January 2020

Virginia Beach

Sea Level Wise

Adaptation Strategy

DRAFT

Sea Level Wise
*A **vibrant** future for Virginia Beach*

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Table of Contents

These pages can be found by clicking *here*

Note: Appendices located in separate document

Key Terminology

Mitigation means reducing the severity of an event. Actions that mitigate flooding are those that reduce the extent, depth, and damage from a flood.

Resilience is the capacity to respond and recover from a negative event. Communities can become more resilient to flooding by taking concrete steps to better understand and cope with flood-related risks before an event takes place.

Adaptation is the process of adjusting to new conditions. Adapting to sea level rise and recurrent flooding means accounting for changing environmental conditions when making plans and investments.

This Adaptation Strategy outlines a proactive, long-term approach to enable the City of Virginia Beach to adapt to changing environmental conditions. Gradual implementation of the Strategy elements will improve the City's resilience to the flood conditions of both today and tomorrow. In turn, this will maintain and improve the quality of life for residents and ensure

a vibrant future

for the City of Virginia Beach.

Executive Summary

In the last five years, the City of Virginia Beach has completed a comprehensive effort to develop strategies to respond to sea level rise and related increases in flooding. The study, known as Sea Level Wise, has produced a wealth of information to understand what challenges the City will face and develop diverse strategies to pro-actively reduce the impacts. This document presents the findings of the Sea Level Wise effort.

Changes to Flooding

Virginia Beach and the Hampton Roads region are experiencing the highest rate of sea level rise on the east coast. Over the last 50 years sea levels have risen by almost one foot. Higher sea levels and heavier rainfall events are already impacting the City's low-lying lands, buildings, and infrastructure, even on sunny days. Looking forward, sea levels will continue to rise at an even faster rate. Regional planning guidance for Hampton Roads suggests communities plan for sea levels to increase by 1.5 ft by 2050, 3 ft by 2050 to 2080, and 4.5 ft by 2080 to 2100. This will further increase the frequency and severity of flooding.

Virginia Beach is exposed to several sources of coastal flooding, including:

- **High Tide Flooding:** Tides are the daily rise and fall of the ocean and connected waterways due to the pull of the moon and sun. Extreme high tide events can generate flooding of the lowest-lying areas. With rising sea levels, these events are expected to reach even further inland and inundate land for longer periods of time.
- **Wind Tide Flooding:** Wind Tide Flooding can occur when winds blow persistently in one direction for multiple days. Winds can push water into coastal bays and waterways, piling it up against the shoreline and causing flooding in low-lying areas.
- **Storm Surge Flooding:** Storm surges are major coastal flooding events caused by gales, northeasters, tropical storms, and hurricanes. These events can result in significant flooding, structural damage, and substantial economic impacts.
- **Rainfall (Compounding) Flooding:** Higher tide elevations reduce and can block the drainage of rainfall. Also, when both storm surge and rainfall happen at the same time, water may flow upstream into drainage ditches and pipes, combining with stormwater runoff and result in more widespread flooding.
- **Groundwater Flooding:** Rising sea levels can raise the freshwater aquifer and shift the boundary between saltwater and freshwater inland. This can result in reduced storage capacity for rainfall, contaminate the fresh water aquifer, and increase ponding and flooding.

In general, the area of the City exposed to coastal flooding will increase by one-and-a-half times in the 2040's, and by two-times in the 2070's. The southern part of the City is low-lying and will experience of bulk of these increases. In most other areas, the floodplain will be similar, but deeper flooding will be experienced as compared to today's conditions.

Impacts of Flooding

Unless significant actions are taken, future flood events will have wide-ranging impacts on the City's infrastructure, economy and overall well-being. As compared to present-day conditions, losses due to coastal flooding are estimated to increase by almost thee times by the 2040s. By the 2070's the growing floodplain and increasing flood depth bring losses to more than a twelve-times increase over today's conditions. These estimates are based on today's built environment and do not include inflation. Over 80-percent of these losses in the 2070s are concentrated in seven areas of the City. The development of adaptation strategies was directly informed by this information.

Adaptation Strategies

Virginia Beach recognizes the realities associated with increases sea level and is taking significant action. However, no single strategy will address the problem. As such, the City combined a variety of approaches in a Adaptation Framework to prepare for the future. The Adaptation Framework consists of four complementary themes, each with a specific approach to flood risk management. The layers are designed to support each other, integrating structural and non-structural measures to ensure comprehensive flood protection across a range of environmental conditions.

NATURAL MITIGATIONS

Natural features both in the water and on land can directly reduce the magnitude of flooding across the City by reducing wave action, stabilizing landscapes, and absorbing excess floodwater.

- **Preserve Environmental Assets:** Protect and expand green infrastructure networks through land conservation and renaturalization programs.
- **Increase Natural and Nature-Based Features:** Invest in the restoration, enhancement, and construction of natural and nature-based infrastructure that mitigate the impacts of flooding

PREPARED COMMUNITIES

Beyond physical interventions, strengthening certain social and economic systems can help individuals prepare before a flood event, and improve the capacity of communities to recover in the aftermath.

- **Grow Educational Outreach** Develop programs and tools to inform vulnerable residents about their flood risk and facilitate access to mitigation, preparedness, and recovery resources.
- **Promote Economic Resilience** Bolster flood resiliency of the City's economic engines through access to planning resources, technical guidance, and financial support.

ENGINEERED DEFENSES

Permanent or deployable structural flood risk reduction elements can be engineered to block specific flood pathways, preventing coastal or riverine floodwaters from passing into inland areas.

- **Pursue an Expansive Defense Network:** Invest in the long-term construction of a large-scale structural defense network that provides wide-reaching protection from increasingly severe coastal flood risks.

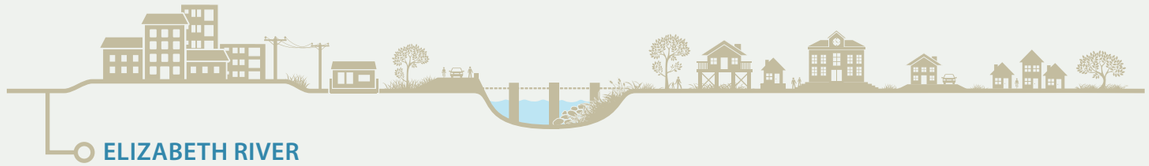
ADAPTED STRUCTURES

Buildings and infrastructure systems can be sited, built, or retrofitted to withstand a certain magnitude of flooding event, helping to manage the residual risk that exists even behind protective infrastructure.

- **Regulate Building and Development:** Require responsible siting, design, and construction practices for new and substantial redevelopment that are reflective of the area's current and future flood risks.
- **Support Risk-Mitigating Interventions**: Provide resources and incentives to encourage flood-resilient design or retrofits on residential and commercial properties.
- **Minimize Infrastructure Vulnerabilities:** Engage with local and regional infrastructure and utility agencies to better understand independent and cascading vulnerabilities and make proactive investments.

Applications at the Watershed Level

The Adaptation Framework encompasses a host of individual strategies, each of which has specific applications across the City. The City's four major watersheds present natural boundaries for taking a more precise look at flood-related challenges and opportunities. Each Watershed Strategy lays out the specific flood drivers and risk types distinct to that watershed, and identifies specific areas for action.



ELIZABETH RIVER

The City's only fully inland watershed, increased urbanization, degradation of naturalized landscapes, and aging infrastructure contribute to flood exposure and vulnerability in the Elizabeth River Watershed. Upgrading infrastructure and maintaining use and access to recreational amenities along the waterfront with higher sea levels will form the foundation for securing flood resilience in the watershed.

Measures proposed include an integrated flood protection system along the Eastern Branch of the Elizabeth River that would block the critical flood entry point, along with complimentary measures that provide redundancy in flood protection and improved connections to the waterfront, including natural wetland buffers and livings shorelines. Broader adaptation measures such as adapted buildings and infrastructure, and community preparedness can provide further protection from sea level rise and coastal flooding.

LYNNHAVEN

The Lynnhaven Watershed is the second largest watershed in Virginia Beach and contains the majority of the City's designated strategic growth areas. Addressing repetitive impacts from recurrent flooding, concentrating development in high and dry areas, and preserving low-lying natural resources will be the foundation for securing flood resilience in the Lynnhaven Watershed.

Outfitting the Lynnhaven Inlet with a storm surge barrier will significantly reduce the influx of coastal flood waters entering into the City from the Chesapeake Bay. Further lines of defense must come from natural infrastructure such as living shorelines, marsh creation and restoration, and conservation of connected green spaces. In addition to this, citizens must be proactive, mitigating homes through elevation and mitigation reconstruction. Pursuing policy and regulatory actions such as expanding the definition of the floodplain can also encourage adequate preparedness in the watershed.

OCEANFRONT

The Oceanfront Watershed is the smallest watershed in the City, but it is densely developed and provides invaluable economic growth from the tourism industry. Protecting existing development and the economic base while encouraging redevelopment or any new growth in high and dry areas will be essential for securing flood resilience.

The Oceanfront Watershed is also one of the most flood-prepared watersheds in the City with high levels of insurance coverage inside and outside the FEMA floodplain.

Structural interventions and seawall elevation paired with nature-based investments and marsh creation at the Rudee Inlet and Lake Rudee will continue to drive economic revenue in the Oceanfront Watershed for years to come.

SOUTHERN RIVERS

The Southern Rivers Watershed is the largest watershed and has the largest amount of low-lying land in the City. Establishing land use strategies that preserve resources and limit new development in areas susceptible to future flooding will be the focus for adaptation in the Southern Watershed.

Measures proposed include an integrated flood protection system that would block several key flood entry points, along with complimentary measures such as living shorelines and open space that provide redundancy in flood protection and improved connections to Back Bay, the North Landing River, and other waterways. These structural and non-structural solutions can provide multiple layers of protection from sea level rise and coastal flooding, in concert with broader adaptation measures such as adapted buildings and infrastructure, and community preparedness.

Moving Forward

Development of this strategy has led to the important acknowledgment that sea level rise adaptation is a complex endeavor with many uncertainties and challenges. This document presents a wide variety of potential adaptation strategies each with its own costs, benefits, and implementation challenges. The City has already initiated or completed marked progress on the identified initiatives.

The City will continue to explore the viability of all of the conceptual adaptation projects presented for each for the City's four major watersheds. As our understanding continues to evolve , this strategy can be further refined. The City will remain open to integrating additional adaptation options as new ideas and solutions arise.

PART I

INTRODUCTION

A Call to Action

The flooding risks posed by rising sea levels and changing rainfall patterns demand City-wide action to protect vulnerable neighborhoods and industries.

Higher sea levels and heavier rainfall events are already impacting the City's low-lying lands, buildings, and infrastructure.

Sea level rise in Virginia Beach is an undisputed fact. The Hampton Roads region is experiencing the highest rate of sea level rise on the east coast. In the last 50-years, sea levels have risen by almost one foot. As a result, Virginia Beach residents have observed higher water levels and experienced more regular flood events, even on sunny days.

Looking forward, sea levels will continue to rise at an even faster rate. They are projected to increase by another 1 to 4.5 feet over the next 80 years.[1] With such stark projections, Virginia Beach is among the top ten cities in the country at risk from sea level rise. It is also ranked 19th in the world for assets exposed to coastal flooding by the 2070s.[2] At the same time, the frequency and intensity of heavy rain and coastal storm events are also expected to increase. Total rainfall is projected to increase by approximately 7% per decade over the next 50 years. These factors will make flooding worse.

We are, therefore, taking significant actions to adapt to changing conditions and mitigate risks across the City.

Maintaining Good Credit

The City's flood risks are also recognized by organizations that rate the financial strength and borrowing ability of municipalities.

In 2014, the credit rating agency Moody's Investors Service Inc. sent a questionnaire to the City. It asked about the City's sea level rise vulnerabilities, expenses, and plans to address future impacts. Thanks to the newly created Sea Level Wise program, the City was able to speak to proactive flood mitigation efforts underway, stating:

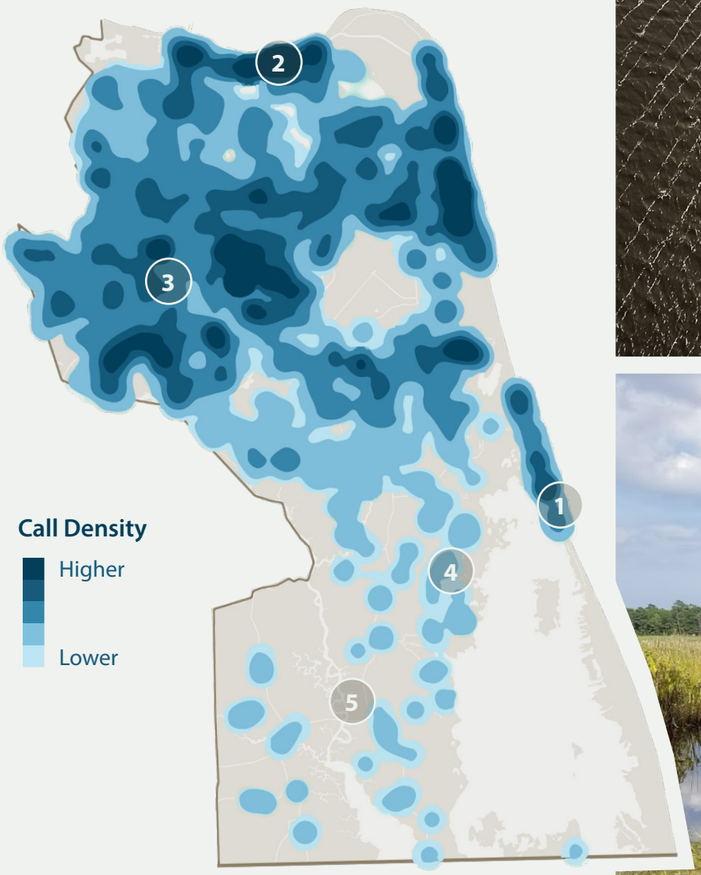
"The City firmly believes that the cost of damage done by ignoring sea level rise will far exceed the cost of mitigation."

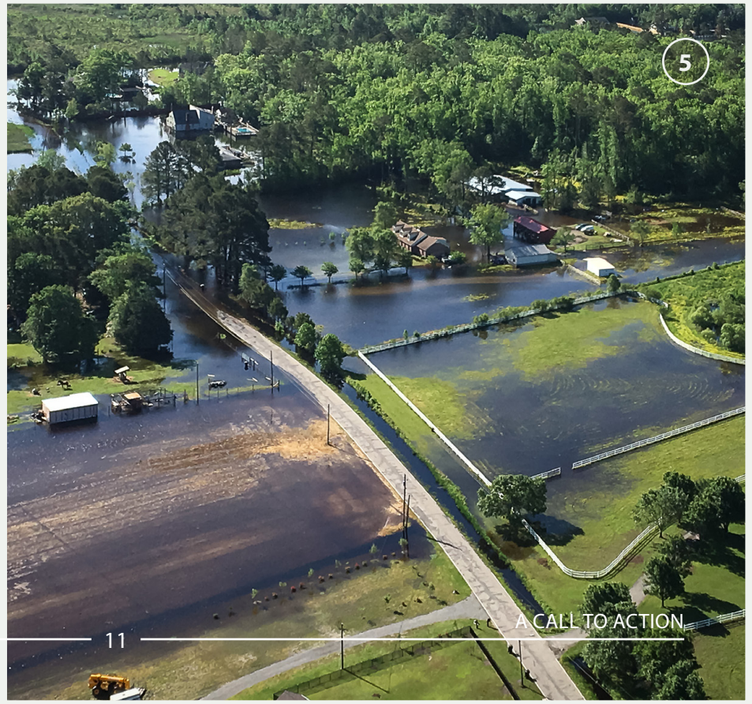
Satisfactory responses to these questions has allowed Virginia Beach to maintain a AAA credit rating. This high credit rating is essential for the affordable financing of City improvement projects through municipal bonds.

Observed Flooding Impacts

The City maintains records of where residents report flood issues. Residents regularly report flood issues through a hotline and submit storm and flooding photographs to **stormpics@vbgov.com**. This data helps to validate flood models and prioritize actions.

The darker areas of the heat map indicate call density between 2001 and 2017 and provide a glimpse into the current flooding "hotspots" across the City.





Becoming Sea Level Wise

Over the past five years, the Sea Level Wise program has engaged technical experts, community participants, and regional partners to advance adaptation efforts.

In 2014, City Council launched the Comprehensive Sea Level Rise and Recurrent Flooding Capital Improvement Program project, which is now known as **Sea Level Wise**. This effort aims to produce information and strategies that enable Virginia Beach to establish long-term resilience to sea level rise and associated recurrent flooding. From the beginning, City Council recognized that accomplishing this goal would involve:

- Gaining a full understanding of flood risk and anticipated changes over time,
- Developing policy and engineering strategies to reduce short- and long-term impacts,
- Creating city-wide and watershed-level 'action plans' to guide strategy implementation, and
- Engaging with community stakeholders to inform and advance resilience initiatives.

We recognize that a strategic approach is needed to reduce flooding impacts. The City of Virginia Beach has made multi-million dollar investments in adaptation-focused engineering analysis, planning, and design. These investments include the Sea Level Wise program and the Master Drainage Study. Together, these two efforts address both the coastal and rainfall aspects of flooding.

City Council allocated $3 million from the Capital Improvement Program from 2015 to 2020 to support the Sea Level Wise effort. The program was further bolstered by an $844,000 regional coastal resilience grant from the National Oceanic and Atmospheric Administration.

Virginia Beach is one of the first communities in the Hampton Roads region to comprehensively study and plan for sea level rise. We have shared our results with numerous regional agencies and municipal governments who have used this research to bolster their own adaptation planning efforts.

Integrated Flood Response

The Sea Level Wise program focuses on coastal hazards and future conditions. The Master Drainage Study is addressing rainfall and stormwater drainage issues. The two programs are running in parallel and address complementary pieces of the City's flooding risks.

The Master Drainage Study has provided details about the City's drainage infrastructure, system capacity, and existing deficiencies. Sea Level Wise provided information related to sea level rise, projected changes in rainfall, and the combined impact of coastal and rainfall flooding to the Master Drainage Study to make sure the two efforts aligned. Moving forward, the City will be prioritizing recommendations of both studies to achieve the best benefit for the City.

Program Phases

Impact Assessment

The first phase of Sea Level Wise focused on establishing a full understanding of flood risks by analyzing sea level rise and recurrent flooding impacts to both built infrastructure and the natural environment. The study team evaluated vulnerability and flood risk exposure of City assets and critical infrastructure for existing and future sea level rise scenarios. A range of conditions—including nuisance tidal flooding, storm surge flooding, and stormwater runoff—were evaluated. This understanding of the local environmental context, worsening flood hazards, and resultant impacts is presented in Part II of this report.

Adaptation Research

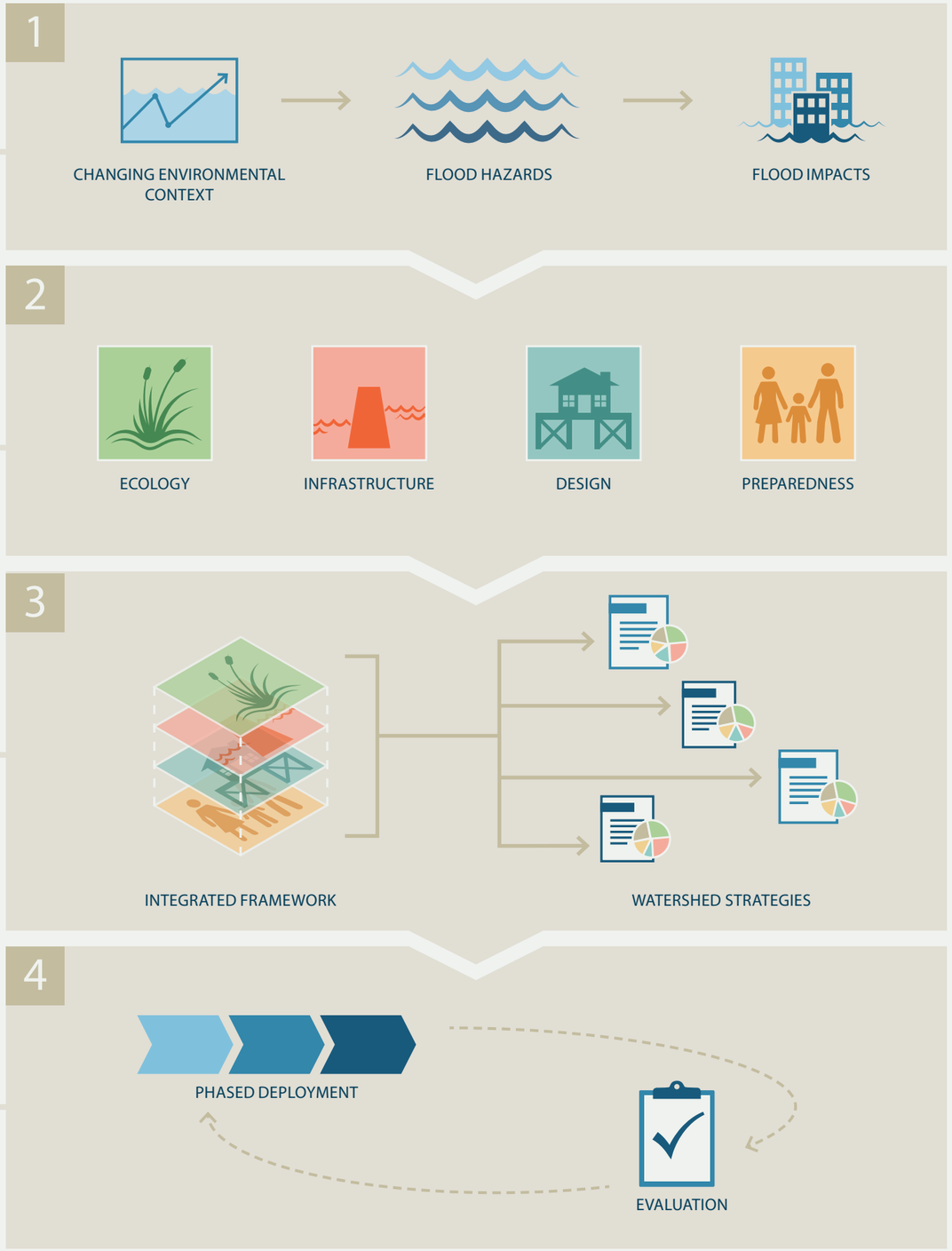
Phase two concentrated on developing and evaluating options for addressing short-term and long-term flood risks. Through targeted research efforts—focusing on the use of natural features, large- and small-scale infrastructure, parcel-level mitigation techniques, and policy and planning actions—an array of possible risk-mitigating interventions were identified. Various policy, programmatic, and engineering approaches provide options for comprehensive city-wide action. This set of complementary ecological, structural, design, and preparedness techniques developed in this process lays the foundation for the Adaptation Framework.

Strategy Development

Next, a comprehensive planning process brought together all the distinct Sea Level Wise components to form an integrated Adaptation Strategy. This Strategy contains a multi-layered framework with high-level strategic objectives to guide adaptation efforts across the entire city, as presented in Part III of this report. It also contains actionable adaptation projects for each of the City's four major watersheds. In developing this Strategy, potential adaptation techniques and projects were systematically evaluated based on costs, benefits, and feasibility in order to help identify the most effective and practical solutions. The watershed-specific strategies and projects are presented in Part IV of this report.

Long-Term Implementation

The final phase involves implementing the projects identified throughout this effort. This will be facilitated and monitored by the City Manager's Working Group on Sea Level Rise, overseen by a Deputy City Manager, reporting to the City Manager. The City will either adopt or further evaluate best approaches for implementation. Such implementation will see strategies integrated into the City's comprehensive plan, as well as other planning and design processes. Financing, additional feasibility studies, design, construction also fall under this phase. The path forward with phased implementation and evaluation are presented in Part V of this report.



Community Engagement

Input from the residents in Virginia Beach helped shape this Adaptation Strategy. Over 500 residents participated in the adaptation strategy development process through a series of thirteen interactive public engagement meetings, and an online portal for residents who were unable to attend the live community meetings. The public meetings were advertised and promoted via multi-media campaigns to ensure perspectives from diverse audience were captured.

The City engaged Old Dominion University social scientists to design the meetings using the Action-Oriented Stakeholder Engagement for a Resilient Tomorrow (ASERT) framework. Through interactive stations that promote learning and participation, this approach to public engagement helps a diverse and inclusive mix of stakeholders better understand community values, challenges, and solutions. While sea level rise adaptation is both an outcome and a process, this approach emphasizes the latter, focusing on learning and taking responsibility for making decisions that ensure a resilient future for Virginia Beach.

The first set of public engagement meetings were held in 2017 and early 2018 . Large printed maps of current and future floodplains help residents visualize and understand flood risks. Interactive stations allowed residents to provide information on flooding challenges and tolerances today, perception of future flood risks, and preference for different types of adaptation strategies. As part of these meetings, Virginia Beach residents identified and mapped vulnerable community assets and flooding challenges, which were used to identify and prioritize flood risk areas.

The second round of meetings was held in 2019 to introduce the public to policy, nature-based, city-wide structural, and site-level flood risk management strategies in development.

Residents shared their preferred adaptation methods and techniques, which has informed the options presented throughout this document.

In both efforts, meetings were held at locations intended to gather input from the diverse physiographic and demographic areas of the City. Through these meetings, participants made it clear that they recognize the increasing flood impacts and understand substantial actions are needed to address the issue.

Community Meeting Locations across the City of Virginia Beach

We asked... and you answered!

Over **500** residents contributed their perspectives either in meetings or online.*

How have you been impacted?

51% have suffered **property damage or loss** due to flooding.

89% have had to **change their normal driving routes** to work, school, or other activities, due to flooding.

64% consider themselves to be **personally vulnerable** to the impacts of flooding.

What actions do you want the City to take?

91% strongly support encouraging the maintenance of natural flood buffers, including living shoreline approaches for managing erosion.

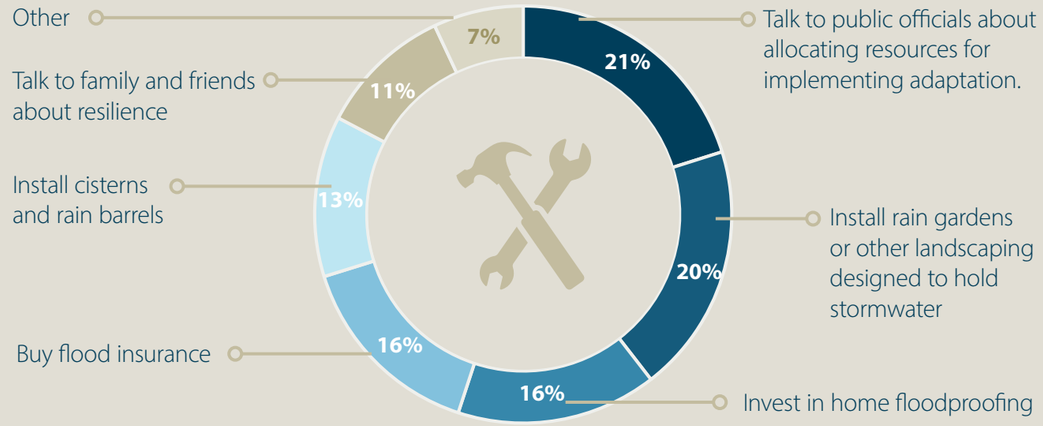
72% support using conventional bonds, such as revenue and general obligation bonds to fund a large-scale structural defense network.

92% support changing ordinances, regulation, codes and/or standards to ensure that new structures are designed, sited, and constructed to be more resilient to future flood risks.

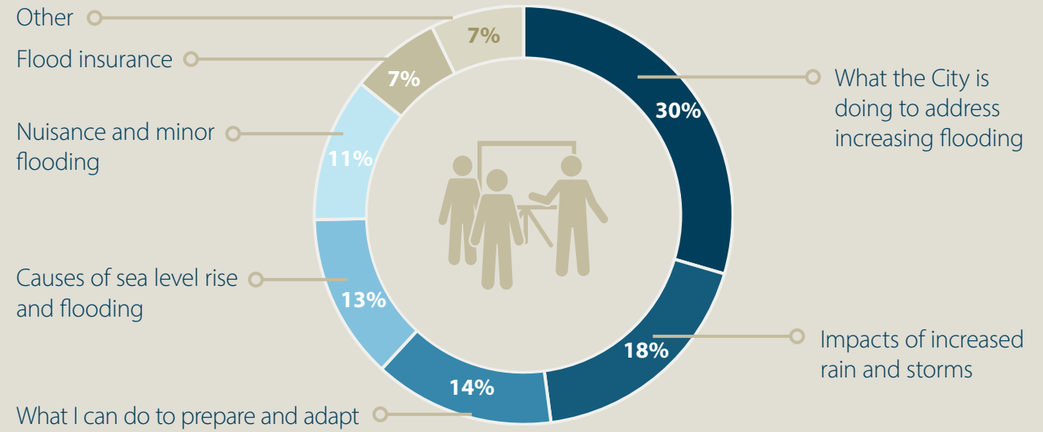
48% do not consider themselves well informed about increasing flooding and its causes and would be interested in more information from the City.

**Not all participants answered the exact same survey questions. The number of responses for each question ranged from 107 to 427. Additional survey response data is presented throughout the Adaptation Framework in "Resident Perspectives" call-outs.*

What actions would you be willing to take?



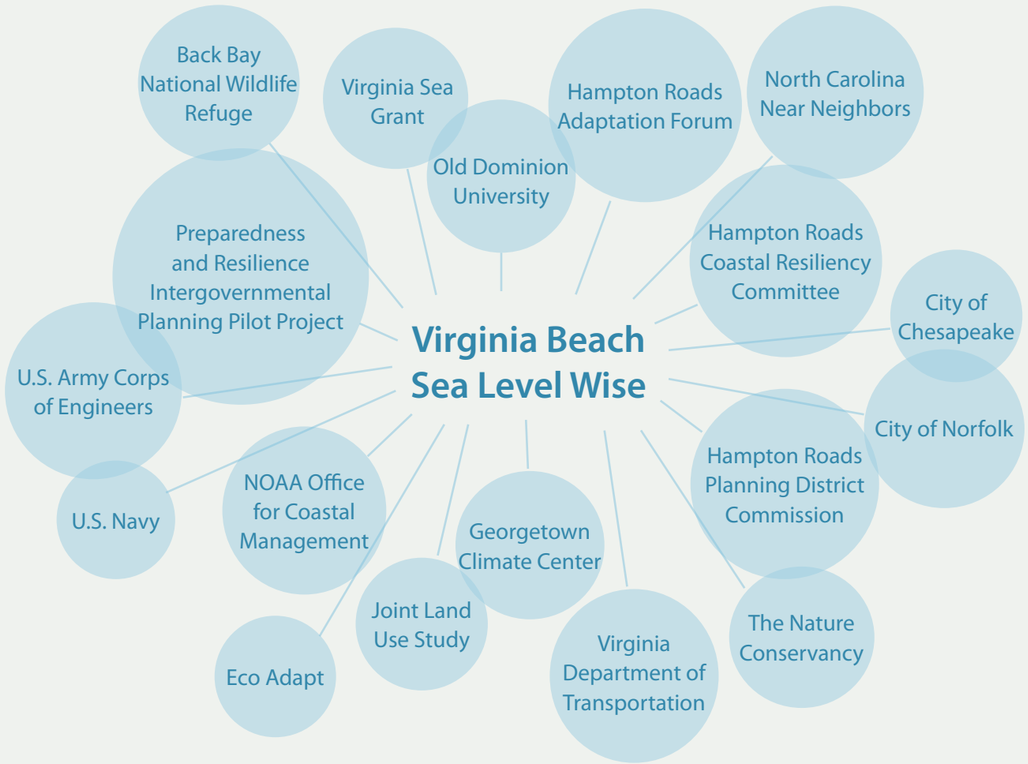
What would you like to know more about?



Regional Connections

Within the Hampton Roads region, the City of Virginia Beach offers a uniquely diverse test-bed for sea level rise adaptation planning. A cornerstone of the region, water-related activities in Virginia Beach tie into regional initiatives as the City's watersheds cross into the cities of Chesapeake and Norfolk, and the state of North Carolina. Our diverse watersheds, each with unique land uses, economics and hazard mitigation challenges, are well representative of the region as a whole. As such, the strategies developed in Virginia Beach can be leveraged through the larger Hampton Roads region, as well as throughout the Mid-Atlantic or similar coastal environments throughout the nation.

By building off regional connections, the City is committed to both leveraging and integrating information that better informs the Sea Level Wise effort as well as disseminating knowledge and tools to benefit others across the region.



A Steadfast Response

"As City Council discussed during the City Council's annual strategic planning workshop this year, effectively dealing with storm water, recurrent flooding and sea level rise is today's version of our historic Lake Gaston water pipeline project. That effort required a long planning horizon and the fortitude to remain steadfast throughout the decade and a half it took to secure a reliable water supply for our community. The same approach is necessary today as we face the formidable but not insurmountable challenge of mitigating flooding."

Excerpt from the 2019-2020 Adopted Resource Management Plan for the City of Virginia Beach

PART II

UNDERSTANDING FLOOD RISKS

Sandbridge Beach during the back to back Nor'easters in 1991

In the last 30 years, the City has worked to add natural beach protection

Our Coastal Context

As a coastal city with both rural and urban landscapes, we face diverse and complex flooding challenges.

Virginia Beach sits at the entrance to the Chesapeake Bay, an area where multiple rivers and the Atlantic Ocean meet, exposing our community to several different flood sources.

When coastal storm surge, high tides, and heavy rainfall occur at the same time, the potential for flooding in low lying coastal areas becomes much greater than when any of these hazards occurs separately. If the ground is already saturated when these conditions occur, flooding can be even more widespread.

Interaction of these flood hazards with the built and natural environment determines the extent and depth of flooding. Increased urbanization and deterioration of ecological assets have both contributed to increased flood risks in Virginia Beach.

Sea level rise and more frequent and intense heavy rainfall events will only intensify flooding impacts. In order to develop strategies to combat these complex and inter-connected issues, it is imperative to understand the processes driving them and the probability of their occurrence.

Coastal Flood Pathways

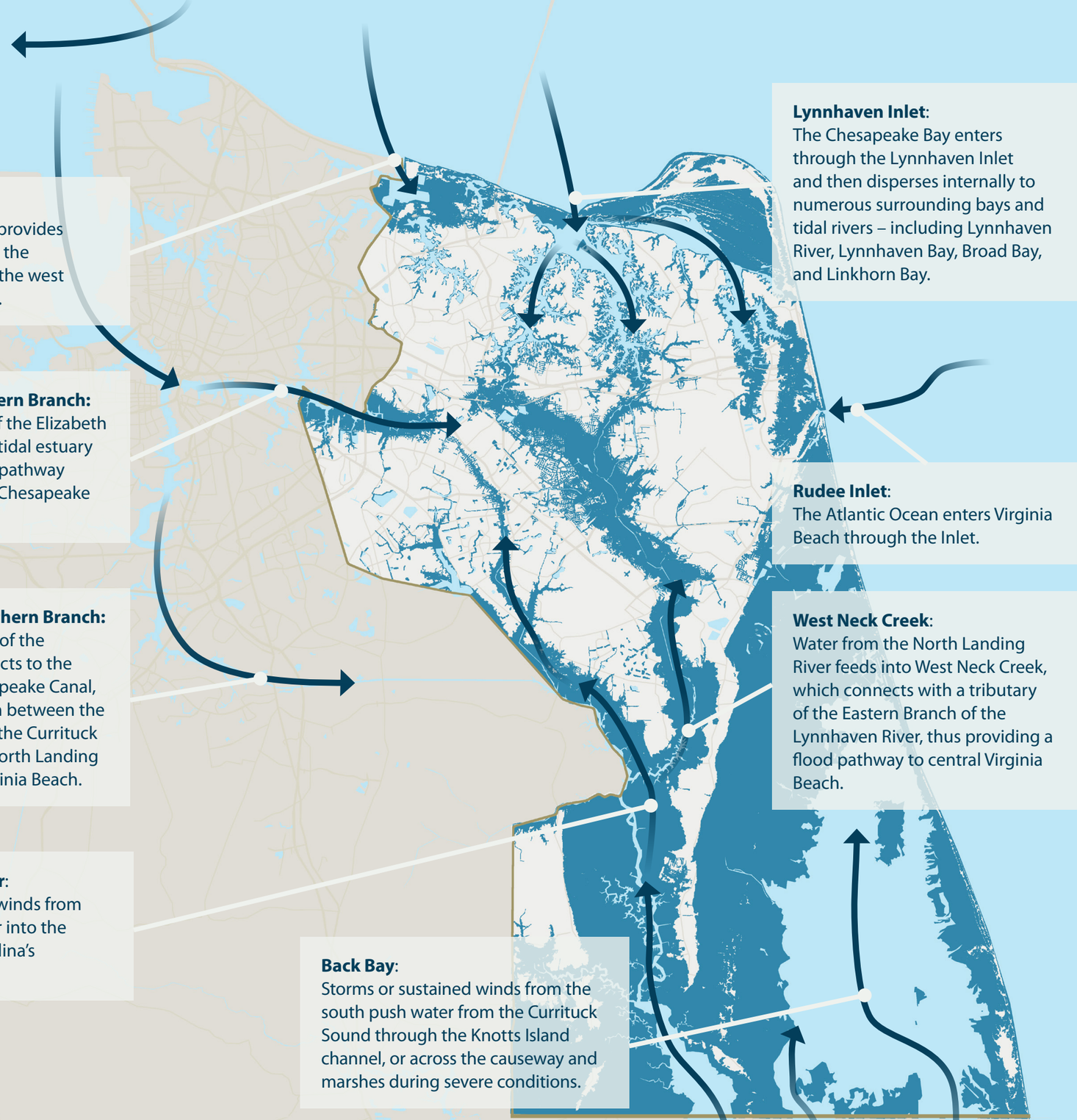
Coastal flooding occurs when land is flooded from tides, winds, nor'easters, or hurricanes that drive water into the City from its surrounding ocean, bays and rivers. Almost all of Virginia Beach's coastal flood risk is not on the open coast, but inside the City's coastal perimeter. This may be unexpected, especially for those of us that live along the open coast where water is highly visible.

Today, flood pathways are distinct, making it relatively easy to understand and identify sources of flooding. As sea levels rise, however, some of these pathways begin to merge and new pathways open up, resulting in more widespread and complex flood challenges.

Most of the Virginia Beach coastline facing the Atlantic Ocean and Chesapeake Bay is naturally protected by our beaches and sand dunes. Although a small amount of overtopping may occur, most flood waters enter the City through key entry points such as tidal rivers, estuaries, bays, and inlets.

Once inside Virginia Beach, flood waters disperse internally to numerous surrounding bays and rivers. Flood waters can be amplified moving upstream as water piles up through these internal water bodies during storm conditions.

Some of these flood pathways cross through adjacent municipalities, such as the adjacent cities of Norfolk and Chesapeake, as well as neighboring State of North Carolina. This requires that the City must coordinate and minimize adverse impacts from any flood reduction strategies.



Little Creek Inlet:
The Little Creek Inlet provides a flood pathway from the Chesapeake Bay into the west side of Virginia Beach.

Elizabeth River Eastern Branch:
The eastern branch of the Elizabeth River is a 9-mile long tidal estuary that provides a flood pathway through Norfolk and Chesapeake into Virginia Beach.

Elizabeth River Southern Branch:
The southern branch of the Elizabeth River connects to the Albemarle and Chesapeake Canal, creating a connection between the Chesapeake Bay and the Currituck Sound through the North Landing River in southern Virginia Beach.

North Landing River:
Storms or sustained winds from the south push water into the City from North Carolina's Currituck Sound.

Lynnhaven Inlet:
The Chesapeake Bay enters through the Lynnhaven Inlet and then disperses internally to numerous surrounding bays and tidal rivers – including Lynnhaven River, Lynnhaven Bay, Broad Bay, and Linkhorn Bay.

Rudee Inlet:
The Atlantic Ocean enters Virginia Beach through the Inlet.

West Neck Creek:
Water from the North Landing River feeds into West Neck Creek, which connects with a tributary of the Eastern Branch of the Lynnhaven River, thus providing a flood pathway to central Virginia Beach.

Back Bay:
Storms or sustained winds from the south push water from the Currituck Sound through the Knotts Island channel, or across the causeway and marshes during severe conditions.

The Challenge of Rising Sea Levels

Sea level rise is occurring at an accelerated rate, increasing tidal and storm surge flooding events.

Sea levels have been rising in Virginia Beach at almost twice the global rate. There are five long-term water level observation stations in Virginia, which measure how much and how fast sea levels have already risen. These stations indicate that the rate of sea level rise in southeast Virginia is among the top 10 percent in the nation.[3]

The Sewell's Point tide gauge, located in Norfolk, Virginia, provides the highest quality and closest long-term record for Virginia Beach with almost 90 years of information. These water level observations show us that sea levels in our region have risen approximately 0.8 feet in the past 50 years.

Sea levels are rising at a faster rate in our region primarily because of the gradual sinking of land, or land subsidence. Estimates state that as much as 50% of the relative sea level rise is due to land subsidence as the land sinks and settles in the Hampton Roads region.[4] Taking water out of the ground is a major driver of land subsidence in our region. As the water level in the ground decreases, the aquifer system compacts, causing the land above to sink. This results in an even higher sea level relative to the land surface – this is called "relative" sea level rise. In the future, global processes are expected to control the rate and magnitude of sea level rise to a much larger degree.

Five Virginia water level stations appear in the nation's top twenty highest sea level rise trends[5]

Station Name	Years of Record	Trends (mm/yr)	Trends (ft/cent.)	Rank
Eugene Island, LA	35	9.65	3.17	1
Grand Isle, LA	66	9.07	2.98	2
Apra Harbor, Guam	20	8.6	2.82	3
Galveston Pleasure Pier, TX	54	6.62	2.17	4
Galveston Pier 21, TX	105	6.35	2.08	5
Chesapeake Bay Bridge Tunnel, VA	38	5.96	1.96	6
Ocean City, MD	38	5.67	1.86	7
Rockport, TX	65	5.53	1.82	8
Lewisetta, VA	39	5.5	1.8	9
Sabine Pass, TX	55	5.46	1.79	10
Colonial Beach, VA	38	4.89	1.6	11
Cape May, NJ	48	4.6	1.51	12
Sewells Point, VA	86	4.57	1.5	13
Duck, NC	35	4.57	1.5	14
Freeport, TX	36	4.43	1.45	15
Atlantic City, NJ	102	4.08	1.34	16
Sandy Hook, NJ	81	4.06	1.33	17
Chesapeake City, MD	41	3.93	1.29	18
North Spit, CA	36	3.86	1.27	19
Gloucester Point, VA	53	3.81	1.25	20

Sea Level Rise Scenarios

Although there is a range of estimates of how much more sea level will rise in the future, there is no doubt that the trend will continue. In selecting sea level rise planning scenarios, the City aimed to strike a balance between the need to proactively plan for changing conditions, cost effectiveness, and uncertainties in the projections from the scientific community.

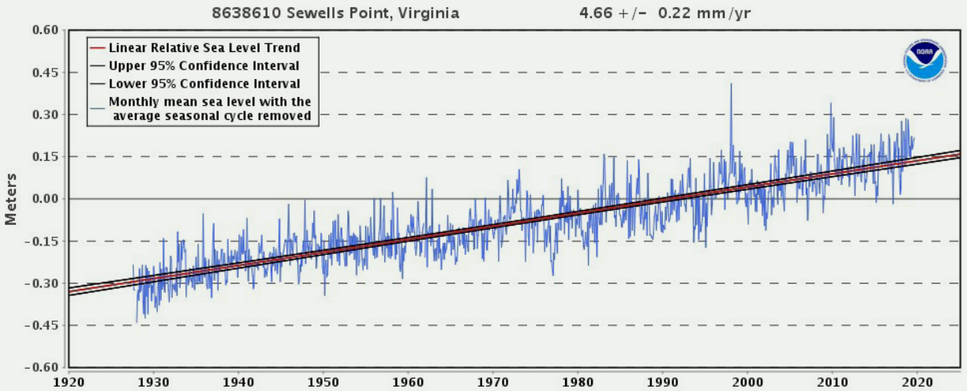
The City selected a sea level rise scenario of 1.5 feet to represent conditions from 2035-2050. This value will be used for near-term planning decisions. To represent conditions from 2065-2085, the City selected a 3 foot increase in sea level. This value is suitable for long-term planning decisions, as well as evaluation and/or design of critical infrastructure – such as emergency evacuation routes, public buildings, and large- scale flood risk reduction measures.

These two selected scenarios fall on the "Intermediate" curve of the most recent sea level projections at Sewells Point, presented in Regional Sea Level Rise Scenarios for the United States – which established updated scenarios for the Fourth National Climate Assessment based on the latest science at the time.[6] Both of the selected scenarios do require an increase in the historical rate of sea level rise. A recent analysis published by the Virginia Institute of Marine Sciences (VIMS) found that such an increase is happening in Hampton Roads. In analyzing the Sewell's Point record, VIMS found that recent increases in the rate of sea level rise would indeed result in an sea level increase of approximately 1.6 feet by 2050.

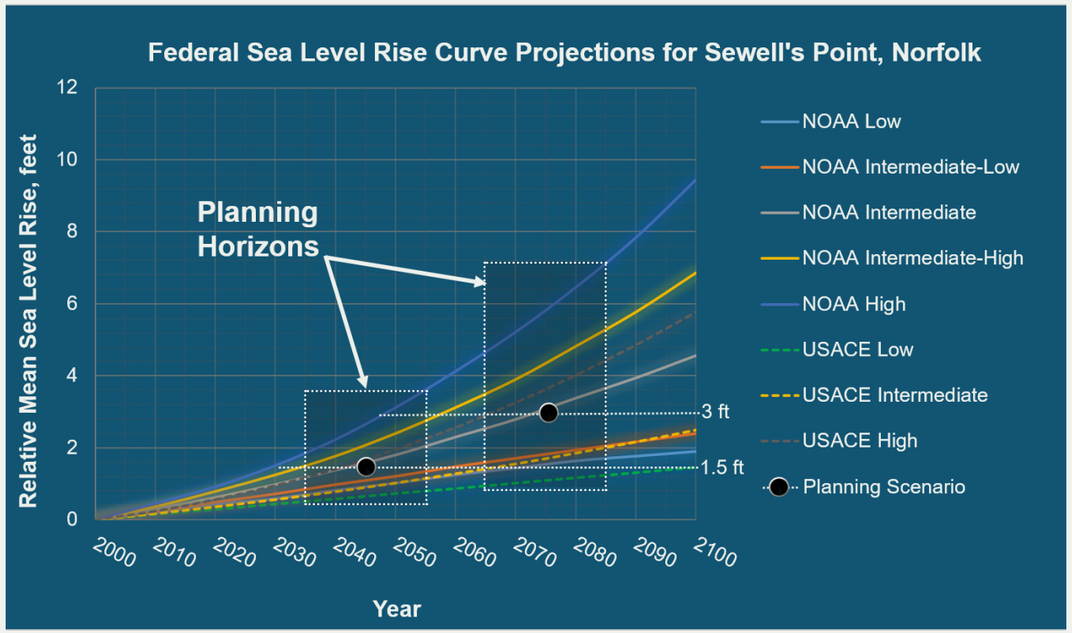
There is agreement that these planning scenarios are reasonable for Hampton Roads. In 2018, the Hampton Roads Planning District Commission unanimously adopted resolution number 2018-01, recommending that the region use the 1.5 foot scenario for near-term planning, 3 foot scenario for mid-term planning, and a 4.5 foot scenario for longer-term planning.

The City recognizes that the science behind the projections is continually improving. The City will review studies and new projections as they are released. Our planning and design scenarios will be updated as needed based on this information. Sea level rise scenarios for any critical infrastructure project design will be evaluated against expected life-span of the project and adjusted accordingly.

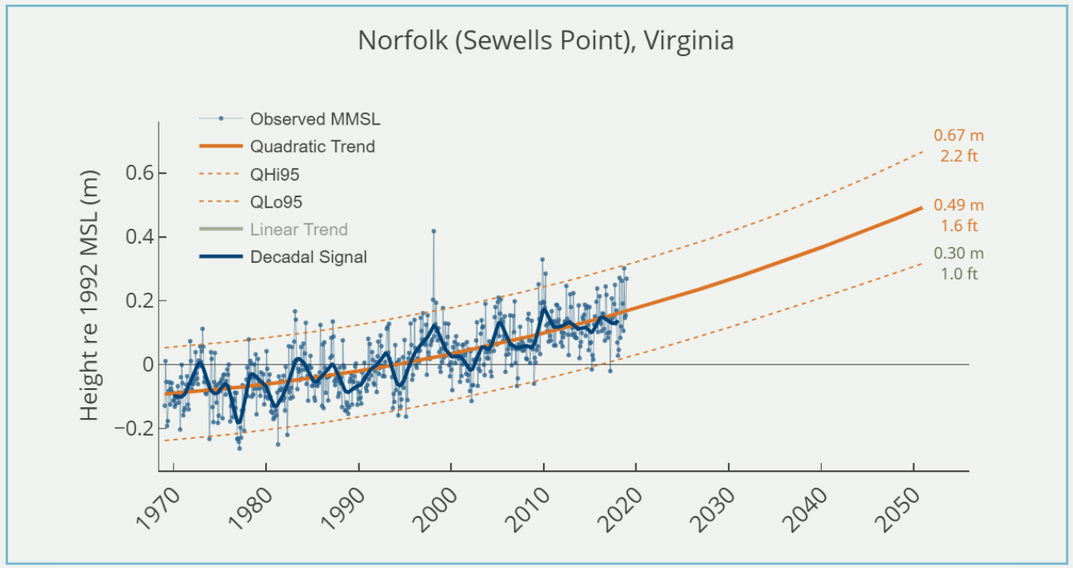
Monthly mean sea levels and long-term trend from historical observations from 1927 to present [7]



Full range of federal relative sea level rise projections for Sewell's Point, Norfolk [8]



Sea level rise projection for 2050 based on analysis of sea level rise acceleration at Sewell's Point [9]



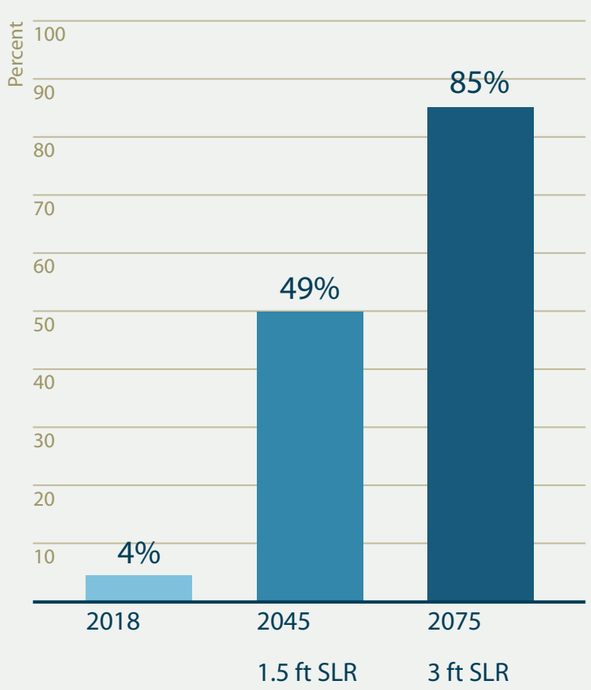
Recurrent Flooding

As sea levels rise in Virginia Beach, it no longer takes a strong storm or hurricane to cause coastal flooding. Flooding now occurs with high tides in many low-lying coastal areas, even on sunny days. This type of flooding is often referred to as "recurrent flooding" because it occurs relatively frequently. These low- levels of inundation typically do not pose significant threats to public safety, but can cause minor property damage, disrupt routine day-to-day activities, and put added strain on infrastructure such as roadways and storm systems. There are two primary types of nuisance flooding in Virginia Beach – tidal and wind-tide flooding.

NOAA defines the "nuisance" flood level, or the level at which a coastal flood advisory is issued, as 2.89 feet (NAVD 88) for Sewell's Point in Norfolk.[10] This elevation is similar to conditions found in the Elizabeth River and Lynnhaven Watersheds, and to a lesser extent, the Oceanfront. In today's conditions, the City may experience this type of condition about 30 times a year, depending on the weather.

Percent of High Tides with Nuisance Flooding under Sea Level Rise (SLR) Conditions

A nuisance flood condition happened for about 4 percent of high tides in 2018. With 1.5 feet of sea level rise, nuisance flooding is expected to occur with 49 percent of high tides, and for 85 percent of the high tides with 3 feet of sea level rise.



Wind Tide Flooding

This type of recurrent flooding can be caused by winds that blow persistently in one direction for long periods of time. Winds can push water onto shorelines and into coastal bays and waterways, causing flooding in low- lying areas.

The amount of flooding depends on the wind direction, duration, and velocity, and whether it is raining during the wind tide. Wind tide flooding is especially prominent in southern Virginia Beach because of the large bodies of water that allow wind to blow with minimal resistance. Five large-scale wind driven flood events occurred between 2017 and 2019, causing mounting concerns from residents and stakeholders.

The City has made significant investments in sophisticated computer models and water level gages to better understand water levels and processes.

See the Southern Rivers Watershed chapter for more information.

High Tide Flooding

Tides are the rise and fall of the sea level on a daily basis, caused by the combined effects of the gravitational forces exerted by the moon and the Sun, and the rotation of the Earth. Extreme high tides, known as perigean or "king tides" occur a few times a year when the sun, moon, and earth align. In Virginia, these events typically happen in the fall. These events can generate widespread flooding of the lowest-lying areas.

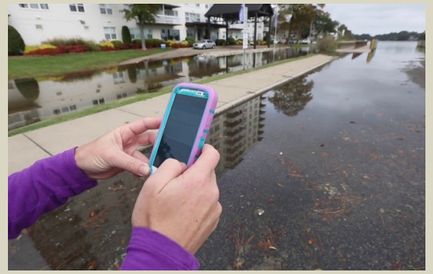
Scientists in our region are keeping a close eye on king tides because they are harbingers of future flood vulnerability. With rising sea levels, these events are expected to reach even further inland and inundate land for a longer period of time.

In the future, land that is currently dry may experience tidal flooding during normal, daily high tides. Flood extents of future high tide flooding, defined by NOAA as Mean Higher High Water, provides information on what land and or property will be essentially "permanently inundated" or lost to flooding with sea level rise.

Catching the King*

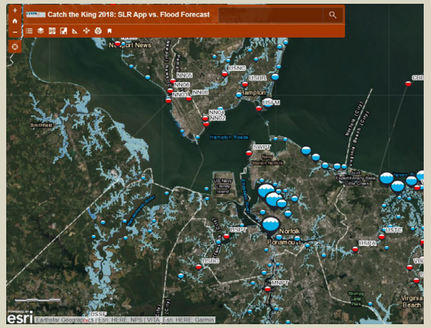
Catch the King is a citizen science data collection effort in our region to map flooding during king tides. This information will help scientists improve flood forecasts and give planners and elected leaders a better handle on our risks from high tide flooding.

Volunteer Opportunities



Ready to help? Download the mobile app for Hampton Roads that you will need to participate in the next king tide mapping event. You can also sign up to be a (Volunteer) King Tide Mapper, King Tide Captain, or Tide Watcher.

- **King Tide Mappers** use the app to drop GPS pins the day of the high tide. Before starting, you'll need to go through training with the app. After training, you'll be assigned to a Tide Captain who'll help you choose a mapping location on the big day. This prevents us from having too many volunteers mapping the same location.
- **King Tide Captains** perform mapping duties and manage a small team. Every big project needs leaders, and here's your chance to step up. Tide Captains lead small groups of mappers, helping to make sure they're trained in the SeaLevelRise app and working with our Volunteer Coordinator to choose mapping areas. Captains are encouraged to host practice mappings of their own.
- **Tide Watchers** document flooding at trouble spots along the shore. Sign up as a Tide Watcher, and we'll help you learn how to record flooding trouble spots throughout the year. This helps us get a better handle on where the risks are located and might help your neighborhood push for action on a pressing problem.



How can you find out if King Tides are coming?

It's a simple matter of looking at tide charts. You can search many years in advance for the astronomical tide predictions for hundreds of tide stations in the U.S. The closest tide stations to Virginia Beach are Sewell's Point in Norfolk, Virginia and Duck, North Carolina. Click on these stations on this list and you can check out predictions for any 31-day period.

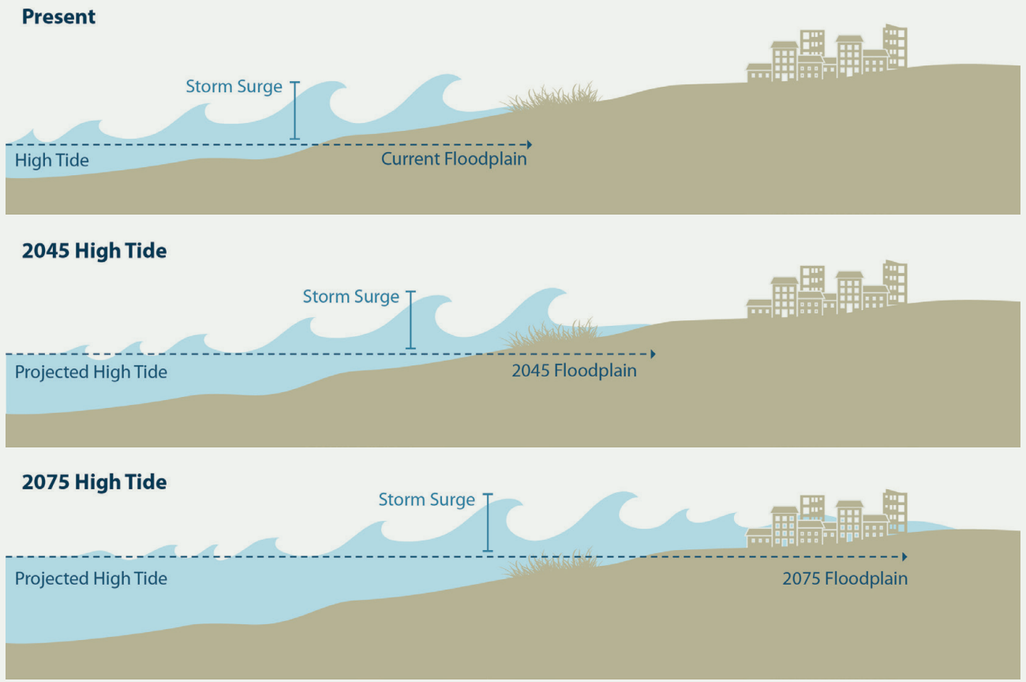
*All excerpts come from the Catch the King website - https://kingtide.whro.org/

Storm Surge Flooding

Storm surges are major coastal flooding events often accompanied by several days of sustained winds, northeasters, tropical storms, and hurricanes. These events can result in significant flooding, structural damage, and substantial economic impacts. Flooding can often be worse when the storm makes landfall during high tide. As sea levels continue to rise, storm surges will be able to reach even further inland.

The extent of storm surge flooding depends on the characteristics of the particular storm and the direction it approaches the coast. FEMA performs a statistical analysis of many potential storms to define the 100-year return period flood – which defines the regulatory floodplain on FEMA flood maps.

When assessing vulnerability to coastal flooding, rather than just looking at one type of storm, the statistical analysis behind FEMA's flood maps was used to look at a range of conditions. Storm surge flooding was assessed for a range of five storm surge conditions, all the way from the small, more frequent events to the catastrophic, rare events. This included the 10-, 25-, 50-, 100-, and 500-year flood events.



Sea level rise raises the relative elevation of water to the ground. Over time, high tides and flood events reach further inland, impacting areas that were previously safe from flooding[11].

10-YEAR MINOR FLOOD EVENT

The 10-year flood event has a 10 percent chance of occurring in a given year and is the current standard for designing storm drainage improvements. Structures located in the 10-year floodplain have a 96 percent chance of flooding at least once during the typical 30-year mortgage period.

25-YEAR MODERATE FLOOD EVENT

The 25-year event has a 4 percent chance of occurring in a given year. Structures located in the 25-year floodplain have a 71 percent chance of flooding at least once during the typical 30-year mortgage period.

100-YEAR MAJOR FLOOD EVENT

A 100-year flood event has a 1 percent chance of occurring in any given year and is a low frequency, but high-impact event often considered for emergency preparedness and design. The 100-year floodplain is also known as a Special Flood Hazard Area (SFHA) on a Federal Emergency Management Agency (FEMA) Flood Insurance Rate Map (FIRM). Structures located in a 100-year floodplain have a 26 percent chance of flooding at least once during the typical 30-year mortgage period.

500-YEAR CATASTROPHIC FLOOD EVENT

A 500-year flood event has a very low chance of occurring in any given year (0.2 percent). While structures located in the 500-year floodplain only have a 6 percent chance of flooding at least once during a 30-year period, impacts can be catastrophic given the amount of storm surge required to push coastal flooding so far inland.

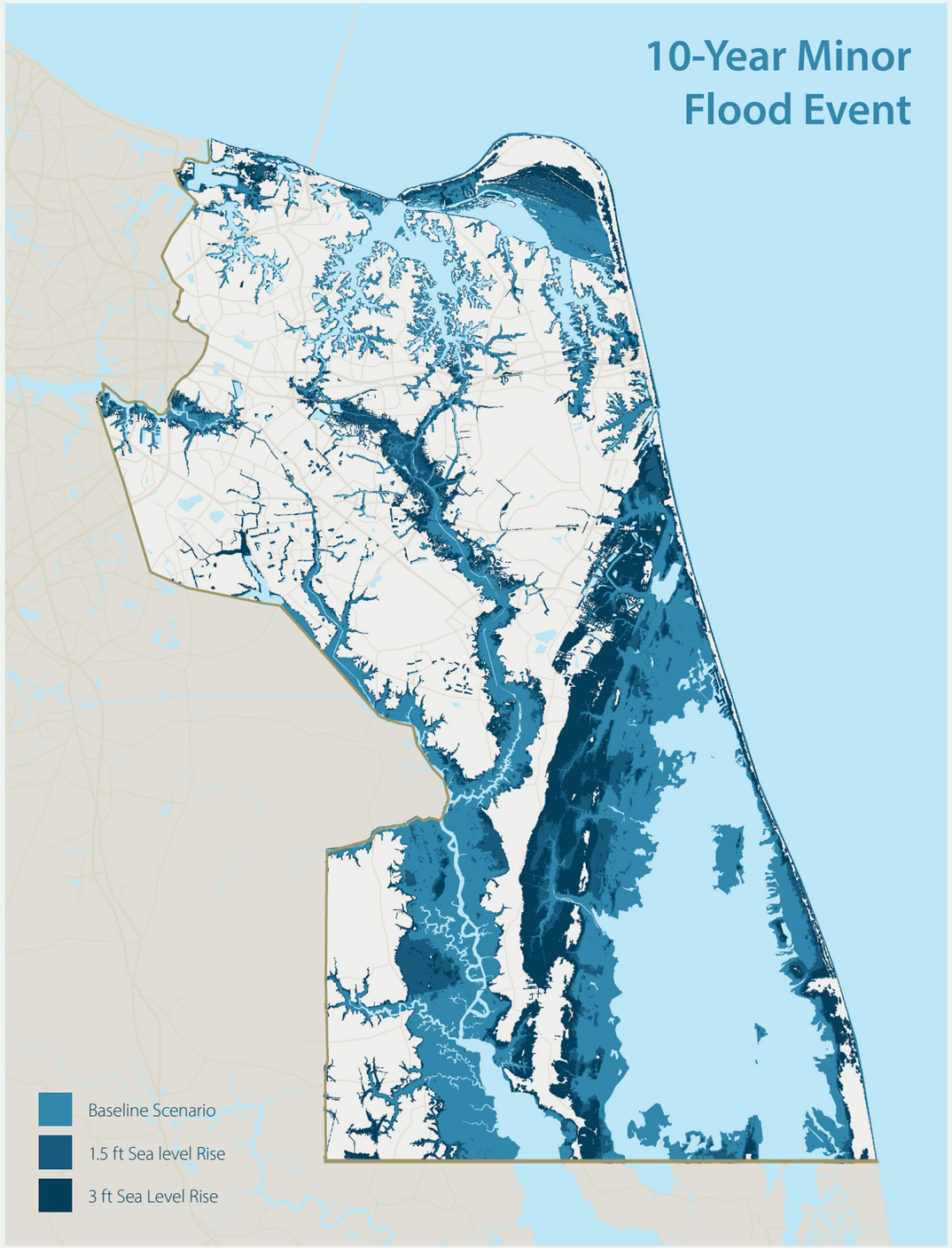
As sea level rise increases the water elevation relative to land, flooding becomes more frequent. In the future, smaller storm events will cause the same amount of flooding as large events today. For example, in today's water condition, a 100-year coastal flood is defined as a 6.9 foot water elevation in the Lynnhaven Bay.[12] Today's more severe flood conditions will become much more common in the future. This is because future water levels will be higher relative to land due to relative sea level rise. It then takes a smaller storm event to cause the same amount of flooding a larger storm event creates today. For example, today, a flood water level of 7 ft within Lynnhaven Bay has a 1 in 100 odds of occurring any given year. With 1.5 ft of sea level rise, these odds increase to 1 in 14. In a scenario with 3 ft of sea level rise, the odds would be 1 in 3.

Projected Changes in Flood Recurrence as estimated for the Lynnhaven Bay [13]

Scenario	10 yr return period	50 yr return period	100 yr return period	500 yr return period
Today	1 in 10	1 in 50	1 in 100	1 in 500
1.5 ft SLR	1 in 3	1 in 8	1 in 14	1 in 100
3 ft SLR	1 in 1	1 in 2	1 in 3	1 in 14

The increasing odds of flooding with future sea level rise (SLR).

10-Year Minor Flood Event



100-Year Major Flood Event