natural Hazards* directive set forth in Section 1 Part D requiring a freeboard standard for state-owned buildings. This report was prepared by an interdisciplinary team from Old Dominion University, supported by the Commonwealth Center for Recurrent Flooding Resiliency.

The research team combined best available sea level rise data, professional engineering standards and guidelines, GIS visualizations of Coastal Virginia in various flood scenarios, and a survey of other standards implemented on a local or statewide scale. This document also refers to the Virginia Institute of Marine Science recommendations for Sea Level Rise Projections: a Report for the Governor's Coastal Climate Resilience Plan of February 2019, submitted in support of Executive Order 24 Section 1 Part C, by the Center for Coastal Resources Management. The VIMS relative sea level rise projection for Coastal Virginia extends to 2050, and is based on tide gauge projections for the Sewell's Point Tide Gauge, as derived from the VIMS Sea Level Rise Report Card. (Boon et al. 2017.) Due to continued rising seas, and increasing uncertainty beyond 2050, VIMS recommends using NOAA curves for considering planning requirements for infrastructure beyond that point. Specifically, VIMS recommends that projects with lifespans beyond 30 years use NOAA climate scenarios for the target lifespan, and in addition they recommend incorporation of higher curves for flood intolerant infrastructure. ASCE Manual of Practice No. 140 *Climate-Resilient Infrastructure* guidelines recommend utilizing a 50-year mid-term outlook for the life of a project for climate change informed design. Thus, recommendations are based on the NOAA Intermediate-High curve, which would suggest approximately 4 ft of relative sea level rise in 50 years, by 2070.

With regard to the siting of new state-owned structures that begin design after January 1, 2020, this report recommends the following: Except in circumstances as determined by the Commonwealth of Virginia's Chief Resilience Officer - first, avoidance of siting buildings within areas likely to be inundated by sea level rise (SLR) or within areas where access or services will be significantly impacted by SLR during the design life of the building and second, not siting buildings within the Special Flood Hazard Area (Zone A or AE) or the Zone B or Zone X (shaded) as designated under the National Flood Insurance Program (100-year and 500-year floodplains).

With regard to freeboard for new state-owned structures that begin design after January 1, 2020, the report recommends that the Commonwealth lead the nation and adopt a Climate Informed Science Approach for establishing the elevation of buildings sited in Coastal Areas. In this report the Coastal Areas are defined as the Coastal Special Flood Hazard Area and the Combined Coastal/Riverine[1] Special Flood Hazard Area and their adjacent Zone X (shaded) (100- and 500-year floodplains). This strategy requires that the minimum elevation of the top of the lowest floor of a structure be above the maximum of the FEMA Base Flood Elevation plus anticipated SLR based on the Virginia's unified SLR projection at year 50 of anticipated service life, and an additional three feet of freeboard. Flood elevations shall be determined from the highest elevation from either the most recent FEMA Flood Insurance Rate Map (FIRM) or the most recent FEMA Flood Insurance Study (FIS) for the jurisdiction. For new state-owned buildings located outside of, but adjacent to the 500-year floodplain, best engineering practice would dictate analysis and consideration of the need to elevate the first floor to account for future sea level rise and freeboard to minimize future risk. At a minimum, adaptive design measures should be implemented so that future protection of the structure is possible. Importantly, the state must continue to review and revise these standards, at a minimum of every four years, as best available climate science and building codes evolve.

Coastal Area Building Elevation Requirements:

Minimum Elevation of the Top of the Lowest Floor = FBFE + Freeboard

Where:

FBFE = FEMA 100-year BFE + anticipated SLR at 50-year service life
Anticipated SLR is based on the NOAA 2017 Intermediate-High Scenario
Freeboard = 3 feet for all projects.
For Coastal High Hazard and Coastal Zone A above requirements apply to the Bottom of the Lowest Supporting Horizontal Structural Member of Lowest Floor.

With regard to freeboard for new state-owned buildings that begin design after January 1, 2020, in the riverine area, the report recommends that the current Commonwealth standards are modified to a freeboard of three feet, to ensure FEMA compliance. The standard is provided below:

Riverine Area Building Elevation Requirements:

Minimum Elevation of the Top of the Lowest Floor = BFE + Freeboard

Where:

BFE = FEMA 100-year BFE
Freeboard = 3 feet for all projects.

[1] FEMA. (2015). Guidance for Flood Risk Analysis and Mapping, Combined Coastal and Riverine Floodplain. Retrieved from https://www.fema.gov/media-library-data/1436989628107-db27783b8a61ebb105ee32064ef16d39/Coastal_Riverine_Guidance_May_2015.pdf

Implementation of these recommendations will allow the Commonwealth to lead amongst states also at risk to coastal flooding and to lead by example within the Commonwealth.

Introduction

The Commonwealth of Virginia issued Executive Order Number Twenty-Four (2018), *Increasing Virginia's Resilience to Sea Level Rise and Natural Hazards*, on November 2, 2018. The order recognizes that climate change impacts have and continue to increase risk from natural hazards across the Commonwealth, and sets forth a plan to protect Virginia's assets and empower communities and residents of the Commonwealth to build resilience. Citing best available science, the Executive Order states that Coastal Virginia has the highest rate of sea level rise (SLR) on the East Coast, and is threatened by extreme weather events and natural hazards which will impact public health and safety, the environment, and the economy and that fiscally responsible planning is necessary to reduce exposure[2].

In order to increase statewide resilience to natural hazards and extreme weather Section 1, Part D of the directive requires a freeboard standard for state-owned buildings be established to ensure their resilience. It is our interpretation of EO 24 that these requirements apply only to state-owned buildings that begin design after January 1, 2020.

Executive Memorandum (EM) 2-97 (July 1, 1997) signed by former Governor George Allen and still in effect, provided floodplain management policies and requirements for the Commonwealth and assigned responsibility for leadership and coordination to the Department of Conservation and Recreation under the Secretary of Natural Resources. EM 2-97 aimed to ensure Commonwealth compliance with the National Flood Insurance Program and other related federal programs, and implemented a policy that prohibited the construction of "new state-owned buildings … within a 100-year floodplain" without a variance granted by the Director, Division of Engineering and Buildings.

This report provides recommendations for a statewide freeboard standard based on current standards and manuals of practice published by the American Society of Civil Engineers (ASCE) including ASCE Standard [ASCE/SEI 24-14], Flood Resistant Design and Construction, and the ASCE Manuals and Reports on Engineering Practice No. 140, *Climate-Resilient Infrastructure: Adaptive Design and Risk Management*.

The Commonwealth Center for Recurrent Flooding Resiliency (CCRFR), established by Virginia Chapter 440 of the 2016 Acts of Assembly (HB 903), is a partnership between Old Dominion University, the Virginia Institute of Marine Science and William & Mary Law Schools' Virginia Coastal Policy Center. CCRFR is charged with providing research services to the Commonwealth in furtherance of building flooding resilience. As such, researchers at Old Dominion University provide this report at the request of the Special Assistant to the Governor for Coastal Adaptation and Protection, Ann C. Phillips, and the Secretary of Natural Resources and Chief Resilience Officer, Matthew J. Strickler.

Sea Level Rise Projections for Coastal Virginia

The National Oceanic and Atmospheric Agency (NOAA), United States Army Corps of Engineers (USACE) and Virginia Institute of Marine Science (VIMS) have each developed and continually update SLR scenarios reflecting rates of relative sea level rise in Hampton Roads Virginia. Figure 1 below, available

[2] Commonwealth of Virginia, Office of Governor. (2018). Executive Order Number Twenty-Four, Increasing Virginia's Resilience to Sea Level Rise and Natural Hazards. Retrieved from: https://www.governor.virginia.gov/media/governorvirginiagov/executive-actions/ED-24-Increasing-Virginias-Resilience-To-Sea-Level-Rise-And-Natural-Hazards.pdf

on the AdaptVA website shows the relationships between these different curves for Norfolk, VA based on the Sewell's Point tide gauge[3]:

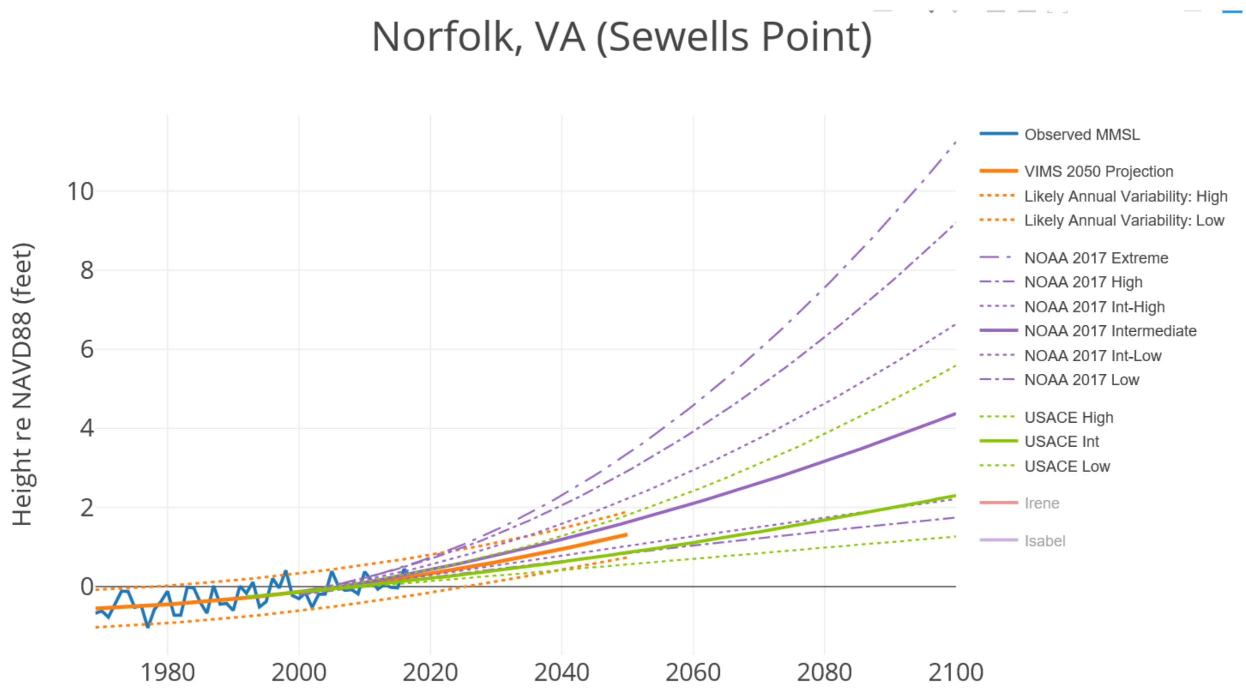

Figure 1. Comparison of Sea Level Rise Scenario Projections for Sewell's Point developed by NOAA, USACE and VIMS

The VIMS projection (shown in orange) is based on analysis of the water observations over the past 40 years and only extends to 2050. Considering that new construction building life would extend beyond the VIMS preferred projection, it is necessary to consider NOAA climate scenarios. Additionally, VIMS recommend that while the "NOAA 2017 Intermediate curve is a potential target for infrastructure that can tolerate moderate flooding, flooding intolerant infrastructure should incorporate higher curves."[4] Buildings are not typically designed to be flooded and based on this guidance from VIMS the NOAA 2017 Intermediate-High curve is recommended for use in developing freeboard standards for state-owned buildings. Using the NOAA 2017 Intermediate or Intermediate-Low scenario curves would represent a higher tolerance to risk and using the High or Extreme scenario curves would represent a lower tolerance to risk.

As part of the Commonwealth's Executive Order Twenty-Four, a regional or statewide SLR projection will be developed concurrently with the freeboard recommendations that will provide a standard approach for predicting SLR when scoping, designing, siting and constructing state-owned buildings. Selection of SLR scenarios to use in planning should consider tolerance to risk, however, the Commonwealth could

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[3] AdaptVa. (2018) Virginia Sea Level, Evidence-based planning for changing climate. Retrieved from: http://adaptva.org/info/virginia_sea_level.html

[4] Center for Coastal Resource Management. (2019). *Recommendations For Sea Level Rise Projections.* Virginia Institute of Marine Science.

choose, based upon VIMS recommendations or emerging data, to use another SLR scenario and still implement the process for determining freeboard presented in this report. For the purpose of this report, the NOAA Intermediate-High scenario curve is used, which represents a moderate tolerance to risk. Figure 2 below provides a table summarizing the NOAA and VIMS scenarios:

Year	NOAA 2017 (Feet)						VIMS 2017
	Low	Int-Low	Int	Int-High	High	Extreme	Gauge-based
2000	-0.17	-0.17	-0.17	-0.17	-0.17	-0.17	-0.14
2010	0.03	0.06	0.13	0.19	0.29	0.29	0.07
2020	0.26	0.33	0.46	0.62	0.75	0.82	0.33
2030	0.42	0.56	0.82	1.08	1.34	1.47	0.62
2040	0.65	0.82	1.21	1.61	2.06	2.29	0.95
2050	0.85	1.05	1.64	2.23	2.95	3.34	1.32
2060	1.08	1.31	2.13	2.95	3.97	4.62	
2070	1.28	1.54	2.62	3.74	5.05	6.03	
2080	1.47	1.77	3.21	4.66	6.3	7.58	
2090	1.61	2	3.77	5.61	7.67	9.28	
2100	1.74	2.23	4.39	6.69	9.28	11.32	

Gauge/Grid Selected: SEWELLS POINT

NOAA2017 VLM: 0.00810 feet/yr
Adjustment to MSL(83-01) Datum: 0.093 feet applied
Adjustment to NAVD88 Datum: -0.26 feet applied
All values expressed in feet

Figure 2. Table of NOAA and VIMS Coastal Virginia Sea Level Rise Scenarios for Sewell's Point using NAVD88 values.[5]

Building design life is a key factor to consider in understanding SLR impacts to the structure and effective use of the structure over the life of a structure. While there is little information on building design lives in the literature, the ASCE Manual of Practice No. 140, *Climate-Resilient Infrastructure: Adaptive Design and Risk Management*, recommends that a *mid-term outlook* for the life of a project, approximately 50 years, be used for climate change informed design. The reasoning is that there is great uncertainty in the SLR curves past this time frame and relying on projections to 100 years "may prove overly conservative or insufficient,"[6] and thus building for such an extended timeline now may result in ineffective use of resources. It is important that adaptive design strategies be incorporated

[5] US Army Corps of Engineers, Sea-Level Change Curve Calculator, (Version 2019.21). Retrieved from: http://corpsmapu.usace.army.mil/rccinfo/slc/slcc_calc.html

[6] American Society of Civil Engineers, Committee on Adaptation to Climate Change. (2018). *Climate-Resilient Infrastructure: Adaptive Design and Risk Management*. American Society of Civil Engineers.

into the building design so that future capital improvements to the structure can be made, accounting for changed conditions over the remaining life of the structure, past 50 years. Further, this point reiterates the need to continually review the SLR scenarios in use, based on best available science.

As stated in Commonwealth Executive Order Twenty-Four (2018) additional freeboard requirements for state-owned buildings will be implemented in 2020, which means that the mid-term outlook for the life of a new state-owned building extends to 2070. Based on the table above, using the NOAA Intermediate-High scenario, new construction guidelines should consider sea level rise of 3.74 feet, which is rounded to 4.0 feet for this recommendation. This value lies between the mid-term (2050-2080) recommendation of 3.0 feet of relative sea level rise above MHHW and the long-term recommendation of 4.5 feet of relative sea level rise above MHHW for long-term (2080-2100) planning and engineering decisions[7] adopted by the Hampton Roads Planning District Commission (HRPDC) as part of their Resolution 2018-01, *Resolution of the Hampton Roads Planning District Commission Encouraging Local Governments in Hampton Roads to Consider Adopting Policies to Incorporate Sea Level Rise into Planning and Engineering Decisions*.

While this report recommends a minimum elevation of the top of the lowest floor calculation that includes freeboard based on a 50-year building life, it is important to consider future conditions in siting and design as well. SLR scenario curves often show the projection of SLR to 2100. As the Commonwealth sets standards related to SLR, it is important to acknowledge that all scientific data indicates that SLR will continue to increase past 2100. Based on the Sewell's Point tide gauge, figure 3 below provides the relative SLR projections from the Sea-Level Change Curve Calculator (Version 2017.55)[8] for Norfolk VA, that extend to 2200.

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[7] Hampton Roads Planning District Commission. (2018). Resolution of the Hampton Roads Planning District Commission Encouraging Local Governments in Hampton Roads to Consider Adopting Policies to Incorporate Sea Level Rise into Planning and Engineering Decisions. Retrieved from: https://www.hrpdcva.gov/uploads/docs/HRPDC%20Resolution_Sea%20Level%20Rise%202018-01.pdf

[8] US Army Corps of Engineers. (2017) Sea-Level Change Curve Additionally, as more scientific studies are completed findings suggest that we are underestimating the impacts of climate change on our environment, sea levels rise is accelerating[8], and future temperatures may be higher than projected[8]Calculator. Retrieved from: http://corpsmapu.usace.army.mil/rccinfo/slc/slcc_calc.html.

Gauge/Grid Selected: SEWELLS POINT
NOAA2017 VLM: 0.00810 feet/yr
Adjustment to MSL (83-01) Datum: 0.093 feet applied
Adjustment to NAVD88 Datum: -0.26 feet applied
All values expressed in feet

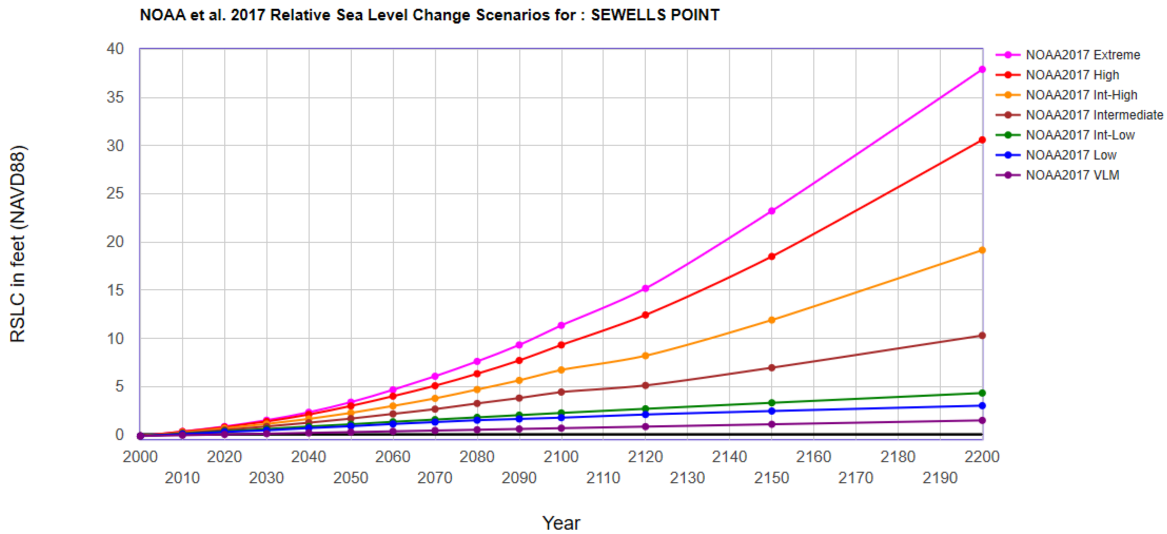

Figure 3. Relative SLR Change Scenarios for Sewell's Point, VA.[3]

Additionally, as more data is collected and scientific studies are completed, findings suggest that the impacts of climate change on our environment are underestimated; SLR is accelerating[9], more frequent and intense rainfall will contribute to flooding impacts[10], and future temperatures may be higher than projected[11]. It is not a matter of *if* SLR will rise 4.0 feet, it is a matter of *when*, and based on current NOAA SLR scenarios, 4.0 feet of SLR may occur as early as 2055 (Extreme scenario) or after 2200 (Low scenario). It is this uncertainty of timing of impacts that supports the adaptive design approach.

In summary, the VIMS projections extend only to 2050, which is 20 years short of the 50-year mid-term building life recommended by the ASCE. The VIMS Center for Coastal Resource Management states that "The Intermediate curve is potential target for infrastructure than can tolerate moderate flooding; flood intolerant infrastructure should incorporate higher curves" in their report titled *Recommendations for Sea Level Rise Projection*s, dated February 2019.[12] Buildings are not typically designed to tolerate moderate flooding and ASCE 24-14 requires that buildings that will be flooded meet additional design requirements. Thus, it is recommended that the NOAA Intermediate-High

[9] NASA, Global Climate Change. (2018) New study finds sea level rise accelerating. Retrieved from: https://climate.nasa.gov/news/2680/new-study-finds-sea-level-rise-accelerating/
[10] City of Virginia Beach, Virginia. (2018). Analysis of Historical and Future Heavy Precipitation. Retrieved from: https://www.vbgov.com/government/departments/public-works/comp-sea-level-rise/Documents/anaylsis-hist-and-future-hvy-precip-4-2-18.pdf
[11] Brown, P.T., and Caldeira, K. (2017). Nature. Greater future global warming inferred from Earth's recent energy budget. Retrieved from: https://www.nature.com/articles/nature24672
[12] Center for Coastal Resources Management. (2019) *Recommendations for Sea Level Rise Projections.* Virginia Institute of Marine Science.

curve be adopted. This would result in 3.74 feet increase in relative sea level along Virginia's coasts by 2070. Further, the recommended methodology for determining the minimum elevation of the top of the lowest floor, that includes appropriate freeboard, for state-owned buildings presented here can be utilized with any chosen SLR scenario, and it is strongly recommended that the Commonwealth adjust SLR scenarios with best available scientific data on a regular basis, specifically every four years.

GIS Analysis of 100- & 500-year Floodplains based on SLR Projections for the Hampton Roads Planning District

Geographic Information Systems (GIS) analyses were performed to discern the first order impact of rising sea level on high risk Special Flood Hazard Areas (SFHA) and areas at moderate risk of flooding. High risk areas are those which comprise the 100-year floodplain (1% annual chance of flooding) and include the following SFHAs: Zone A, Zone AO, Zone AH, Zones A1-A30, Zone AE, Zone A99, Zone AR, Zone AR/AE, Zone AR/AO, Zone AR/A1-A30, Zone AR/A, Zone V, Zone VE, and Zones V1-V30. Moderate risk areas are those falling between the limits of the 100- and 500-year flood (0.2% annual chance of flooding) which include B and X (shaded) zones.[13]

The examined geographic region includes the 17 member cities and counties of the Hampton Roads Planning District, which are as follows: Chesapeake, Franklin, Gloucester County, Hampton, Isle of Wight County, James City County, Newport News, Norfolk, Poquoson, Portsmouth, Smithfield, Southampton County, Suffolk, Surry County, Virginia Beach, Williamsburg, and York County. The Hampton Roads region (Fig. 4) includes both rural and urban areas, providing a testbed with diverse topography, land use, and population density. The methods employed for this study are easily extensible to other coastal regions within the Commonwealth and beyond.

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[13] FEMA. (2018, 09/14/2018). "Flood Zones." Retrieved 1/25/2019, from https://www.fema.gov/flood-zones.

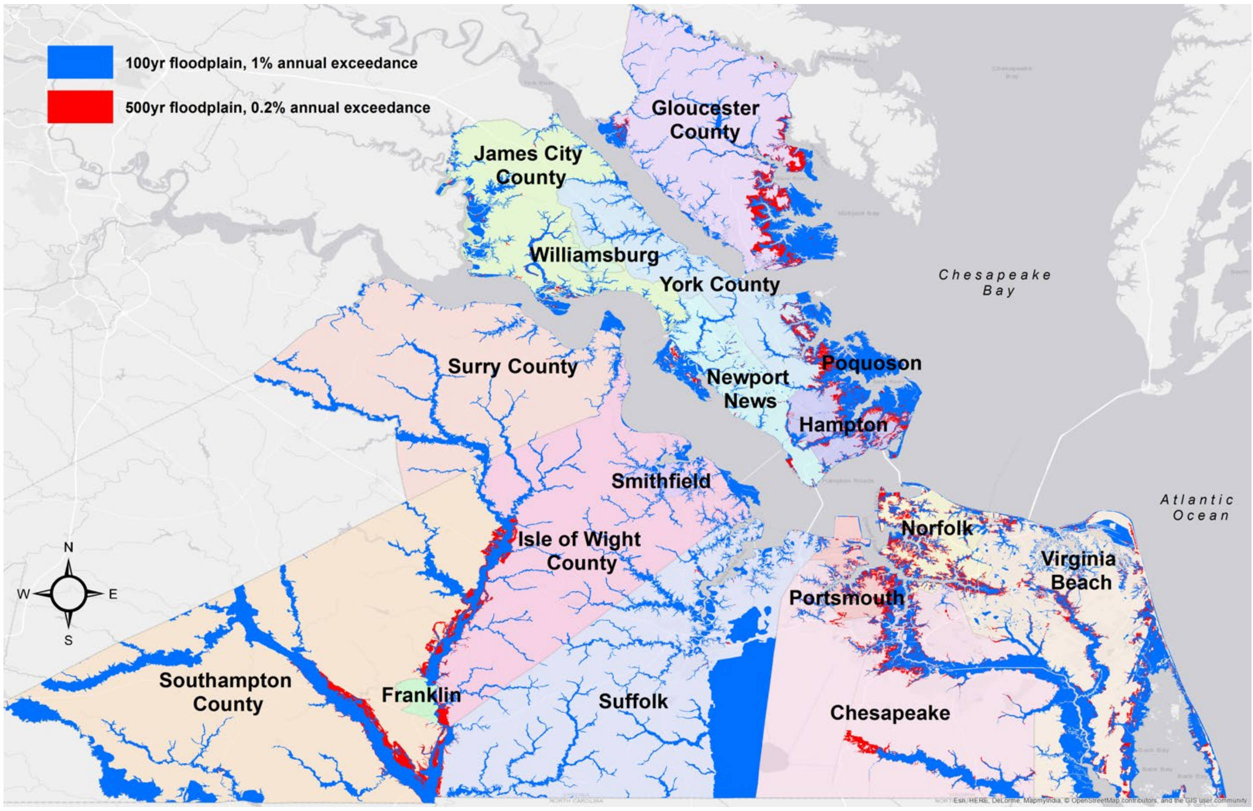

Figure 4. Study area: 17 cities and counties of the Hampton Roads Planning District.

Flood zone GIS data were acquired through the Virginia Flood Risk Information System (VFRIS).[14] These data were aggregated into region-wide 100- and 500-year floodplain layers.

Total areas of 100-year (high risk, 1% annual exceedance probability) and 500-year (moderate risk, 0.2% annual exceedance probability) flood zones were calculated for the entire study region and separately for each municipality. Appendix 1 provides a table detailing the area (mi^2) and % of inundation of the 100 year and 500-year flood zones for each municipality.

Spatial modeling of future SLR of 3.0 feet above Mean Higher High Water (MHHW) was performed in order to delineate which portions of the present day 100- and 500-year floodplains will be permanently inundated at these levels. All land elevation and inundation data were referenced against the MHHW datum, which is the average of the higher high water height of each tidal day observed over the 19-year National Tidal Datum Epoch.[15] Use of the MHHW datum ensures that areas of predicted inundation occur over non-tidal areas which are normally not flooded.

The modeled 3.0 feet SLR inundation layer was overlain atop the SFHA risk layers, allowing for the calculation of the area and percentage of inundation of the 100- and 500-year floodplains. Figure 5 shows this overlay for both a rural (Gloucester) and an urban (Norfolk) area.

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[14] DCR. (2019, 06/28/2018). "Virginia Flood Risk Information System." from http://www.dcr.virginia.gov/dam-safety-and-floodplains/fpvfris.

[15] NOAA. (2018, 08/08/2018). "Tidal Datums." Retrieved 01/25/2019, from https://tidesandcurrents.noaa.gov/datum_options.html.

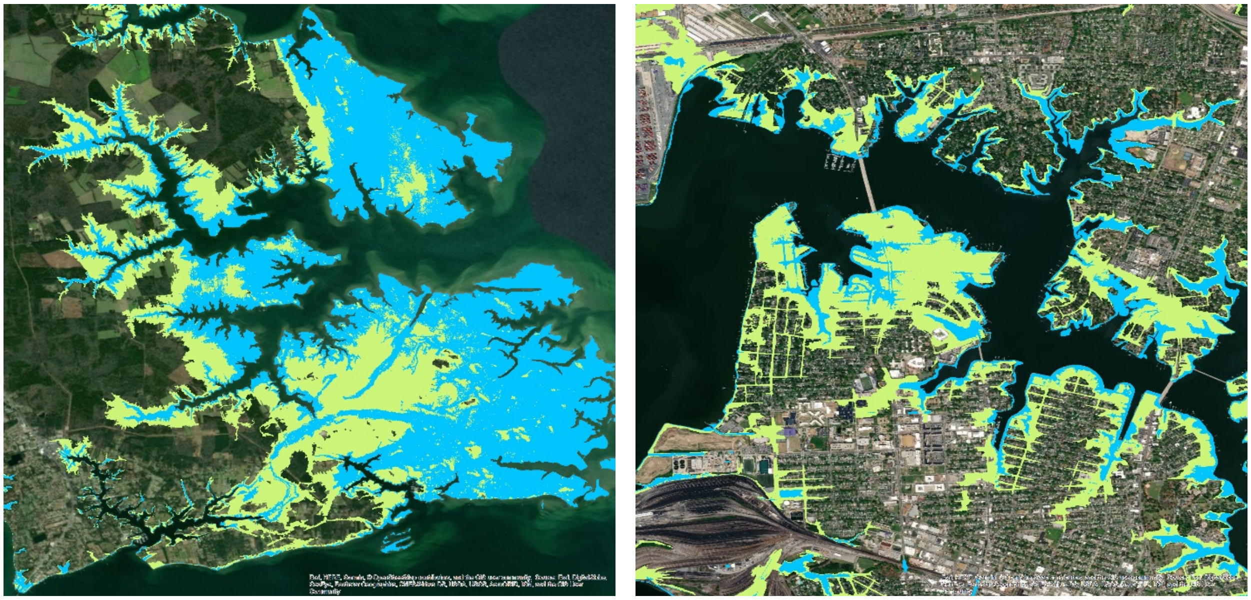

Figure 5. Overlay of 3’ of sea level inundation (blue) atop SHFA high risk zones (green) for portions of Gloucester (left at 1:50k scale) and Norfolk (right at 1:20k scale).

As shown in figure 6, approximately 38% of the total area of the current 100-year floodplain will be permanently inundated by +3 feet SLR. It should be noted that inundation percentages are not uniform and vary significantly by municipality, ranging from 10% to 89.3%. These differences are the result of wide variance of topography and SFHA zones between municipalities and should be the subject of further examination.

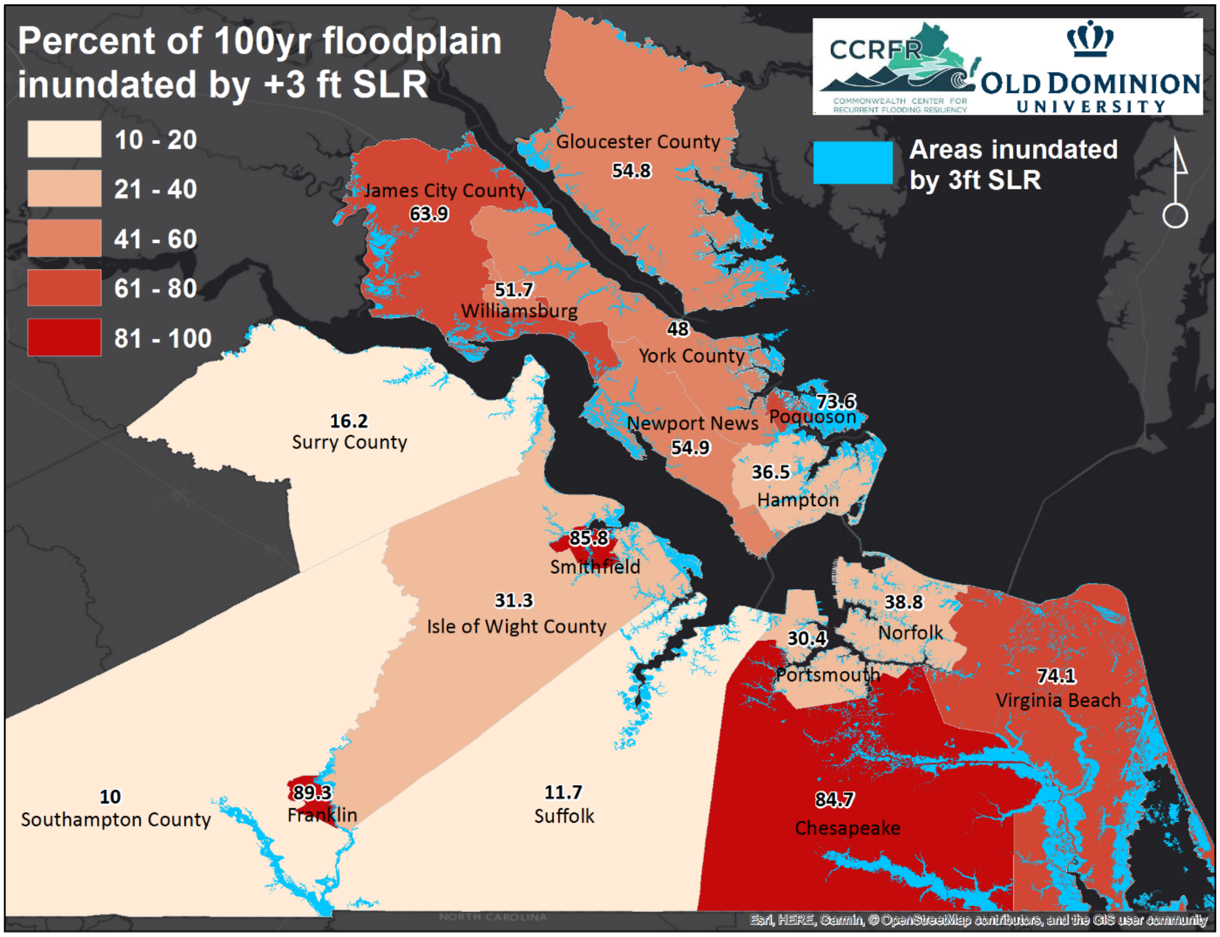

Figure 6. Map shows percentage of 100-year floodplain (by municipality) which will be inundated by 3.0 feet SLR. Approximately 189 square miles, 38%, of the entire 100-year floodplain in the Hampton Roads Region will be perpetually flooded.

Figure 7 illustrates that approximately 5% of the total area of the current 500-year floodplain will be permanently inundated by +3ft SLR. As is the case with the 100-year floodplain, the impacts of SLR are not uniform regarding the 500-year floodplain. Most Hampton Roads municipalities show little or no inundation, while the moderate hazard zones of Virginia Beach (18.7%) and Chesapeake (13.6%) experience non-trivial areas of inundation.

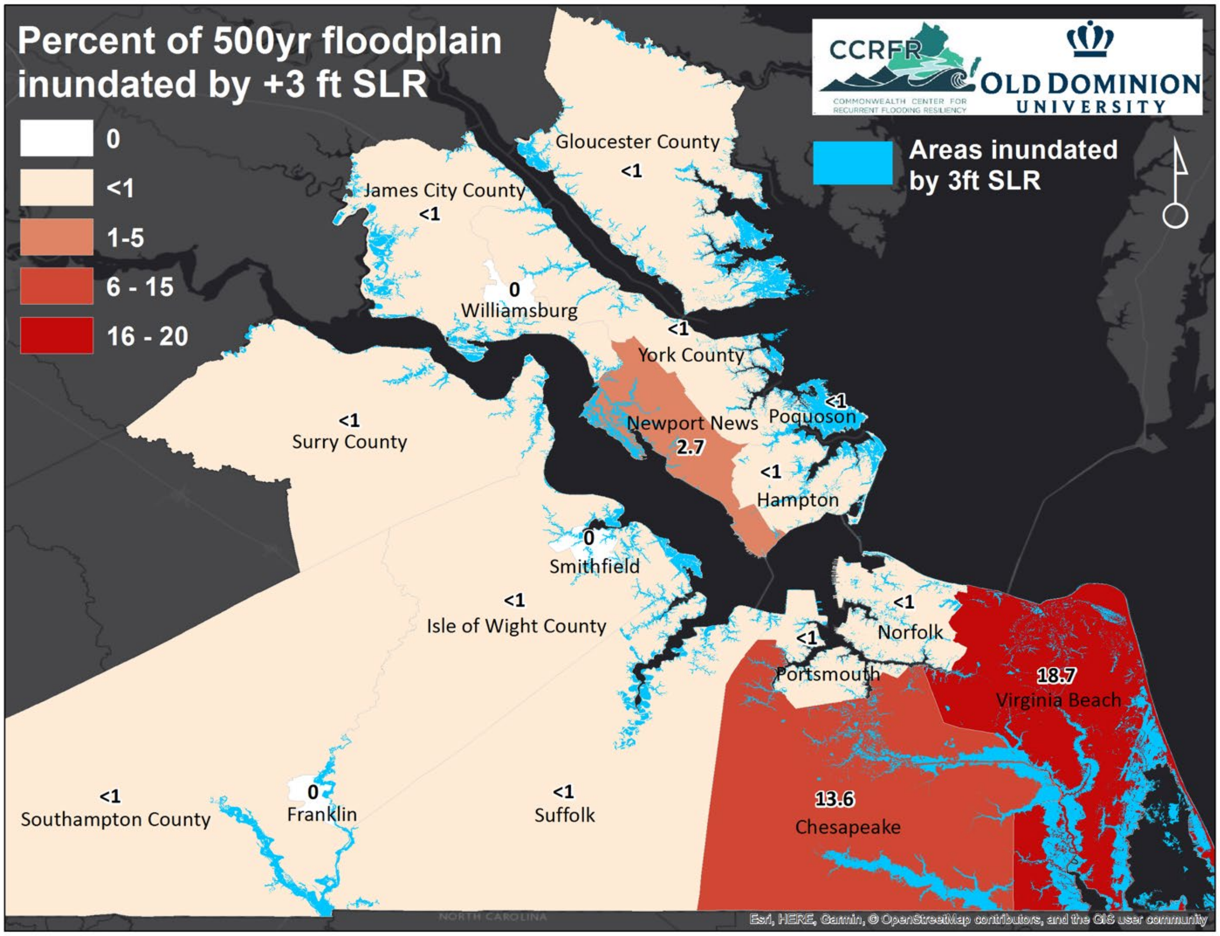

Figure 7. Percentage of 500-year floodplain which will be permanently inundated by 3.0 feet SLR.

It is recommended that this work be extended, and additional analysis performed to quantify the regional impacts of SLR in smaller geographic areas considering *parcel level* data. Areas of potential critical impact should be identified for high-resolution, focused analyses of the physical and economic impacts of SLR.

Building Codes

This report recommends aligning requirements for Commonwealth-owned buildings with standard best engineering practice and allowing for adaptation as additional information and data on SLR and flooding becomes available. Below is an explanation of standards and guidelines from ASCE, a review of freeboard requirements adopted in other states at similar risk and in communities in the Commonwealth, as well as recommendations for application to Section 1 Part D of Executive Order Twenty-Four with regards to new construction that begins design after January 1, 2020.

ASCE Standard, [ASCE/SEI 24-14], Flood Resistant Design and Construction[16]

ASCE Standards provide technical standards for engineering professionals worldwide, undergo rigorous review and regular updates, and are a basis for model building codes. ASCE Standard 24-14, revised in 2015, provides minimum requirements for flood resistant design and construction of structures that are subject to building code requirements and that are located, in whole or in part, in Flood Hazard Areas. Further, ASCE Standard 24-14 meets or exceeds FEMAs requirements for buildings or structures. The standard applies to: (1) new construction, including subsequent work to such structures, and (2) work classified as substantial improvement of an existing structure that is not a historic structure.

The standard establishes a Flood Design Class for buildings and structures. Buildings are assigned a flood design class 1 through 4. The flood design class is similar although not equivalent to the occupancy category or risk category (I-IV) assigned to buildings according to the ASCE 7 standard or building code. Description of the Flood design class is shown in figure 8 below (taken from ASCE 24-14 Table 1-1).

Table 1-1 Flood Design Class of Buildings and Structures

Use or Occupancy of Buildings and Structures	Flood Design Class
Buildings and structures that normally are unoccupied and pose minimal risk to the public or minimal disruption to the community should they be damaged or fail due to flooding. Flood Design Class 1 includes (1) temporary structures that are in place for less than 180 days, (2) accessory storage buildings and minor storage facilities (does not include commercial storage facilities), (3) small structures used for parking of vehicles, and (4) certain agricultural structures.[a]	1
Buildings and structures that pose a moderate risk to the public or moderate disruption to the community should they be damaged or fail due to flooding, except those listed as Flood Design Classes 1, 3, and 4. Flood Design Class 2 includes the vast majority of buildings and structures that are not specifically assigned another Flood Design Class, including most residential, commercial, and industrial buildings.	2
Buildings and structures that pose a high risk to the public or significant disruption to the community should they be damaged, be unable to perform their intended functions after flooding, or fail due to flooding. Flood Design Class 3 includes (1) buildings and structures in which a large number of persons may assemble in one place, such as theaters, lecture halls, concert halls, and religious institutions with large areas used for worship; (2) museums; (3) community centers and other recreational facilities; (4) athletic facilities with seating for spectators; (5) elementary schools, secondary schools, and buildings with college or adult education classrooms; (6) jails, correctional facilities, and detention facilities; (7) healthcare facilities not having surgery or emergency treatment capabilities; (8) care facilities where residents have limited mobility or ability, including nursing homes but not including care facilities for five or fewer persons; (9) preschool and child care facilities not located in one- and two-family dwellings; (10) buildings and structures associated with power generating stations, water and sewage treatment plants, telecommunication facilities, and other utilities which, if their operations were interrupted by a flood, would cause significant disruption in day-to-day life or significant economic losses in a community; and (11) buildings and other structures not included in Flood Design Class 4 (including but not limited to facilities that manufacture, process, handle, store, use, or dispose of such substances as hazardous fuels, hazardous chemicals, hazardous waste, or explosives) containing toxic or explosive substances where the quantity of the material exceeds a threshold quantity established by the authority having jurisdiction and is sufficient to pose a threat to the public if released.[b]	3
Buildings and structures that contain essential facilities and services necessary for emergency response and recovery, or that pose a substantial risk to the community at large in the event of failure, disruption of function, or damage by flooding. Flood Design Class 4 includes (1) hospitals and health care facilities having surgery or emergency treatment facilities; (2) fire, rescue, ambulance, and police stations and emergency vehicle garages; (3) designated emergency shelters; (4) designated emergency preparedness, communication, and operation centers and other facilities required for emergency response; (5) power generating stations and other public utility facilities required in emergencies; (6) critical aviation facilities such as control towers, air traffic control centers, and hangars for aircraft used in emergency response; (7) ancillary structures such as communication towers, electrical substations, fuel or water storage tanks, or other structures necessary to allow continued functioning of a Flood Design Class 4 facility during and after an emergency; and (8) buildings and other structures (including, but not limited to, facilities that manufacture, process, handle, store, use, or dispose of such substances as hazardous fuels, hazardous chemicals, or hazardous waste) containing sufficient quantities of highly toxic substances where the quantity of the material exceeds a threshold quantity established by the authority having jurisdiction and is sufficient to pose a threat to the public if released.[b]	4

[a] Certain agricultural structures may be exempt from some of the provisions of this standard; see Section C1.4.3.
[b] Buildings and other structures containing toxic, highly toxic, or explosive substances shall be eligible for assignment to a lower Flood Design Class if it can be demonstrated to the satisfaction of the authority having jurisdiction by a hazard assessment as described in Section 1.5.3 of *Minimum Design Loads for Buildings and Other Structures* that a release of the substances is commensurate with the risk associated with that Flood Design Class.

Figure 8. Flood Design Class of Buildings and Structures, ASCE 24-24, Table 1-1

Flood Zones are defined according to the FEMA Flood Insurance Rate Maps (FIRM). Using the definitions provided in ASCE 24-14:

Coastal High Hazard Area (CHHA)—Area within a *special flood hazard area* extending from offshore to the inland limit of a primary frontal dune along an open coast and any other area

[16] American Society of Civil Engineers. (2015). Flood Resistant Design and Construction. American Society of Civil Engineers.

that is subject to *high velocity wave action* from storms or seismic sources. This area is designated on *FIRM*s as velocity zones V, VO, VE, or V1-30.

Coastal A Zone (CAZ)—Area within a *special flood hazard area*, landward of a *V Zone* or landward of an open coast without mapped *V Zones*. In a Coastal A Zone, the principal source of flooding must be astronomical tides, storm surges, seiches, or tsunamis, not riverine flooding. During the *base flood* conditions, the potential for breaking *wave heights* shall be greater than or equal to 1.5 ft. The inland limit of the Coastal A Zone is (1) the *Limit of Moderate Wave Action* if delineated on a *FIRM*, or (2) designated by the *authority having jurisdiction*.

Within the standard, separate provisions are provided for each flood zone. Within ASCE 24-14, Chapter 4 contains provisions for Coastal High Hazard Zones and Coastal A Zones; Chapter 2 contains provisions for flood hazard zones that are not classified as a Coastal High Hazard Zone or a Coastal A Zone. Additionally, Chapter 3 contains provisions for special High Risk Flood Hazard areas subject to one or more of the following hazards: alluvial fan flooding, flash floods, mudslides, erosion, high-velocity flows, high-velocity wave action, breaking wave heights greater than or equal to 1.5 feet (Coastal High Hazard Area and Coastal A Zone) and damage-causing ice or debris. Areas classified according to Chapter 3 must also satisfy requirements of Chapter 2.

Siting and Elevation Requirements

Separate siting and elevation requirements are established in ASCE 24-14 for Coastal High Hazard and Coastal A zones versus zones that do not fall within those zones. Elevations are specified relative to the Base Flood Elevation (BFE) or the Design Flood Elevation (DFE). The Base Flood Elevation is the elevation of flooding including wave height that has 1% annual probability of exceedance. Similarly, the Design Flood Elevation is elevation of the *design flood*, including *wave height*, relative to the *datum* specified on the community's *flood hazard map*. The design flood is the flood associated with the greater of the following two areas: (1) area within a *floodplain* subject to a 1% or greater chance of flooding in any year, i.e., the BFE, or (2) area designated as a *flood hazard area* on a *community's flood hazard map* or otherwise legally designated. FEMA maps are based on the BFE, so if a locality has adopted the FIRM, the DFE will correspond to the BFE. However, communities may elect to adopt Design Flood Elevations that are higher than those provided by FEMA.

Zones Not Classified as Coastal High Hazard or Coastal A

New construction and substantial improvements are required to set the elevation of the top of the lowest floor (including basements) above a minimum level depending on the Flood Design Class. The elevations are shown in figure 9 (Table 2-1 from ASCE 24-14).

Table 2-1 Minimum Elevation of the Top of Lowest Floor—Flood Hazard Areas Other Than Coastal High Hazard Areas,[a] Coastal A Zones,[a] and High Risk Flood Hazard Areas[a]

Flood Design Class[b]	Minimum Elevation, Relative to Base Flood Elevation (BFE) or Design Flood Elevation (DFE)
1[c]	DFE
2[d]	BFE + 1 ft or DFE, whichever is higher
3[d]	BFE + 1 ft or DFE, whichever is higher
4[d]	BFE + 2 ft or DFE, or 500-year flood elevation, whichever is higher

[a] Minimum elevations shown in Table 2-1 do not apply to Coastal High Hazard Areas and Coastal A Zones (see Table 4-1). Minimum elevations shown in Table 2-1 apply to other high risk flood hazard areas unless specific elevation requirements are given in Chapter 3 of this standard.
[b] See Table 1-1 for Flood Design Class descriptions.
[c] Flood Design Class 1 structures shall be allowed below the minimum elevation if the structure meets the wet floodproofing requirements of Section 6.3.
[d] For nonresidential buildings and nonresidential portions of mixed-use buildings, the lowest floor shall be allowed below the minimum elevation if the structure meets the dry floodproofing requirements of Section 6.2.

Figure 9. Minimum Elevation of the Top of Lowest Floor – Flood Hazard Areas Other Than Coastal High Hazard Areas, Coastal A Zones and High-Risk Flood Hazard Areas, (ASCE 24-14, Table 2-1).

Zones Classified as Coastal High Hazard or Coastal A

For new construction and substantial improvements in Coastal High Hazard and Coastal A zones, the minimum elevation is specified in figure 10 (Table 4.1 from ASCE 24-14). Whereas for areas not classified as Coastal High Hazard or Coastal A, the elevation limit was at the top of floor elevation, for areas classified as Coastal High Hazard or Coastal A, the minimum elevation specified is to the bottom of the lowest horizontal structural member. Foundation elements (piles, pile caps, spread footings, grade beams, mat foundations) provided that they are designed to handle the loads imposed by flooding in accordance with section 4.5 Foundation Requirements of ASCE 24-14 are not required to meet the minimum elevation.

Table 4-1 Minimum Elevation of Bottom of Lowest Supporting Horizontal Structural Member of Lowest Floor—Coastal High Hazard Areas and Coastal A Zones

Flood Design Class[a]	Minimum Elevation, Relative to Base Flood Elevation (BFE) or Design Flood Elevation (DFE)
1	DFE
2	BFE + 1 ft or DFE, whichever is higher
3	BFE + 2 ft or DFE, whichever is higher
4	BFE + 2 ft or DFE, or 500-year flood elevation, whichever is higher

[a] See Table 1-1 for Flood Design Class descriptions.

Figure 10. Minimum Elevation of Bottom of Lowest Supporting Horizontal Structural Member of Lowest Floor – Coastal High Hazard Areas and Coastal A Zones (ASCE 24-14, Table 4-1).

Coastal High Hazard and Coastal A zones must also satisfy the following siting requirements

1. New construction, not including substantial improvements, shall be located landward of the reach of mean high tide;
2. New construction and substantial improvements shall be sited landward of shoreline construction setbacks, where applicable; and
3. New construction and substantial improvements shall not remove or otherwise alter sand dunes and mangrove stands, unless an engineering report documents that the alterations will not increase potential flood damage by reducing the wave and flow dissipation characteristics of the sand dunes or mangrove stands.

Per ASCE 24-14, buildings are assigned to a Flood Design Class 1-4.

ASCE *Climate-Resilient Infrastructure: Adaptive Design and Risk Management*[3]

Climate-Resilient Infrastructure is an ASCE Manuals and Reports on Engineering Practice No. 140. While not a Standard, a Manual of Practice consists of an orderly presentation of facts on a particular subject as it would apply to an engineer engaged in day to day work on the subject. Manuals of Practice often serve to inform future developments and updates to Standards.

Manual of Practice #140 includes background information as well as perspective on FIRM Mapping as it relates to engineering design. It also incorporates and reiterates important FEMA definitions, including SWEL - the still water elevation level. The Base Flood Elevation (BFE) is the still water elevation level plus the greater of 1) the maximum wave crest elevation or 2) the maximum vertical extent of wave runup. According to FEMA FIRM mapping, the base flood elevation is given by the extents of the Coastal A and Coastal High Hazard Zones which correspond to the 1% annual exceedance probability (100-year storm). It should be noted that the 0.2% annual exceedance probability (500-year flood which corresponds to the FIRM Zone X) does not include additional flooding resulting from wave crest elevations or wave runup. The recommended best practice is that engineering design decisions be made with the Base Flood Elevation as the basis.

The Design Flood Elevation, DFE, is defined as the Base Flood Elevation in addition to some freeboard. The freeboard can be considered a factor of safety to account for modelling and mapping uncertainties or the many uncertainties that could affect flood heights. *Freeboard is not intended to account for future SLR.* As previously discussed, according to ASCE 24, the recommended freeboard varies according to the risk category of the asset and the flood hazard zone within which the asset is sited. The values of freeboard in ASCE-24 vary from one to three feet.

Climate-Resilient Infrastructure references Presidential Executive Order 13690 which was signed in 2015 and established a federal flood risk management standard (FFRMS). The executive order has since been rescinded, but it established a useful framework for flood protection initially intended for federal buildings and infrastructure. It provides recommendations similar to ASCE 24, however it incorporates recommendations for accommodating SLR. The executive order proposed three methodologies for selecting an elevation for flood protection.

1. Climate Informed Science Approach (CISA) – Use the best available hydrologic and hydraulic data that integrate climate science and other factors to determine the flood elevation and corresponding floodplain.
2. Freeboard Value Approach – use the BFE (or 1% Annual Exceedance Probability (AEP)) and add an additional freeboard height.
3. 0.2 Percent Change Flood Approach (0.2PFA). Use the 0.2 AEP flood elevation (500-year flood elevation)

The climate informed science approach is the preferred approach. Of note, the 2019 National Defense Authorization Act (NDAA) essentially adopted this standard for defense- related infrastructure construction.[17]

Climate Informed Flood Design Elevation

Since most areas have FEMA FIRM maps, unless it is a large scale project that warrants more detailed analysis or FIRM data is not available, it is recommended that the FEMA base flood elevation (which is generally based on a 1% AEP) be used as the basis for design elevation.

ASCE Manual of Practice No. 140 recommends that current freeboard standards used in ASCE 24 be adopted when considering climate informed flood design.

For assets intended to have a long service life, considerations of future SLR should be included in the determination of the elevations, so it is recommended that the projected SLR be added to the BFE to obtain a Future BFE (FBFE). Freeboard should then be added to this FBFE to serve as a factor of safety. It should be noted that with increases in sea-level, the effects of surge, wave heights or wave runup will change, potentially extending the hazard area beyond the zone quantified by the BFE + SLR.

ASCE Manual of Practice No. 140 further recommends that long-term structures include an accommodation for SLR based on a benefit-cost or feasibility assessment that weighs costs against various SLR projections (e.g. low, middle, high). When project elements can be designed without significant implications to a higher level (up to a plausible upper-bound SLR projection) they should be, otherwise they should be designed so that additional protection can be added at a later date if SLR levels in the future make that appropriate.

Because the uncertainty of future SLR predictions increases exponentially with time, making design decisions at projected times too far into the future (100 years) may prove overly conservative, or inefficient. It is recommended that engineering design decisions be made at a *mid-term outlook on the order of 50 years*. When making such mid-term projections, provisions should be included in the initial design to accommodate adjustments to the design flood elevation as necessary. Flood elevations should be evaluated periodically, and updated as necessary.

Climate Informed Design for Riverine Flooding

To plan for flooding in Riverine zones, the amount of rainfall is estimated using Intensity-Density-Frequency (IDF) curves that relate the intensity of the rainfall to the duration of the rainfall. IDF curves are derived from historical rainfall data and published for different levels of storm frequency (10-year recurrence interval, 100-year recurrence interval, etc.) A shorter duration storm will have a higher intensity of rainfall (measured in inches per hour) than a longer duration storm. The total volume of water generated by a rainfall event is the product of the intensity and the duration. During a rainfall event, a portion of the water infiltrates and the remainder must be managed as surface runoff. The amount of surface runoff is determined by estimating the area of permeable surfaces versus impermeable surfaces. Naturally, areas that are developed are converted from largely permeable surfaces to impermeable surfaces, which increases the amount of runoff. The interaction between runoff and infiltration, while simplified in this discussion, is quite complex making understanding the

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[17] Committee on Armed Services House of Representatives. (2019). National Defense Authorization Act for Fiscal Year 2019. Retrieved from https://www.congress.gov/115/crpt/hrpt676/CRPT-115hrpt676.pdf

potential impacts of changes in precipitation on flood probability difficult to quantify. As the area of a watershed increases, the variability increases exponentially.

Engineering design is based on designing for the most extreme event that the structure will encounter in its lifetime with additional consideration for the consequence of failure. Therefore, a critical flood works project may be designed for an event with a recurrence interval of 100 years, whereas a typical building would be designed for an event with a recurrence interval of 50 to 100 years. To climate scientists, an extreme event is typically defined on a much shorter return interval on the order of 10 years, and many trends are observed and projected based on the changing climate. It is likely that some areas of the globe will see an increase in the frequency of heavy rainfall events or an increase in the total precipitation from a heavy rainfall event. Furthermore, while the number of tropical cyclones is projected to remain nearly constant, the intensity of these storms is likely to increase, bringing higher wind speeds and higher total precipitation amounts. It stands to reason that the projected increases in precipitation volumes will contribute to rain generated flooding. While logical reasoning leads to this conclusion, there is limited statistical data at this point to support this conclusion. More high fidelity data collection is required over longer periods of time to be able to make meaningful engineering predictions on increased riverine flooding risks.

There are several resilience strategies proposed for adapting to climate change. In general, initial design is performed based on the most probable event during the project life. Future deviations are anticipated, and a course of action or design modifications are developed at the onset. Performance is monitored over time and modifications implemented as changes are observed. This type of resilience strategy is appropriate for changes that occur slowly over time, such as sea-level rise. Rainfall-induced flooding events are less suited for this strategy as a result of the uncertainty of predicting the impacts of future rainfall events. As additional data is collected and methods for improving the projection of the impacts of future events improve, this methodology may be implemented. Furthermore, as great a threat as climate induced changes in precipitation is changes in urban development represent additional risk. As more land is developed, permeable surfaces are converted into impermeable surfaces and rain induced flooding risks are likely to change. As with climate change, development changes are a time-dependent phenomenon. Philosophies for design considering the effects of changes in development should be applied to and used in conjunction with changes in climate.

Given the uncertainty of the future impacts of climate change on rainfall induced flooding, it is recommended that a freeboard of three feet be used for all riverine area design classes. The standard is provided below:

Riverine Area Building Elevation Requirements:

Minimum Elevation of the Top of the Lowest Floor = BFE + Freeboard

Where:

BFE = FEMA 100-year BFE
Freeboard = 3 feet for all projects.

It is recommended that this topic be revisited every four years as it is anticipated that as additional data is collected, better methodologies will be developed for predicting the impacts of the anticipated changes in precipitation on engineering works.

Freeboard Standards on Atlantic and Gulf of Mexico Coastlines

In determining recommendations for freeboard for the Commonwealth of Virginia other coastal state requirements have been researched. Connecticut, Florida, New Jersey, and Louisiana have adopted ASCE 24 as the flood design standard, which include freeboard standards based on building flood class. These standards were adopted prior to the ASCE Manual of Practice # 140, *Climate-Resilient Infrastructure: Adaptive Design and Risk Management* publication in 2018. New York State has adopted a Climate informed Science Approach (CISA), requiring structure design to consider hydraulic data that integrates climate science and other factors to determine the flood elevation plus 2-3 feet of freeboard depending on type of facility outside of tidal areas, and for tidal areas, they are requiring base flood elevation plus the applicable high sea-level rise projection applicable for the full, expected service life of the facility, plus two to three feet of freeboard, depending on facility type. Delaware, Maryland, Georgia, Maine and Rhode Island set freeboard standards that vary, based on location and type of facility from one foot to three feet.

Freeboard Standards Adopted by Communities in Virginia

Communities in Virginia, especially many of those located in the coastal plain have already begun requiring freeboard standards generally in the Special Flood Hazard Area (SFHA), but sometimes in additional areas to be adopted for new construction or renovation meeting a certain threshold. Further, in 2015, the HPRDC adopted a Resolution 2015-01 a *"Resolution of the Hampton Roads Planning District Commission Encouraging Local Governments in Hampton Roads to Consider Adopting New or Higher Freeboard Requirements to Reduce the Impacts of Recurrent Flooding and Sea Level Rise on Public and Private Property."* The Resolution does not recommend adoption of a particular freeboard nor does it recommend a particular methodology.

As a component of its Sea Level Rise Adaptation Guide, the non-profit organization Wetlands Watch maintains case studies, sample ordinances, and resources for use by communities.[18] As a part of the FEMA NFIP, participating localities may receive Community Ratings System (CRS) points for adoption of freeboard. Locality freeboard requirements in the SFHA range from BFE to 3 feet. Freeboard requirements outside of the SFHA are less common, however Norfolk and Hampton require freeboard of 18 inches above grade in the Shaded X-Zone. Localities may also require V-Zone standards to apply in the Coastal A-Zone or in the case of York County an additional foot of freeboard in Coastal A-Zones and V-Zones resulting in a total of 4.0 feet of freeboard.

Executive Order Twenty-Four, Section 3, though not the primary focus of this report, directs increased coordination and empowerment of localities and individuals to reduce risk. Adoption and adherence to strong freeboard standards for state-owned structures does just that, and will incentivize localities to adopt and enforce similar standards.

[18] Stiff, Mary Carson and Ross Weaver, "Sea Level Rise Adaptation Guide: *Freeboard Requirement*", Wetlands Watch, Available: http://wetlandswatch.org/freeboard-requirement/.

Recommendations

Executive Order Number Twenty-Four (2018), Section 1: Making Commonwealth Holdings More Resilient, Item D. Freeboard Standard for State-Owned Buildings requires that a minimum freeboard standard be set for state-owned buildings. While establishing a freeboard standard for the Commonwealth is important because it can be adopted by the local municipalities for a consistent freeboard standard throughout the state, providing siting and design guidelines offers a broader strategy to minimize risk to state-owned buildings under design. Siting and design standards can also provide guidance for coastal communities as they plan to increase their resilience.

New State-Owned Building Siting Guidelines:

The following are recommended siting guidelines that would apply to all state-owned projects beginning initial design on or after January 1, 2020:

1. New state-owned buildings of the Commonwealth of Virginia may not be sited within areas likely to be inundated by SLR or within areas that SLR will cause significant loss of access or services within the design service life of the building based on the Commonwealth's unified SLR projections for state owned buildings.
2. New state-owned buildings of the Commonwealth of Virginia shall not be located within the Special Flood Hazard Area or Zone X (shaded) designated under the National Flood Insurance Program (100-year and 500-year floodplains) and shall be protected from damage and significant loss of access as a result of projected SLR based on the Commonwealth's unified SLR projections for state owned buildings.
3. It is recommended that these guidelines be updated on a regular basis or at a minimum every four years to take into consideration continued refinement of climate change impacts and any building code recommendations.

Exceptions to these guidelines may be warranted under extenuating circumstances as determined by the Commonwealth of Virginia Chief Resilience officer.

Making the Case for Restricting Siting of New State-Owned Buildings in the 100- and 500-year Floodplain:

While it has been Commonwealth policy to avoid construction within the 100 year floodplain since the issuance of EM 2-97 by former Governor George Allen, it is important to reiterate present best practices with regards to siting within the 100 year floodplain as the pre-existing policy allows for variances to be granted by the Chief Building Official for state-owned buildings if certain conditions are met.

GIS analysis has shown that 38% of the 100-year floodplain in the Hampton Roads Region will be inundated with 3.0 feet SLR. While only 5% of the total area of the 500-year floodplain will be permanently inundated by 3 feet of SLR, the impacts are not uniform. While most cities show little or no inundation both the cities of Virginia Beach (18.7%) and Chesapeake (13.6%) experience non-trivial areas of inundation. This could occur as early as 2044 (NOAA extreme scenario) or, based on SLR planning timelines developed by the Hampton Roads Planning District Commission and based on NOAA Intermediate/Intermediate-High scenarios, within 50-80 years (mid-term). It is clear from SLR projections, and projections of inundations of floodplains that the horizontal boundaries of 100- and 500-year floodplains will change as SLR conditions change, shifting landward.

Sustainable building design practices and green building rating systems restrict new site development in the 100-year floodplain, with the purpose of minimizing the environmental or ecological system impact. The Living Building Challenge rating systems specifically restricts development in the 100-year floodplain. This restriction will reduce risk to new state-owned buildings, by removing them from future inundation pathways.

The Federal government, via the United States General Services Administration (GSA), has restricted siting of buildings in the 100-year floodplain since 2010 by Executive order and GSA policy. Additionally, it restricts the siting of "critical action" buildings within the 500-year floodplain.

The Hampton Roads Sea Level Rise Preparedness and Resilience Intergovernmental Pilot Project, Phase 2 Report: Recommendations, Accomplishments and Lessons Learned, recommended developing building code strategies to mitigate against flooding, severe wind and SLR, including 500-year floodplain management strategies[19].

Currently the 500-year floodplain (0.2% annual exceedance probability) *does not include additional flooding resulting from wave crest run-up or wave run-up.* As SLR increases, and floodplains migrate landward, wave impacts will become a factor in areas that are now the 500-year floodplain, and that will become the 100-year floodplain.

New State-Owned Building Freeboard Standard Guidelines:

The following are recommended design guidelines that apply to all state-owned projects beginning initial design on or after January 1, 2020:

1. The minimum elevation of the top of the lowest floor (see Figure 11) for new state-owned buildings in the coastal area shall be the Future Base Flood Elevation (FBFE) (defined below) plus three feet of freeboard. In this report the Coastal Areas are defined as the Coastal Special Flood Hazard Area and the Combined Coastal/Riverine[20] Special Flood Hazard Area and their adjacent Zone X (shaded) (100- and 500-year floodplains).

[19] Steinhilber, E., Boswell, M., Considine, C., and Mast, L. (2016). Hampton Roads Sea Level Rise Preparedness and Resilience Intergovernmental Pilot Project, Phase 2 Report: Recommendations, Accomplishments and Lessons Learned. Retrieved from:
https://digitalcommons.odu.edu/cgi/viewcontent.cgi?article=1003&context=hripp_reports

[20] FEMA. (2015). Guidance for Flood Risk Analysis and Mapping, Combined Coastal and Riverine Floodplain. Retrieved from https://www.fema.gov/media-library-data/1436989628107-db27783b8a61ebb105ee32064ef16d39/Coastal_Riverine_Guidance_May_2015.pdf

Coastal Area Building Elevation Requirements:

Minimum Elevation of the Top of the Lowest Floor = FBFE + Freeboard

Where:

FBFE = FEMA 100-year BFE + anticipated SLR at 50-year service life
Anticipated SLR is based on the NOAA 2017 Intermediate-High Scenario
Freeboard = 3 feet for all projects.
For Coastal High Hazard and Coastal Zone A above requirements apply to the Bottom of the Lowest Supporting Horizontal Structural Member of Lowest Floor.

The use of a freeboard of 3 feet is intended to supersede the provisions of ASCE 24-14 which prescribe a variable freeboard according to the Flood Design Class of the building. The Future Base Flood Elevation (FBFE) is defined in the ASCE Manual of Practice No. 140, *Climate-Resilient Infrastructure: Adaptive Design and Risk Management*, as the Base Flood Elevation (BFE) plus an accommodation for sea level rise. The BFE shall correspond to the elevation of the nearest 100-year floodplain (1% annual exceedance probability) and the anticipated SLR shall be based on the NOAA 2017 Intermediate-High Scenario at year 50 of anticipated service life. Flood elevations shall be determined from the highest elevation from either the most recent FEMA Flood Insurance Rate Map (FIRM) or the most recent FEMA Flood Insurance Study (FIS) for the jurisdiction. For new state-owned buildings located outside of, but adjacent to the 500-year floodplain, best engineering practice would dictate analysis and consideration of the need to elevate the first floor to account for future sea level rise as well as freeboard to minimize future risk. At a minimum, adaptive design measures should be implemented so that future protection of the structure is possible. **The Commonwealth of Virginia will lead as the first state to incorporate sea level rise into first floor elevation.**

2. The minimum elevation of the top of the lowest floor (see Figure 12) for new state-owned buildings in the riverine area shall be:

Riverine Area Building Elevation Requirements:

Minimum Elevation of the Top of the Lowest Floor = BFE + Freeboard

Where:

BFE = FEMA 100-year BFE
Freeboard = 3 feet for all projects.

3. It is recommended that these guidelines be updated on a regular basis or minimum of every four years to take into consideration continued refinement of climate change impacts and any building code revisions.

Exceptions to these guidelines may be warranted under extenuating circumstances as determined by the Commonwealth of Virginia Chief Resilience officer.

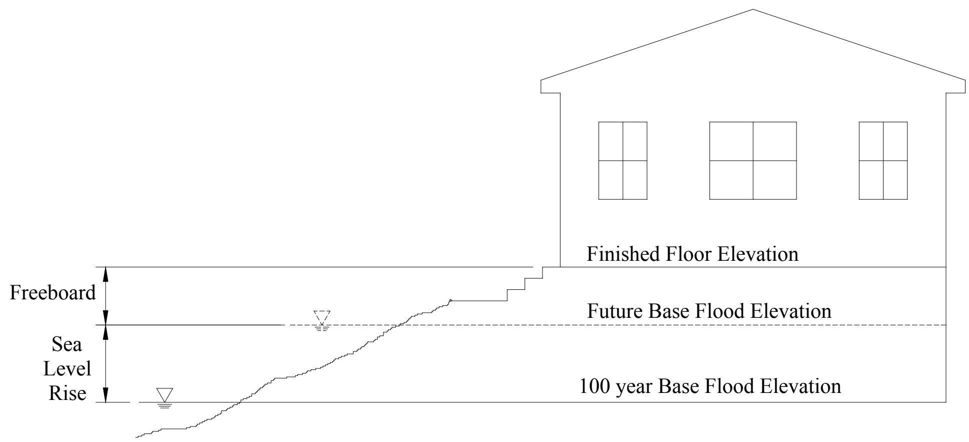

Figure 11. Coastal Area Finished Floor Elevation relative to the Base Flood Elevation. (Note: For Coastal High Hazard and Coastal Zone A above requirements apply to the Bottom of the Lowest Supporting Horizontal Structural Member of Lowest Floor.)

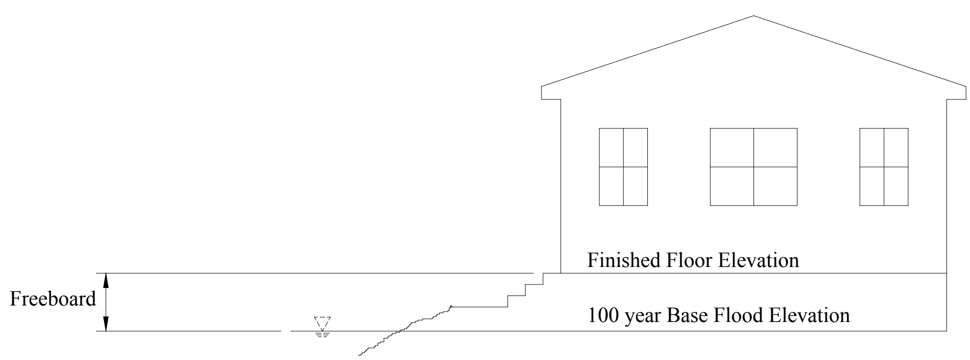

Figure 12. Riverine Area Finished Floor Elevation relative to the Base Flood Elevation.

Recommendations for Additional Data Needs and Evaluation

The following data and analysis needs have been identified as a result of these recommendations:

1. Additional GIS analysis should be performed to quantify the regional impacts of SLR in smaller geographic areas considering *parcel level* data. Areas of potential critical impact should be identified for high-resolution, focused analyses of the physical and economic impacts of SLR.
2. Percentage of land inundated by +3 feet of SLR are not uniform and vary significantly by municipality, for the 100-year floodplain, ranging from 10% To 89.3%. These differences are the result of wide variance of topography and SFHA zones between municipalities and should be the subject of further examination
3. Accurate mapping of 100- and 500-year floodplains is still needed in some localities within the Commonwealth. Where 100- and 500-year floodplain data is out of date, inaccurate, or not available additional hydrologic and hydraulic modeling will be required to determine extent of floodplains prior to siting state-owned building.
4. The Commonwealth should designate Coastal and Riverine Areas explicitly based on tidal influences. Currently the boundary between coastal, combined coastal and riverine and riverine only boundaries are not labeled on the FIRM.
5. Analysis of how floodplains will migrate landward as sea level rises and the extent of additional flooding resulting from wave crest run-up or wave run-up is needed. From this data, freeboard recommendations outside the 500-year floodplain should be developed for future coastal flood zones.

Conclusion

While there is some uncertainty of the timing of the impacts of SLR, it is clear that SLR poses a threat to coastal communities in Virginia and that the rising seas will change the boundaries of the 100- and 500-year floodplains in coastal regions, moving them inland. It is prudent for the Commonwealth of Virginia to consider the risks of SLR and the threats of extreme weather and natural hazards in establishing siting and freeboard standards for state-owned buildings, which will ultimately reduce the impact of these conditions to public health and safety, the environment, and the economy of the Commonwealth.

Appendix 1

The table below summarizes the areas **(mi²)** and percent inundated of the 100 year and 500-year flood zones by +3 feet SLR for each municipality in Hampton Roads.

Municipality	100-yr FP area	500-yr FP area	100-yr area flooded by 3' SLR	100-yr % flooded by 3' SLR	500-yr area flooded by 3' SLR	500-yr % flooded by 3' SLR
Chesapeake	35.577	8.797	30.14	84.7	1.2	13.6
Gloucester	36.883	10.623	20.22	54.8	0.0001	0.0
Hampton	19.349	5.365	7.057	36.5	0.049	0.9
Isle of Wight	32.803	3.416	10.26	31.3	0.002	0.1
James City	21.5	1.111	13.74	63.9	0.00014	0.0
Newport News	12.127	1.4098	6.659	54.9	0.0375	2.7
Norfolk	10.596	8.196	4.108	38.8	0.038	0.5
Poquoson	13.221	1.581	9.725	73.6	0.007	0.4
Portsmouth	6.088	4.414	1.848	30.4	0.011	0.2
Southampton	95.525	12.552	9.565	10.0	0.05	0.4
Suffolk	98.816	1.103	11.609	11.7	0.006	0.5
Surry	27.015	0.115	4.364	16.2	0.0001	0.1
Virginia Beach	68.844	10.997	51.002	74.1	2.051	18.7
York	14.19	2.681	6.814	48.0	0.015	0.6
Williamsburg	0.238	0.019	0.123	51.7	0	0.0
Franklin	0.028	0.002	0.025	89.3	0	0.0
Smithfield	1.77	0.017	1.519	85.8	0	0.0
Total	494.57	72.3988	188.778	38.2	3.46684	4.8