January 2020

Virginia Beach

Sea Level Wise

Adaptation Strategy

DRAFT

Sea Level Wise
A vibrant future for Virginia Beach

Acknowledgments

The City of Virginia Beach would like to recognize the following for their contributions to the contents of this report:

City of Virginia Beach, City Manager's Office
for guidance and review

City of Virginia Beach, City Manager's Working Group on Sea Level Rise
for guidance and review

City of Virginia Beach, Department of Public Works
for project management, review, and technical support

City of Virginia Beach, Department of Planning and Community Development
for project coordination and review support

City of Virginia Beach, Department of Emergency Management
for project coordination and review support

Dewberry
for report preparation, graphics, and technical analysis, where not otherwise attributed

City of Virginia Beach photographer and staff
for report images, where not otherwise attributed

WPL
for renderings of conceptual city-wide defense structures

Georgetown Climate Center
for background legal and adaptation strategy research and engagement

Old Dominion University
for facilitation of the ASERT public engagement process and surveys

The Miles Agency
for public engagement facilitation

MetStat, Inc.
for data preparation in support of rainfall analysis, and analysis of southerly wind conditions

Syndeste
for flood insurance data analysis

We would like to thank Dave Hansen, John Fowler, C. Gregory Johnson and Shanda Davenport for initiating, leading, and providing the institutional insight into the impact of sea level rise on the City of Virginia Beach.

This is a work product of National Oceanic and Atmospheric Administration Office of Coastal Management award number NA16NOS4730011

Table of Contents

Acknowledgments iv
Table of Contents v
Key Terminology xi
Executive Summary 2

PART I INTRODUCTION 6

A Call to Action 8
- Observed Flooding Impacts 10

Becoming Sea Level Wise 12
- Program Phases 14
- Community Engagement 16
- Regional Connections 20

PART II UNDERSTANDING FLOOD RISKS 22

Our Coastal Context 25
- Coastal Flood Pathways 26

The Challenge of Rising Sea Levels 29
- Sea Level Rise Scenarios 30
- Recurrent Flooding 32
- Storm Surge Flooding 36

Compounding Factors 41
- Coastal-Rainfall (Compound) Flooding 42
- Urban Development 44
- Aging Infrastructure 46
- Groundwater Changes 48
- Ecological Decline 50

Flood Impacts 55
- The Cost of Inaction 56
- Where are Losses Occurring? 58
- Physical Damages 60
- Indirect Economic Impacts 62
- Social Implications 64

PART III ADAPTATION FRAMEWORK 66

Multiple Layers of Adaptation 68
Integrating Policy and Planning 70
City-Wide Objectives 72
Envisioning an Adapted Virginia Beach 75

NATURAL MITIGATIONS 77

Preserve Environmental Assets 79
Land Conservation Techniques 80
Increase Natural and Nature-Based Features 83
Non-Structural Protections 84
Hybrid Protections 86

ENGINEERED DEFENSES 89

Pursue an Expansive Flood Defense Network 91
Inland Structural Defenses 92
In-Water Structural Defenses 94

ADAPTED STRUCTURES 103

Regulate Building and Development 105
Siting and Design Regulations 106
Support Risk-Mitigating Interventions 111
Site-Scale Mitigation Methods 112
Financial Incentives and Assistance 116
Minimize Infrastructure Vulnerabilities 119
Infrastructure Management Techniques 120

PREPARED COMMUNITIES 123

Grow Educational Outreach 125
Engagement Methods 126
Promote Economic Resilience 129
Economic Resilience Techniques 130

PART IV WATERSHED STRATEGIES 134

Watershed Approach 136
Applying the Adaptation Framework 138

ELIZABETH RIVER 141

Community Context 143
Flood Pathways and Extents 145
Notable Impacts 146
Adaptation Vision 148
Living Shoreline 151
Marsh Restoration 152
Land Conservation 153
Elizabeth River City-Wide Alignment 154
Commercial Floodproofing 158
Floodplain Regulation 159
Resilient Roadways 160
Responsible Development 161
Building Elevation 162
Business Outreach and Education 163
Flood Insurance Expansion 164
Residential Community Education 165

LYNNHAVEN 167

Community Context 169
Flood Pathways and Extents 171
Notable Impacts 172
Adaptation Vision 174
Beach and Dune Nourishment 177
Ecological Revetments 178
Land Conservation 179
Living Shoreline 180

Marsh Restoration and Creation 181
Shellfish Reefs and Oyster Restoration 182
Seagrass Restoration 183
Chesapeake Bay City-Wide Alignment 184
West of Lesner Bridge Neighborhood Alignment 188
East of Lesner Bridge Neighborhood Alignment 190
Commercial Floodproofing 192
Floodplain Regulation 193
Mitigation Reconstruction 194
Resilient Roadways 195
Responsible Development 196
Building Elevation 197
Business Outreach and Education 198
Flood Insurance Expansion 199
Residential Community Education 200

OCEANFRONT 203

Community Context 205
Flood Pathways and Extents 207
Notable Impacts 208
Adaptation Vision 210
Beach and Dune Nourishment 212
Ecological Revetments 213
Land Conservation 215
Marsh Restoration and Creation 216
Shellfish Reefs and Oyster Restoration 217
Atlantic Oceanfront City-Wide Alignment 218
Rudee Heights Neighborhood Alignment 222
Commercial Floodproofing 224
Floodplain Regulation 225
Mitigation Reconstruction 226
Resilient Roadways 227
Responsible Development 228
Structure Elevation 229
Business Outreach and Education 230
Flood Insurance Expansion 231
Residential Community Education 232

SOUTHERN RIVERS 235

Community Context 237
Flood Pathways 239
Sustained Southerly Winds 240
Flood Extents 243
Notable Impacts 244
Adaptation Vision 246
Beach and Dune Nourishment 248
Land Conservation 250
Living Shorelines 251
Marsh Restoration and Creation 252
Seagrass Restoration 254
West Neck Creek City-Wide Alignment 256
Muddy Creek Road City-Wide Alignment 260
Sandbridge City-Wide Alignment 264
Alternatives to Sandbridge and Muddy Creek Road City-Wide Alignments 270
Building Elevations 272
Commercial Floodproofing 273
Floodplain Regulation 274
Mitigation Reconstruction 275
Responsible Development 276
Resilient Roadways 277
Residential Community Education 278
Business Outreach and Education 279
Flood Insurance Expansion 280

PART V THE PATH FORWARD 282

Planning and Coordination 284

Planning Processes and Frameworks 286

Project Implementation 290

Federal Funding Sources 292

State Funding Sources 296

Other Funding Sources 298

Continued Commitment 303

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.

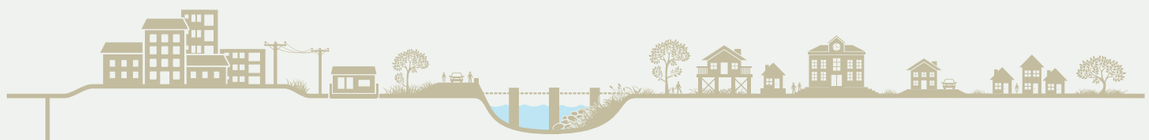
ADAPTED STRUCTURES

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:

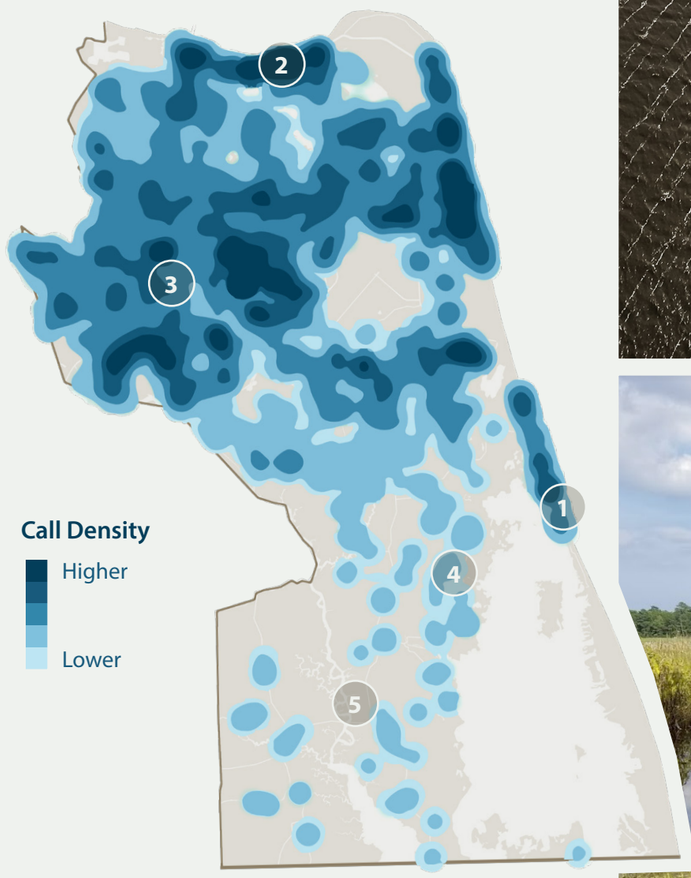
"The City firmly believes that the cost of damage done by ignoring sea level rise will far exceed the cost of mitigation."

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

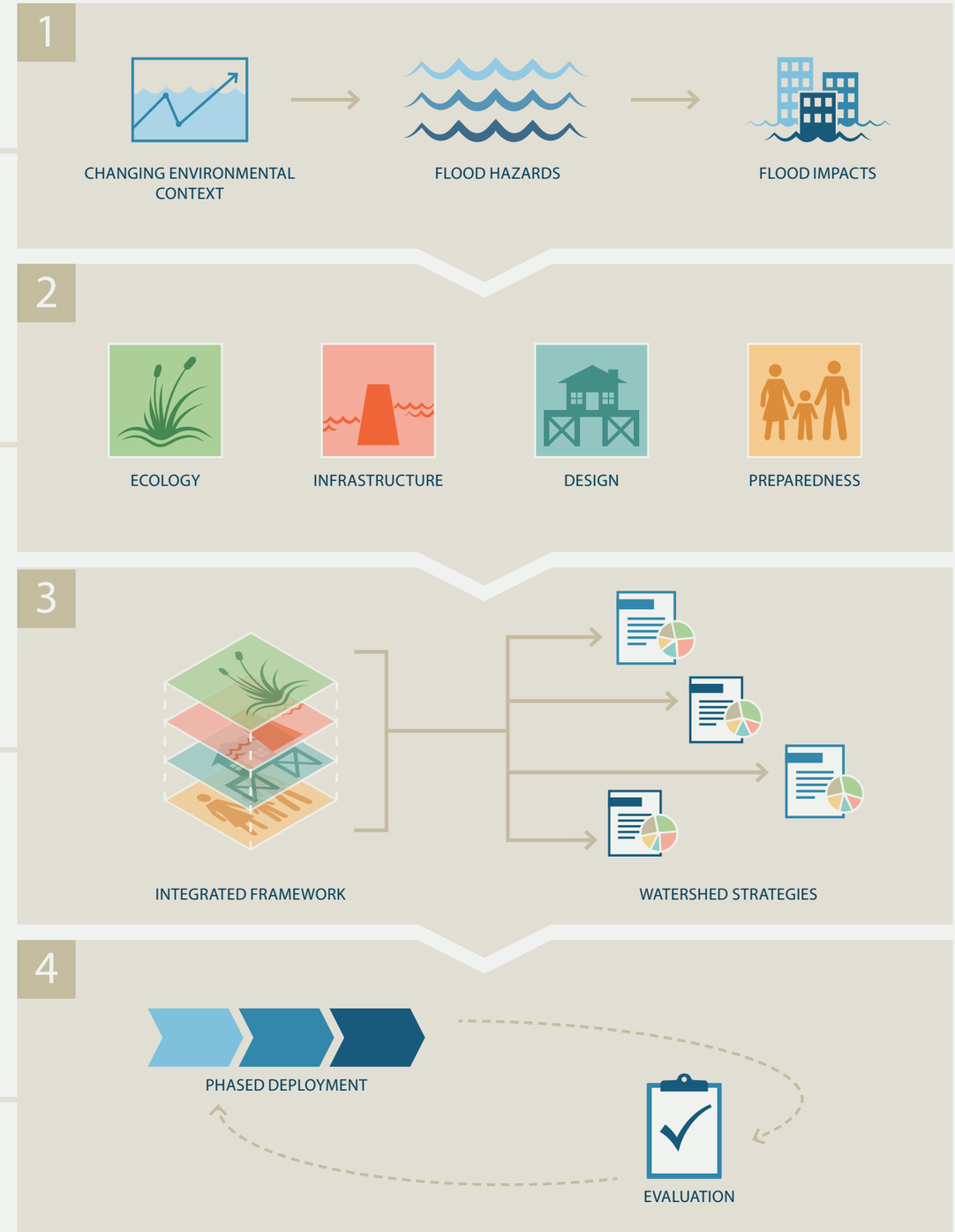
Phase two concentrated on developing and evaluating options for addressing short-term and long-term flood risks. Through targeted research efforts—focusing on the use of natural features, large- and small-scale infrastructure, parcel-level mitigation techniques, and policy and planning actions—an array 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.

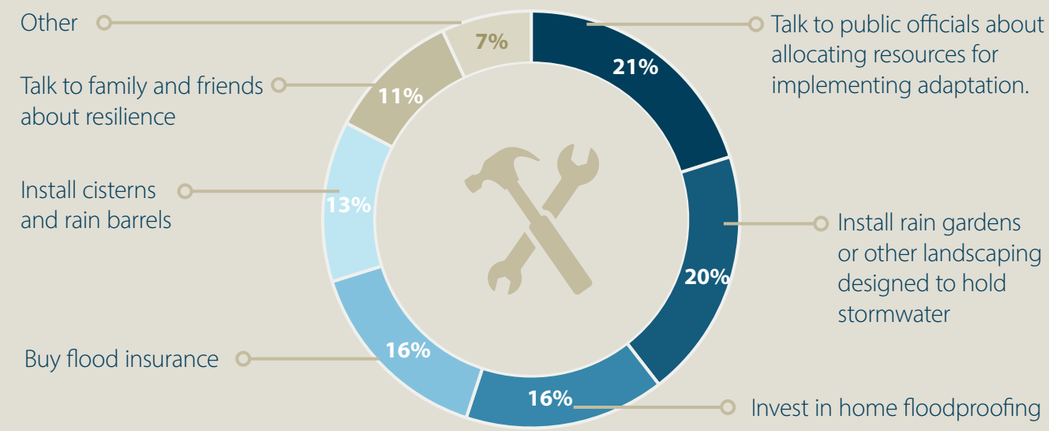
72% support using conventional bonds, such as revenue and general obligation bonds to fund a large-scale structural defense network.

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.

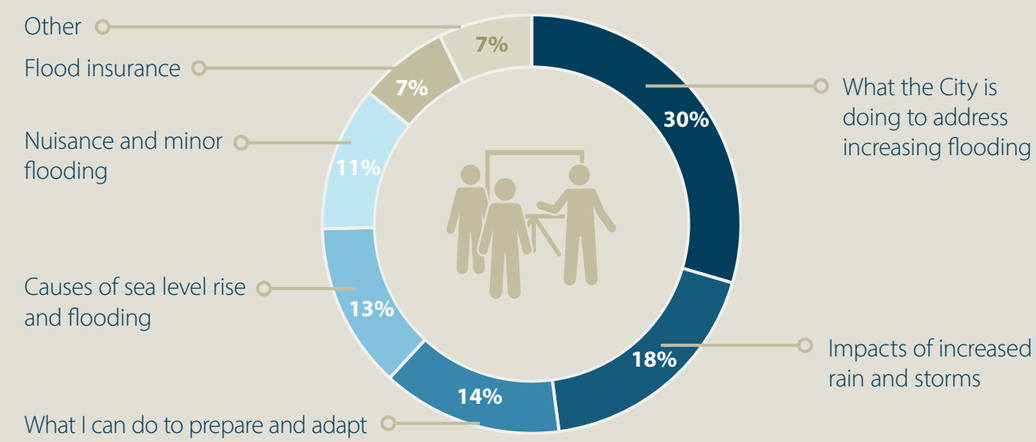
48% do not consider themselves well informed about increasing flooding and its causes and would be interested in more information from the City.

**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?



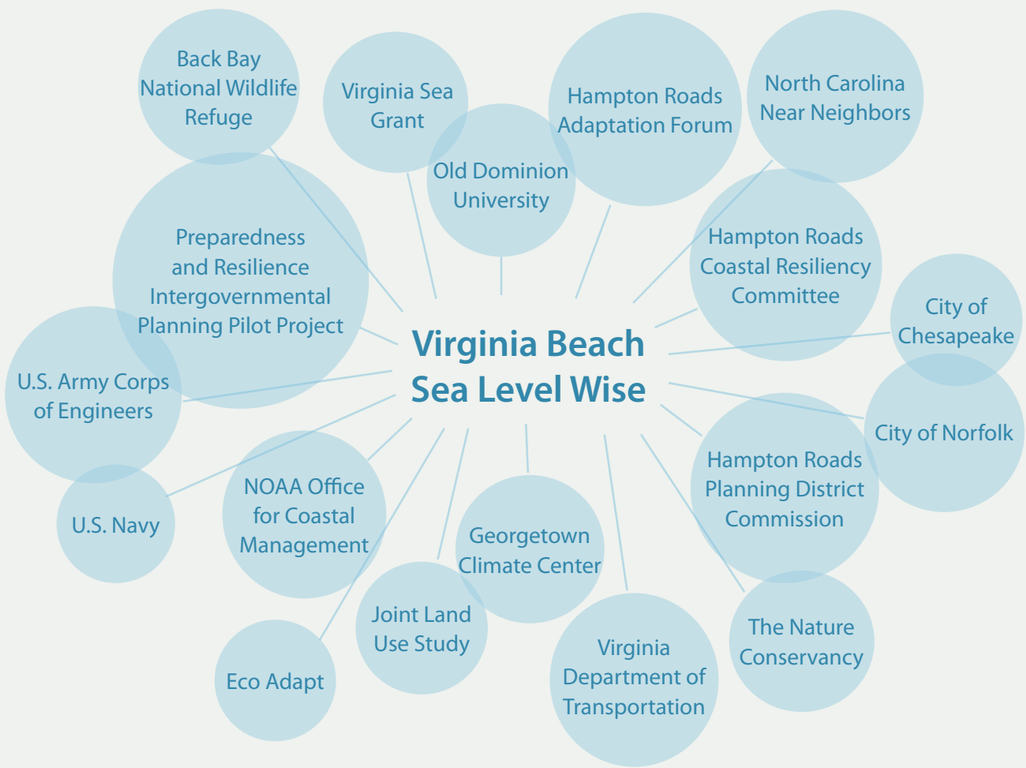
What would you like to know more about?



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

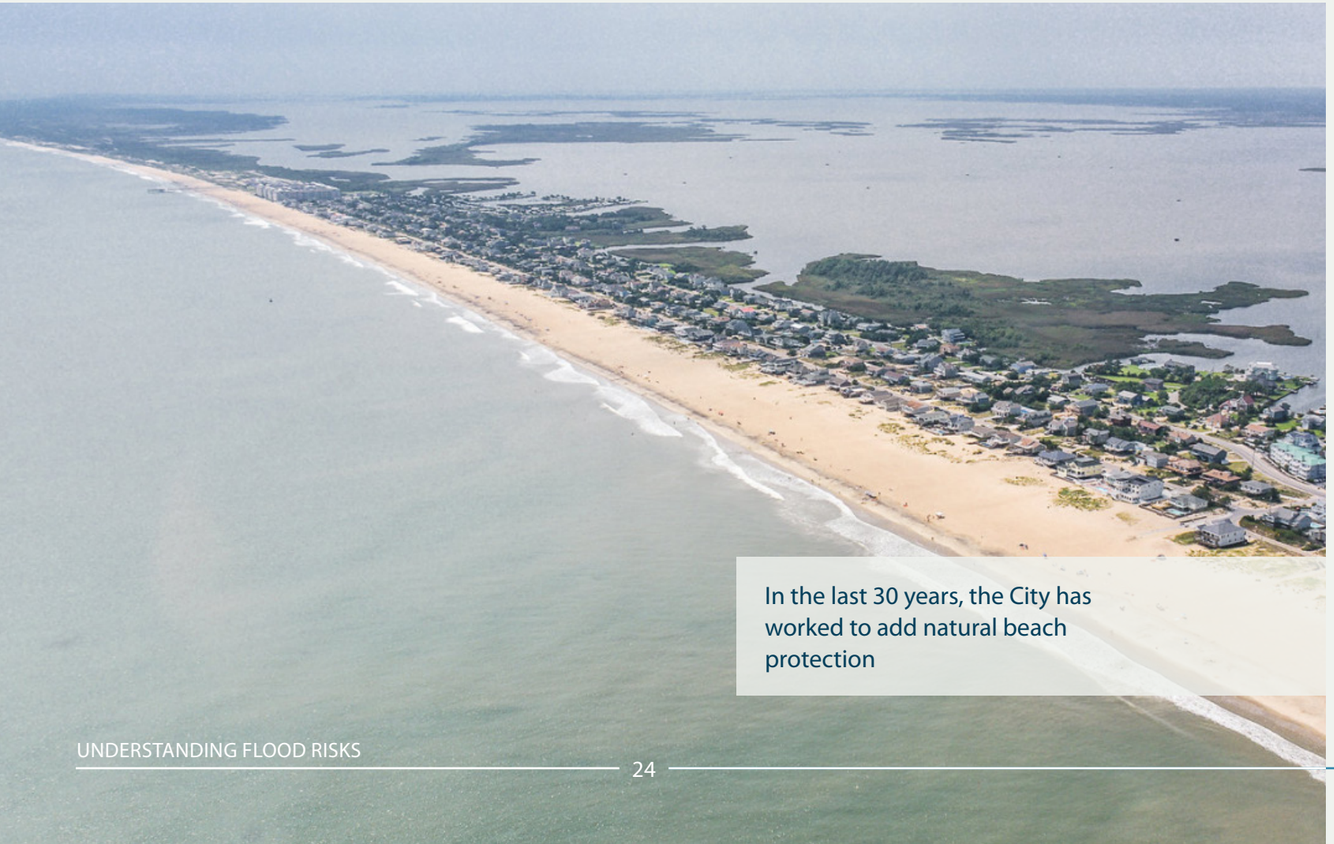
"As City Council discussed during the City Council's annual strategic planning workshop this year, effectively dealing with storm water, recurrent flooding and sea level rise is today's version of our historic Lake Gaston water pipeline project. That effort required a long planning horizon and the fortitude 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

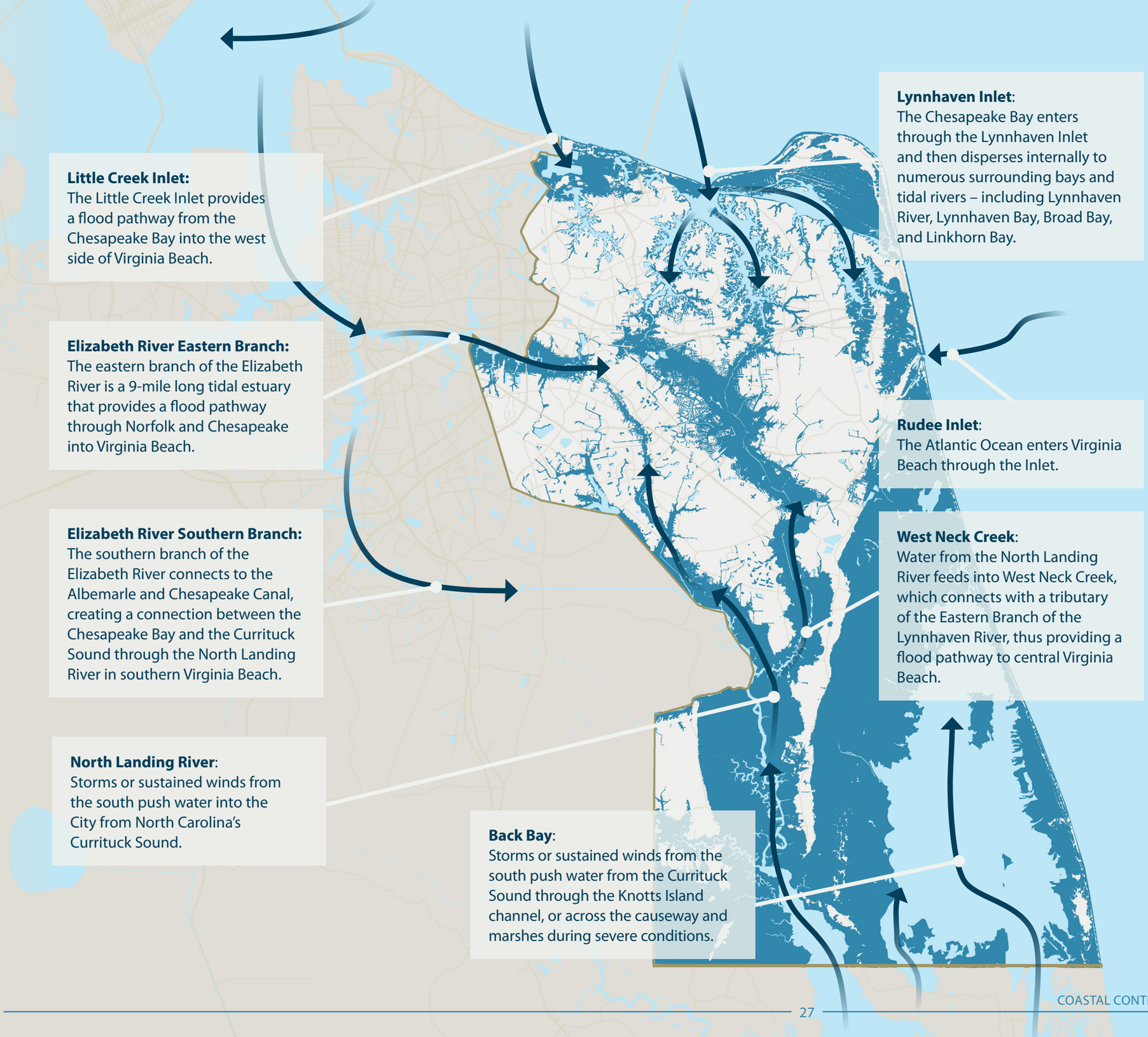
Coastal flooding occurs when land is flooded from tides, winds, nor'easters, or hurricanes that drive water into the City from its surrounding ocean, bays and rivers. Almost all of Virginia Beach's coastal flood risk is not on the open coast, but inside the City's coastal perimeter. This may be unexpected,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



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.

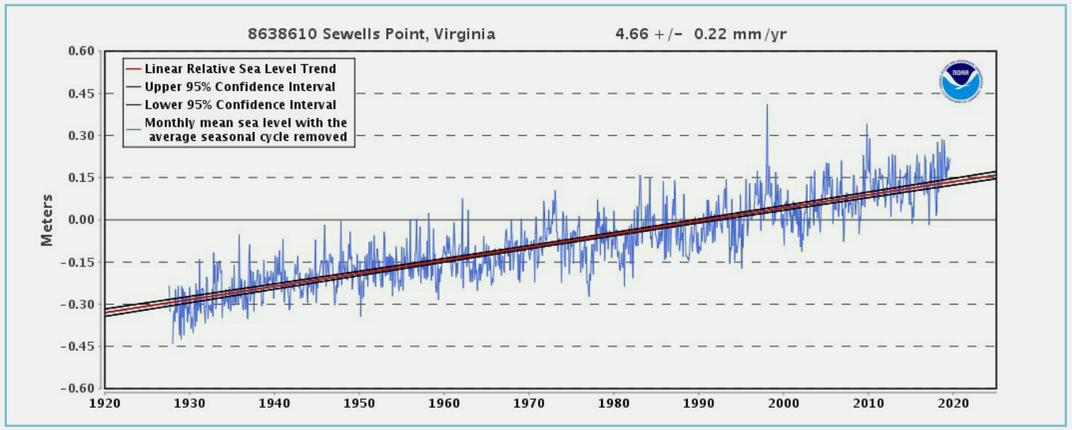
The City selected a sea level rise scenario of 1.5 feet to represent conditions from 2035-2050. This value will be used for near-term planning decisions. To represent conditions from 2065-2085, the City selected a 3 foot increase in sea level. This value is suitable for long-term planning decisions, 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.

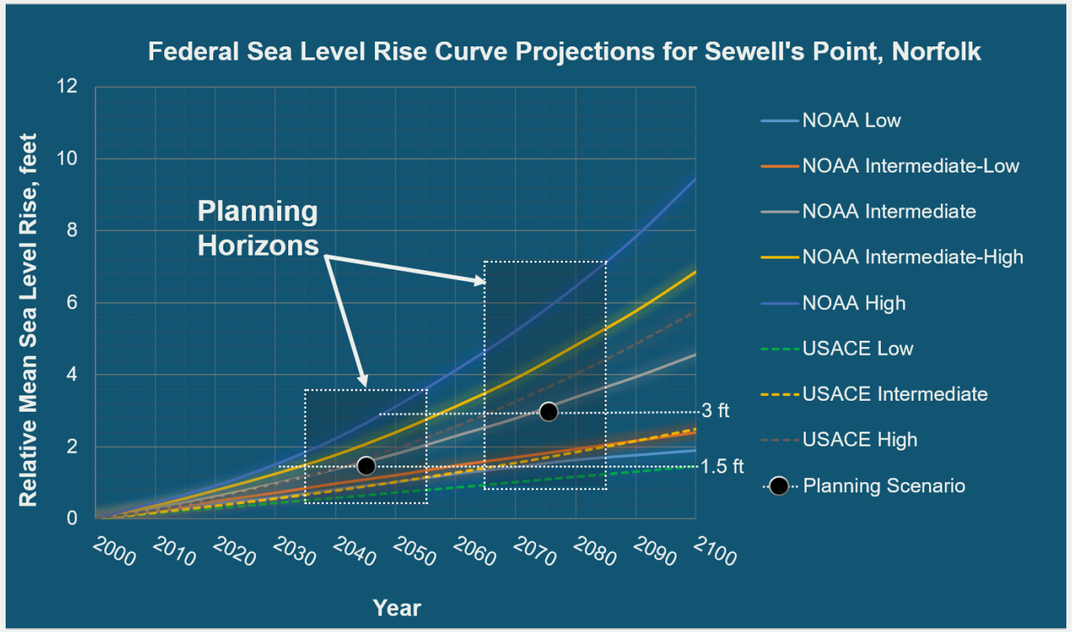
There is agreement that these planning scenarios are reasonable for Hampton Roads. In 2018, the Hampton Roads Planning District Commission unanimously adopted resolution number 2018-01, recommending that the region use the 1.5 foot scenario for near-term planning, 3 foot scenario for mid-term planning,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

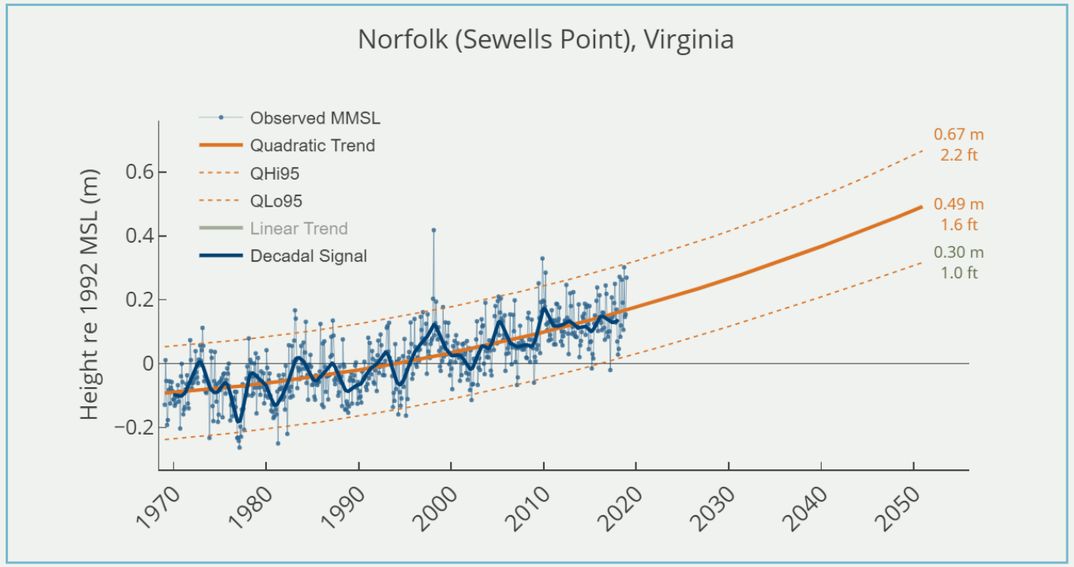
Monthly mean sea levels and long-term trend from historical observations from 1927 to present [7]



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]



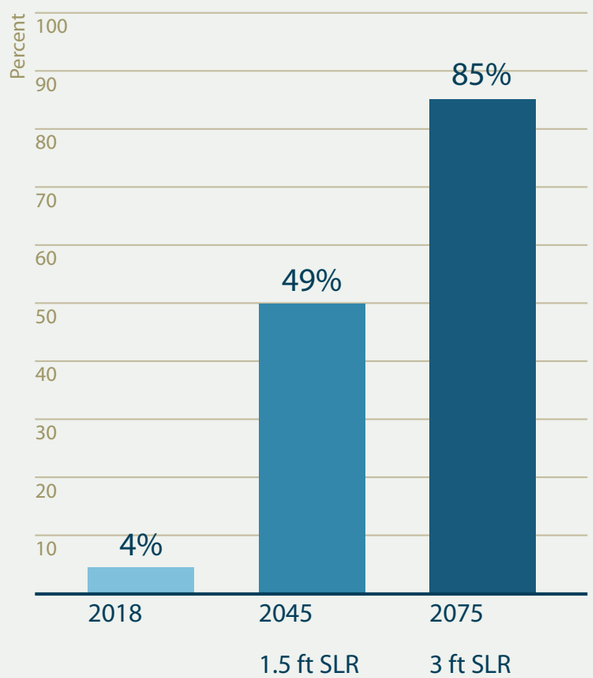
Recurrent Flooding

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.

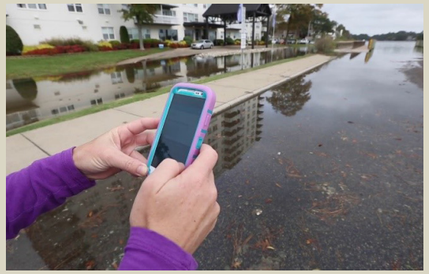
Scientists in our region are keeping a close eye on king tides because they are harbingers of future flood vulnerability. With rising sea levels, these events are expected to reach even further inland and inundate land for a longer period of time.

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*

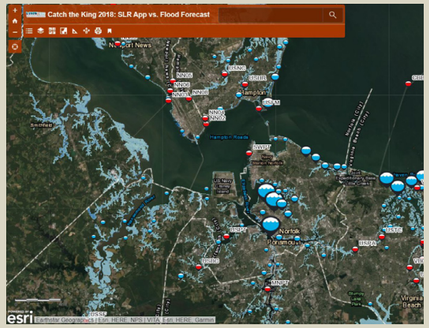
Catch the King is a citizen science data collection effort in our region to map flooding during king tides. This information will help scientists improve flood forecasts and give planners and elected leaders a better handle on our risks from high tide flooding.

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.

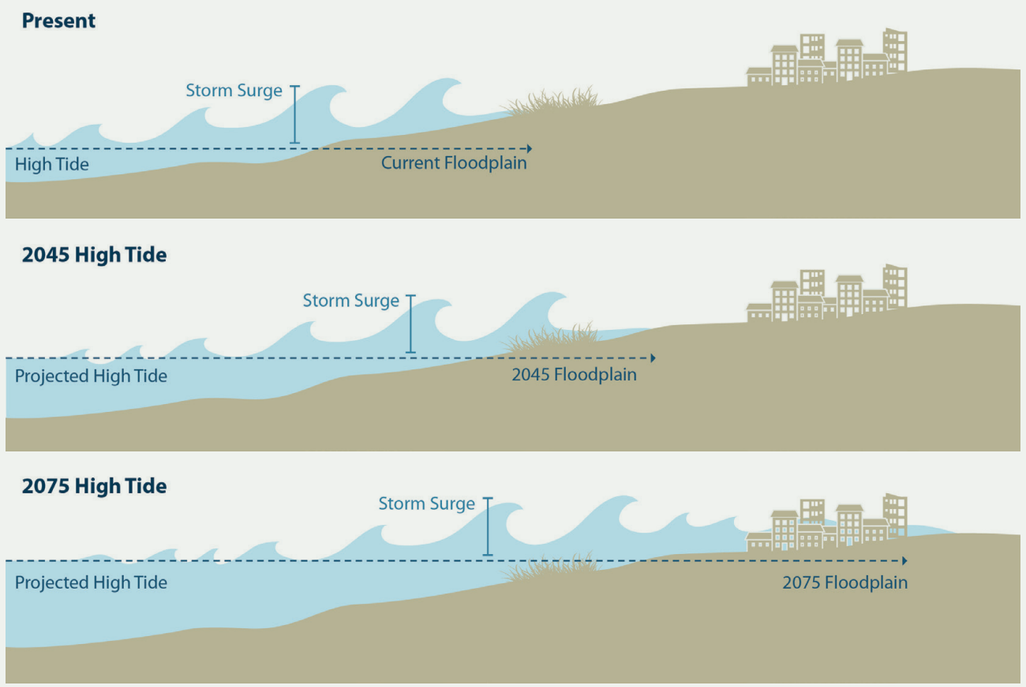
*All excerpts come from the Catch the King website - https://kingtide.whro.org/

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

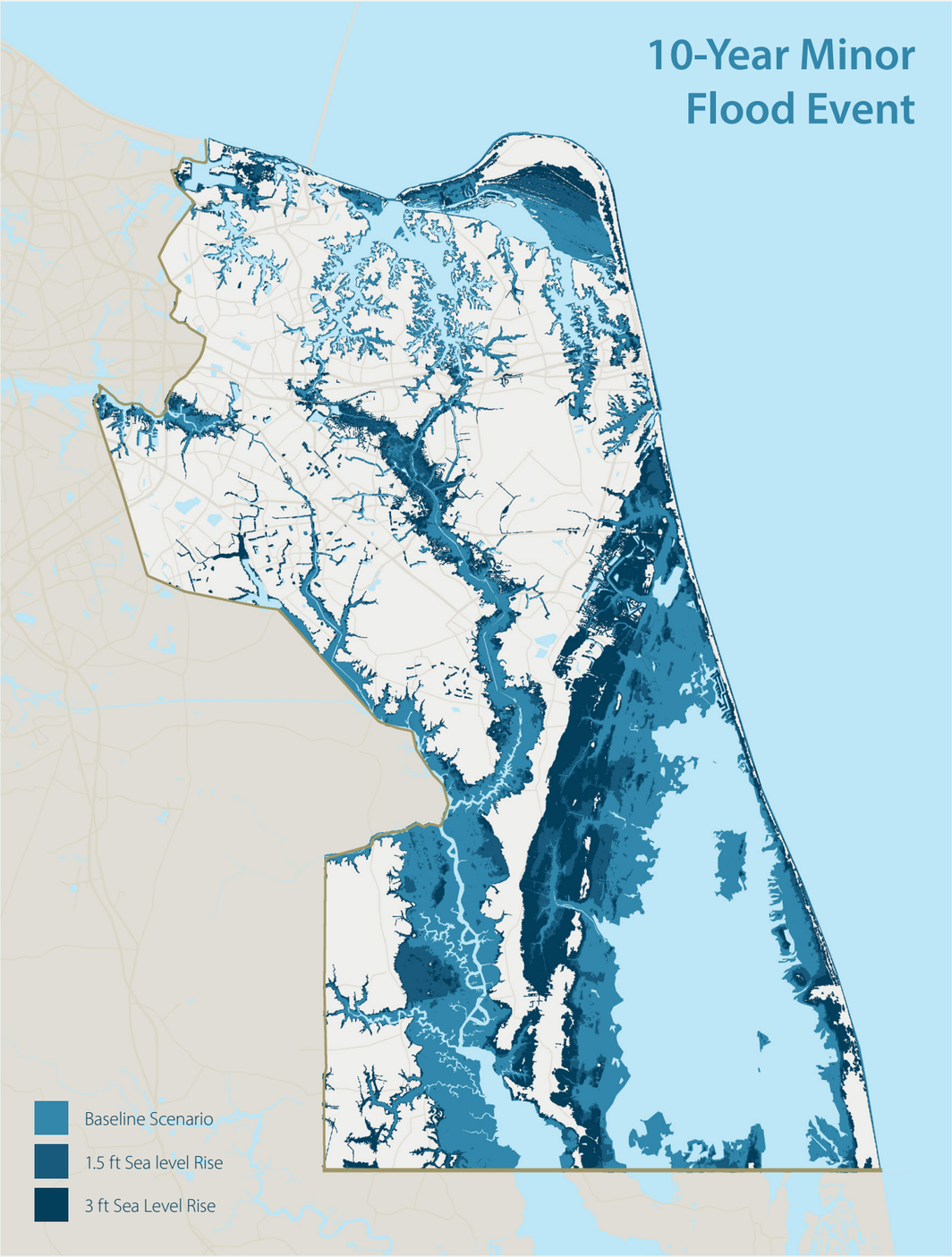
A 500-year flood event has a very low chance of occurring in any given year (0.2 percent). While structures located in the 500-year floodplain only have a 6 percent chance of flooding at least once during a 30-year period, impacts can be catastrophic given the amount of storm surge required to push coastal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

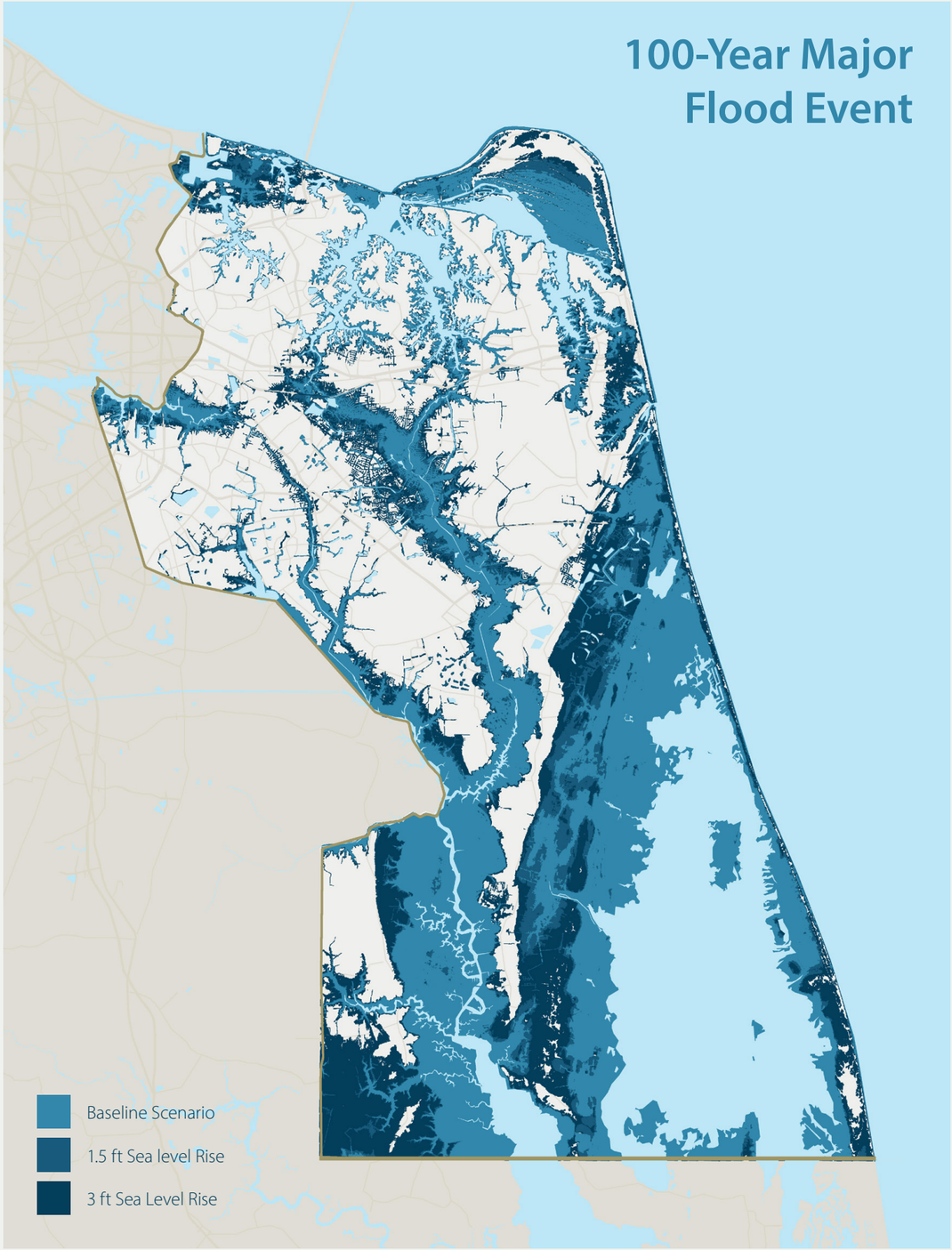
As sea level rise increases the water elevation relative to land, flooding becomes more frequent. In the future, smaller storm events will cause the same amount of flooding as large events today. For example, in today's water condition, a 100-year coastal flood is defined as a 6.9 foot water elevation 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).

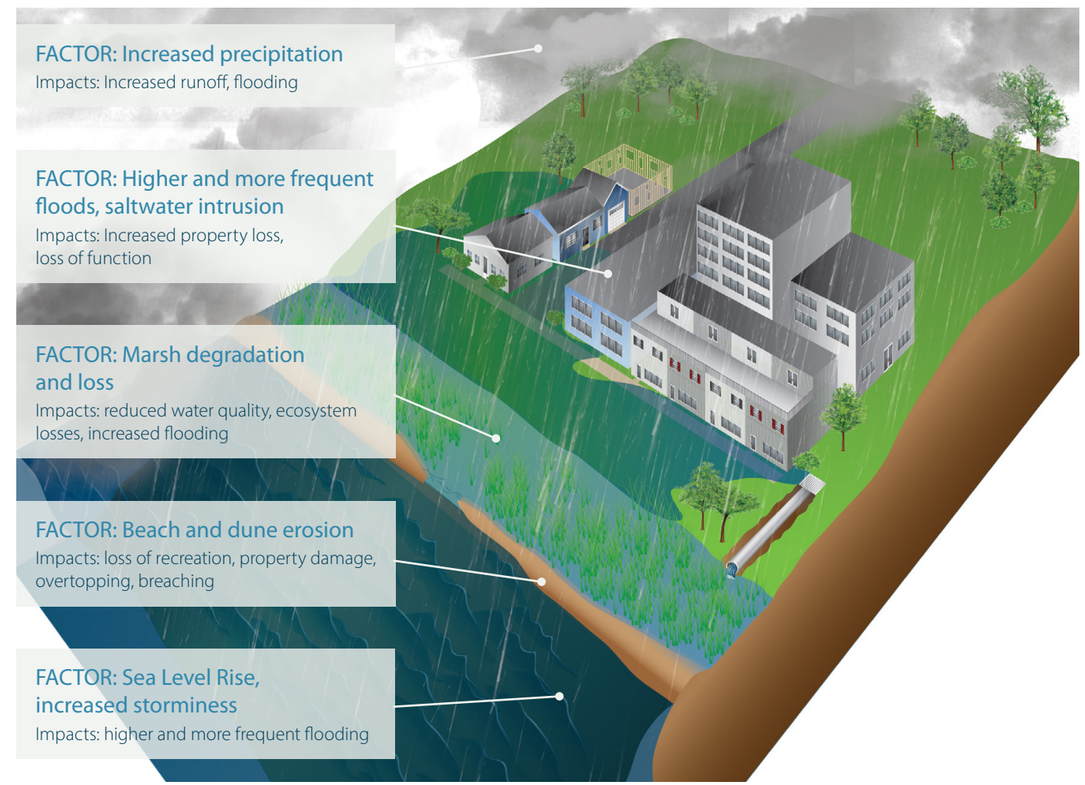

10-Year Minor
Flood Event
Baseline Scenario
1.5 ft Sea level Rise
3 ft Sea Level Rise


100-Year Major
Flood Event
Baseline Scenario
1.5 ft Sea level Rise
3 ft Sea Level Rise

Compounding Factors

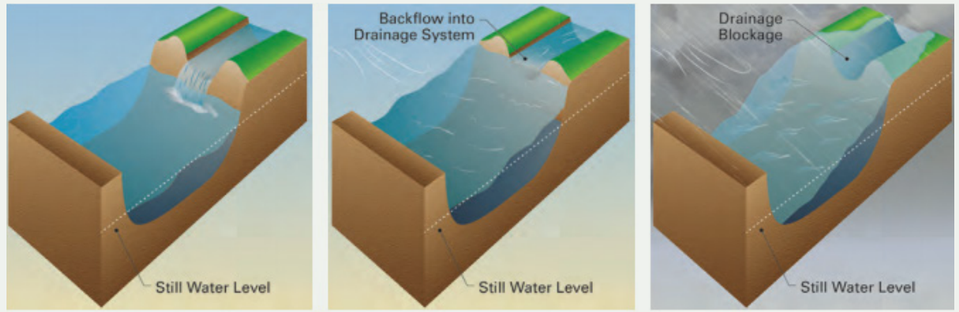
All flood types are exacerbated by compounding factors due to changes in both the natural and built environment.

Flooding can be affected by natural features and the built environment, and their ability to block, absorb, filter, and drain water properly. All these factors play a part in influencing the extent and depth of flooding.



Coastal-Rainfall (Compound) Flooding

Flooding can be much worse when both storm surge and rainfall happen at the same time. In an ideal condition, water from rainfall can easily drain from interior areas through the stormwater drainage system and into our coastal water bodies. When coastal water elevations are elevated, however, either due to extreme high tides or coastal storms, drainage of rainfall can become blocked. Water may flow upstream into drainage ditches and pipes, combining with stormwater runoff and resulting in more widespread flooding.



Storm surges can block stormwater drainage outfalls, causing stormwater systems to become overwhelmed and incapable of draining inland rainfall.

HOW OFTEN DOES HEAVY RAINFALL OCCUR WITH HIGH COASTAL WATERS?

In recent years, we have observed many cases of flooding where heavy rainfall appeared to coincide with elevated coastal water levels. The City completed an analysis to better understand this, comparing more than 60 years of historical rainfall records against maximum tide levels. It was found that over 50% of the rainfall events occurred while the water level was higher than average daily high tide. Given this, there is a high chance that the water level in coastal water bodies will be elevated when the City is experiencing a rainfall event. After this initial analysis, the City performed a joint-probability analysis to identify the probabilities of co-occurrence and made adjustments to design regulations to improve drainage capacity of future drainage projects.

IS RAINFALL CHANGING?

The City also found that the frequency of heavy rain events, where two or three inches of rainfall in a short period of time, are becoming more frequent. In 2016, Virginia Beach experienced 3 events with rainfall amounts greater than the 100-yr return period. This included Hurricane Matthew where Virginia Beach received a record-setting rain of more than a foot in 12 hours. The ground was already saturated from Tropical Storm Julia, which had flooded streets a few weeks earlier and left coastal water levels higher than normal.

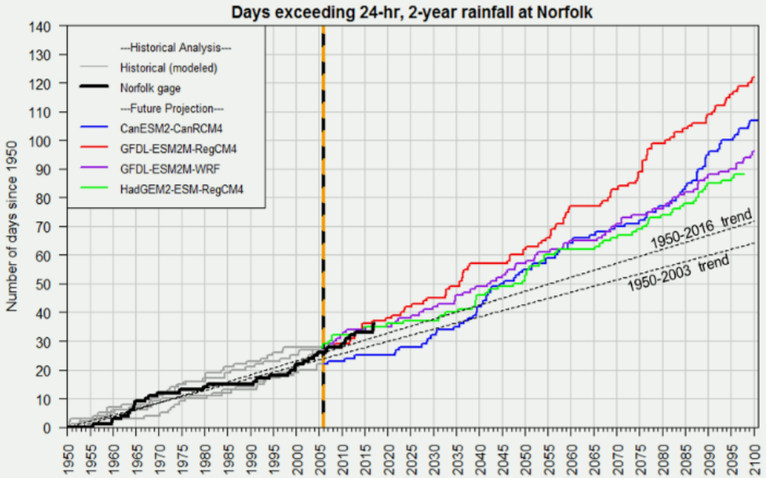
Stunned by the flooding from Hurricane Matthew, the City decided to undertake an analysis of heavy rainfall to see if conditions are changing. The analysis evaluated a historical rainfall record at the Norfolk Airport rain gage dating back to the early 1900s. The early part of the record shows us that heavy precipitation events have been increasing at about 3 percent per decade. From 1950 through today, we start to see a higher rate of change – at approximately 7 percent increase per decade.

Using an average increase of 5 percent per decade suggests a 20 percent increase over the next 40 years. Regional climate models that project changes in rainfall patterns around the world tell a similar story. These models show that the frequency of heavy rainfall events are deviating from the historical trend. The City is using this information to update the stormwater design standards to ensure new infrastructure can accommodate the anticipated increases in rainfall and elevated water levels along the coast over their design life.

The City is also bringing together coastal flood modeling from the Sea Level Wise with stormwater flood modeling from the Master Drainage Study to better understand the potential for combined coastal-stormwater flooding. By analyzing the two flood hazards together, we can provide a more comprehensive picture of flood risk.

Historical trends and projections of heavy precipitation

These projections show the number of two-year rainfall events, which can accumulate nearly 4 inches of rain in a day (24-hour period). The black line shows the historical trend whereas the colorful lines depict various model projections.

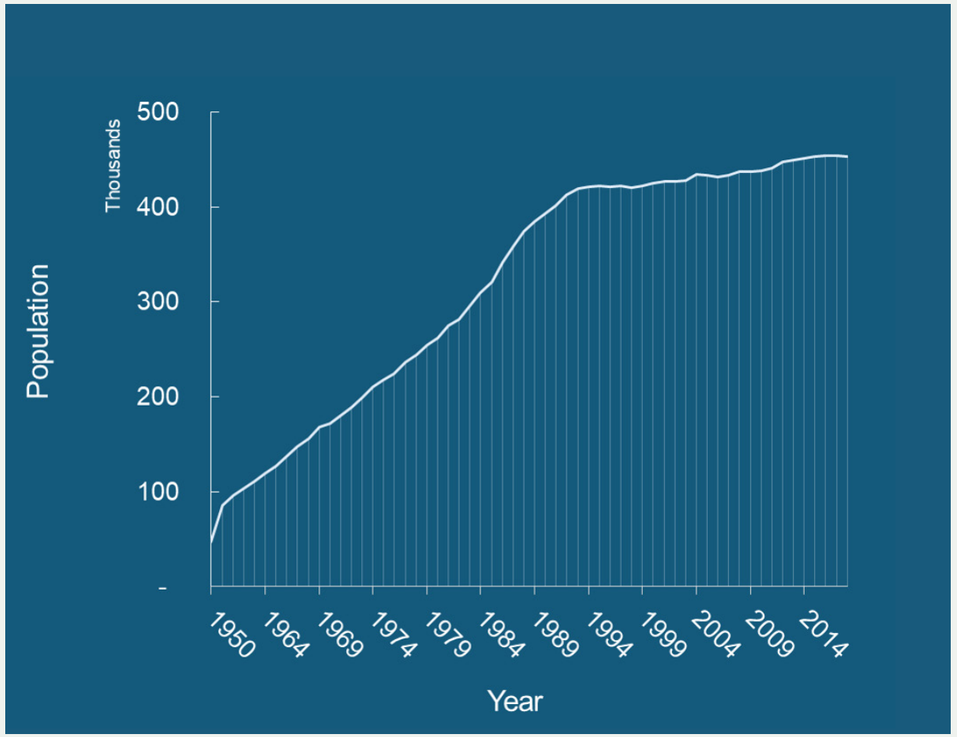


Urban Development

The City is comprised of both rural and urban areas. Recognizing the importance of preserving the City's rural areas, Virginia Beach established an innovative planning policy in 1979 by introducing the 'Green Line' urban growth management tool. This policy was designed to channel growth and infrastructure improvements to the northern half of the City. As developable land in this area built out over time into a sprawling suburban development pattern, the City recognized the need to accommodate future growth and preserve the established, stable residential neighborhoods in these areas.

The solution was to identify areas that could be redeveloped into more urban style areas – known as Strategic Growth Areas (SGAs).

While growth of the City and urban development in previously rural regions has been beneficial for the growth and economic prosperity of the community, it has significantly reduced green areas and open space throughout the City. The reduction of permeable surface areas into neighborhoods, business districts, and community areas has served to increase the flood risk of the community.



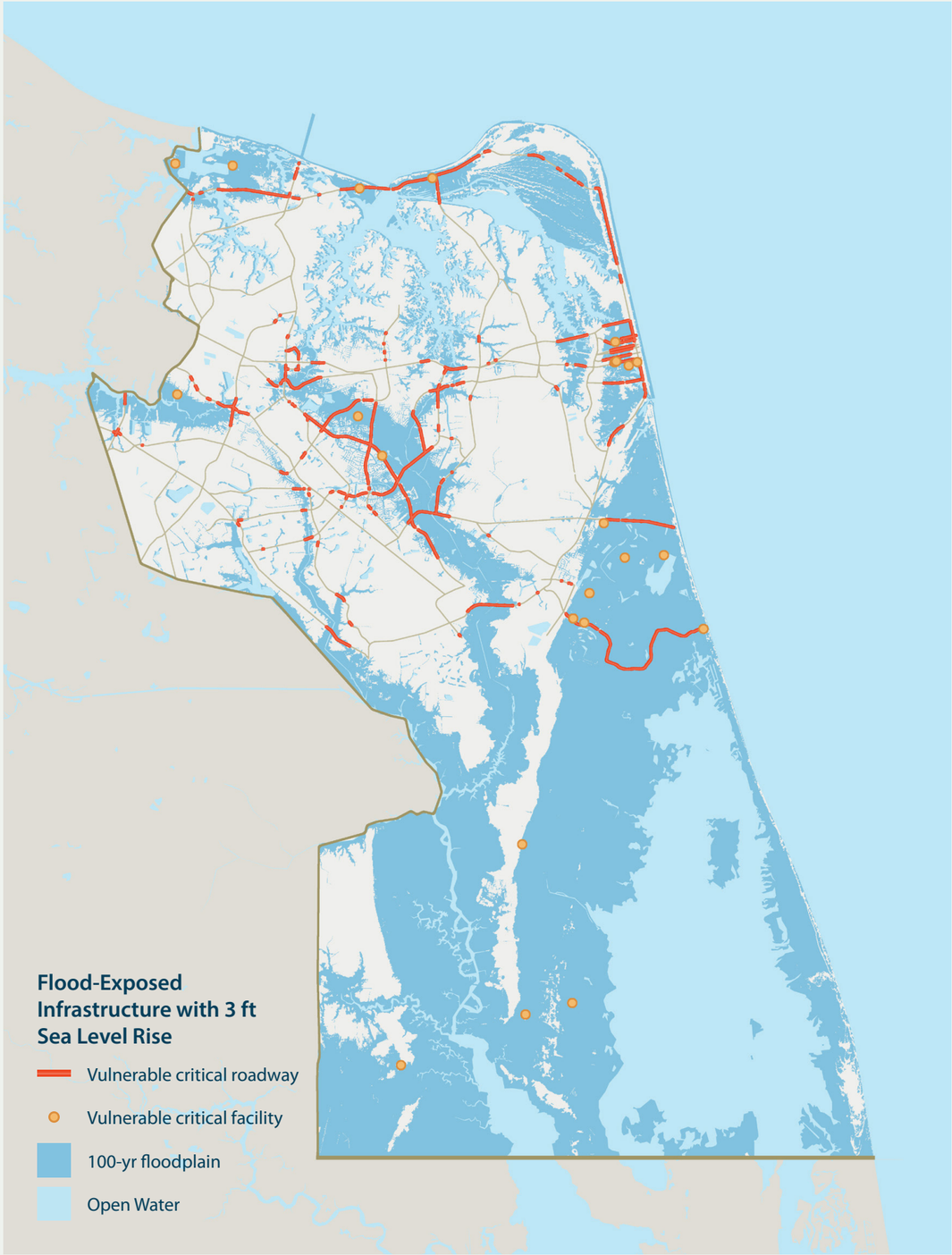
Recorded by the Census Bureau and University of Virginia Welcon Cooper Center for Public Service.

Princess Anne Plaza and Windsor Woods in 1954

Princess Anne Plaza and Windsor Woods in 2019

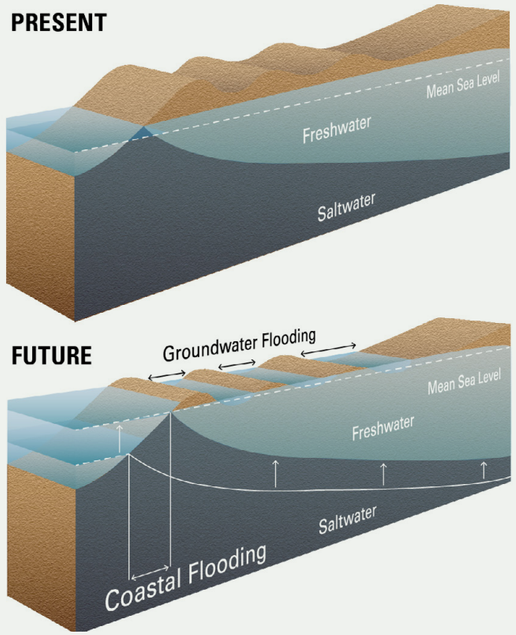
Aging Infrastructure

Generally speaking, most of the early developments in Virginia Beach were designed and built to the standards of the day. Much of the stormwater infrastructure was built as the City grew in the 1950s, and is now nearing the end of its design lifecycle. At the time it was designed, there was less understanding and awareness of issues such as increasing sea levels and changing rainfall. As a result, some of the infrastructure does not perform as originally designed. The City is presently evaluating the performance of the drainage system through a new Master Drainage Study. Studies undertaken in Sea Level Wise have looked at how design conditions are changing, and created adjustments to the updated design standards. These adjustments help ensure that the new or modified infrastructure continues to perform to current design standards over its intended lifecycle.



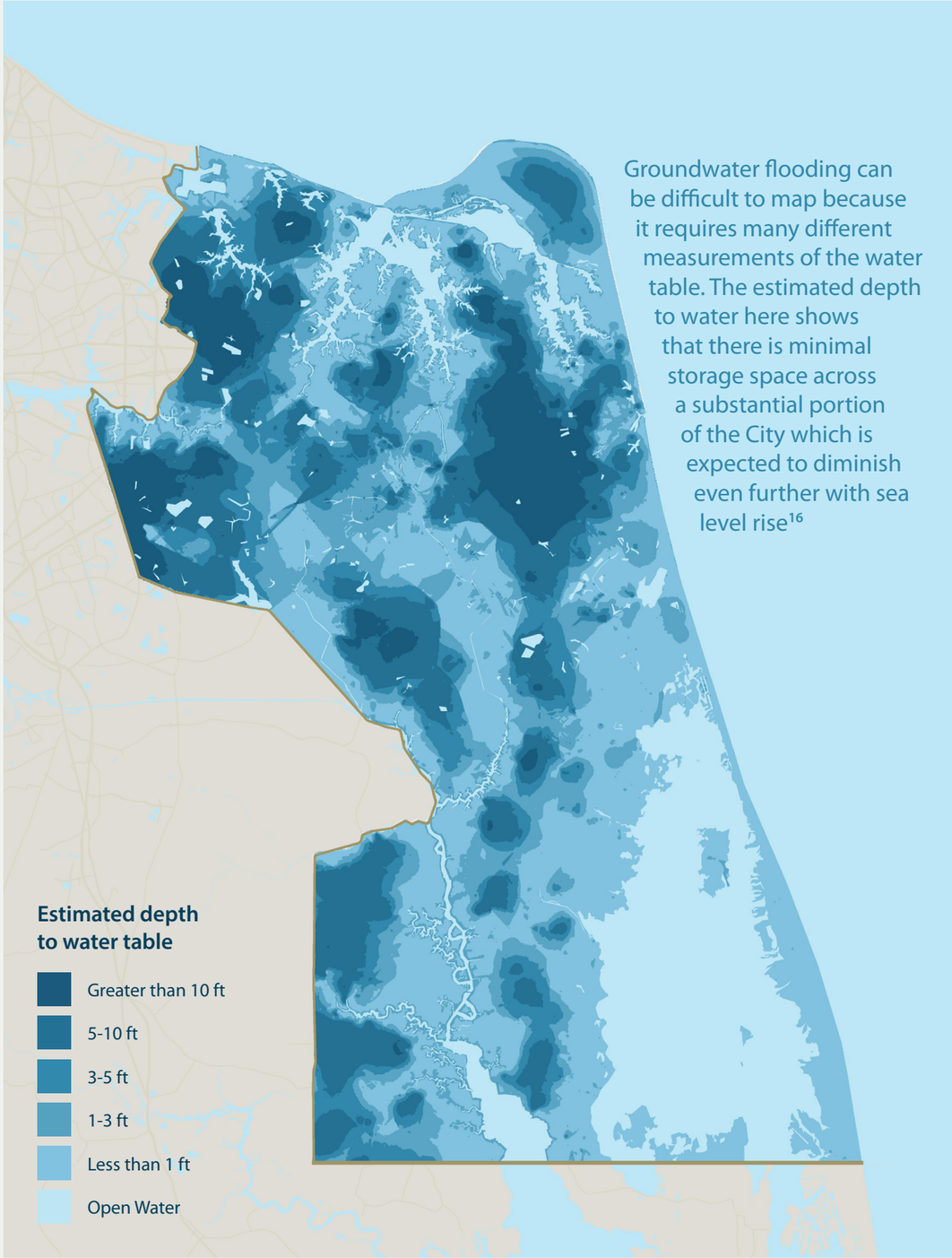
Groundwater Changes

Groundwater in coastal areas is dynamic and responsive to surrounding conditions. Rising sea levels induce an upward and landward shift in the position of the boundary between the freshwater aquifer and saltwater from the ocean or the bay. This can result in two impacts: contamination of the water supply in the fresh water aquifer and an additional source of coastal flooding. The capacity of the soil to absorb water depends on the amount of unsaturated space beneath the ground – what we call the depth to the water table. When the water table is high, it can quickly fill up during rainfall events and rise above the ground surface. Just one inch of rainfall can result in five inches of rise in the water table[14]. Along the coastline, the water table can rise along with fluctuations in water levels, resulting in even less storage space. Groundwater flooding can be hard to map because it requires many different measurements of depth to the water table. The estimated depth to water in the figure to the right shows that there is minimal storage space which is expected to diminish even further with sea level rise.



Sea level rise can cause the boundary between fresh and saltwater move upwards and landwards[15]

SWIFT is an innovative water treatment initiative in eastern Virginia designed to ensure a sustainable source of groundwater while addressing sea level rise and saltwater intrusion. The SWIFT Research Center is now open and replenishing the Potomac Aquifer with up to one million gallons of drinking water quality SWIFT Water daily. While SWIFT offers promising potential, slowing the rate of sea level rise in our region, it is important to remember that local land subsidence contributes to approximately half of our observed sea level rise in Virginia Beach. Even if subsidence was slowed or stabilized, global sea level rise will still continue to impact Virginia Beach. For more information about SWIFT, visit http://swiftva.com/.

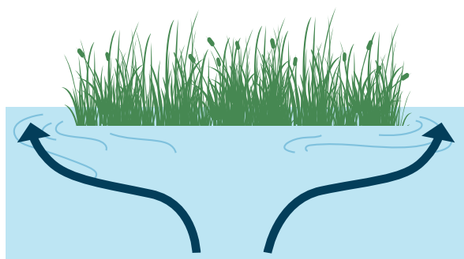


Groundwater flooding can be difficult to map because it requires many different measurements of the water table. The estimated depth to water here shows that there is minimal storage space across a substantial portion of the City which is expected to diminish even further with sea level rise[16]

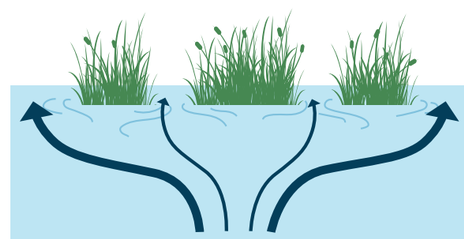
Ecological Decline

Many of the ecological assets, such as coastal marshes and woody wetlands, are deteriorating in response to recurrent flooding and associated hazards. The low-lying nature of these habitats at the interface between the land and the water makes them particularly vulnerable to sea level rise. In addition to providing home for numerous fish, bird, and plant communities, they also play an important flood attenuation role during storm events as they act as a sponge, slowing down the movement of water.

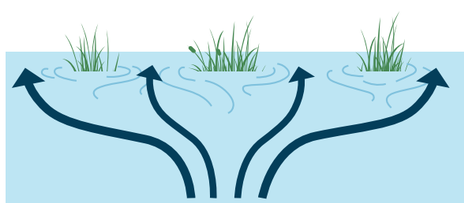
A widely used computer model was used to simulate response of wetland and marsh habitat to sea level rise. The model showed that fast rates of sea level rise result in smaller habitats as marshes are not able to grow fast enough. Fragmented habitats are less likely to provide ecosystem services such as flood control. In particular, loss of marsh islands in the middle of Lynnhaven and Back Bay widen and open up new flood pathways as water is able to flow with less resistance.



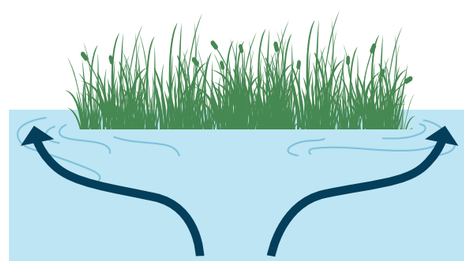
1. Past marsh island. Historically, marshes were more widespread and continuous.



2. Existing marsh island. Marshes throughout the City have been declining. As marsh loss occurs, new flood pathways open up, allowing more water to flow to vulnerable areas.



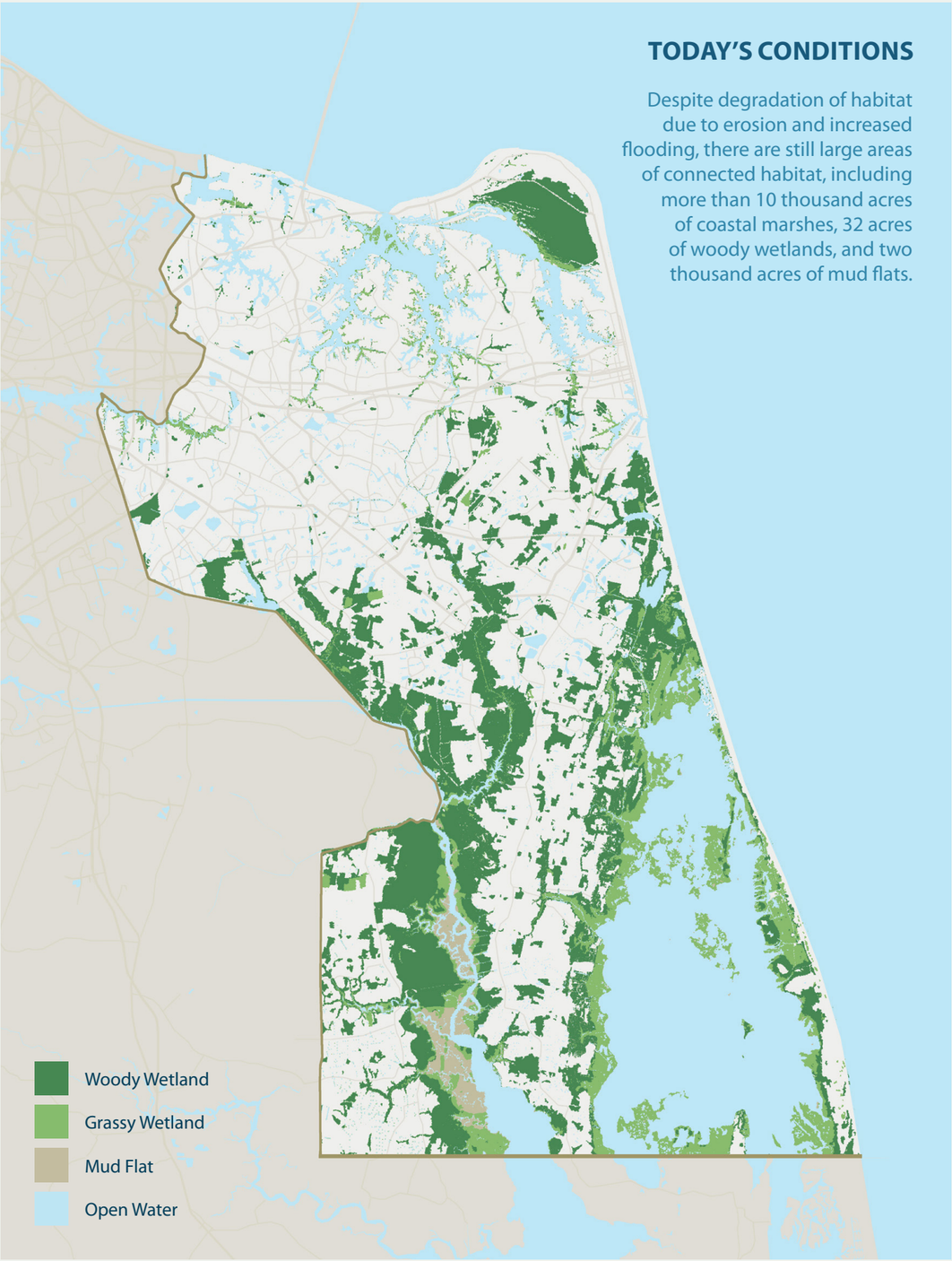
3. Future marsh island in response to sea level rise. Further degradation of the islands allows even more water to flow.



4. Future marsh island, restored and keeping pace with sea level rise.

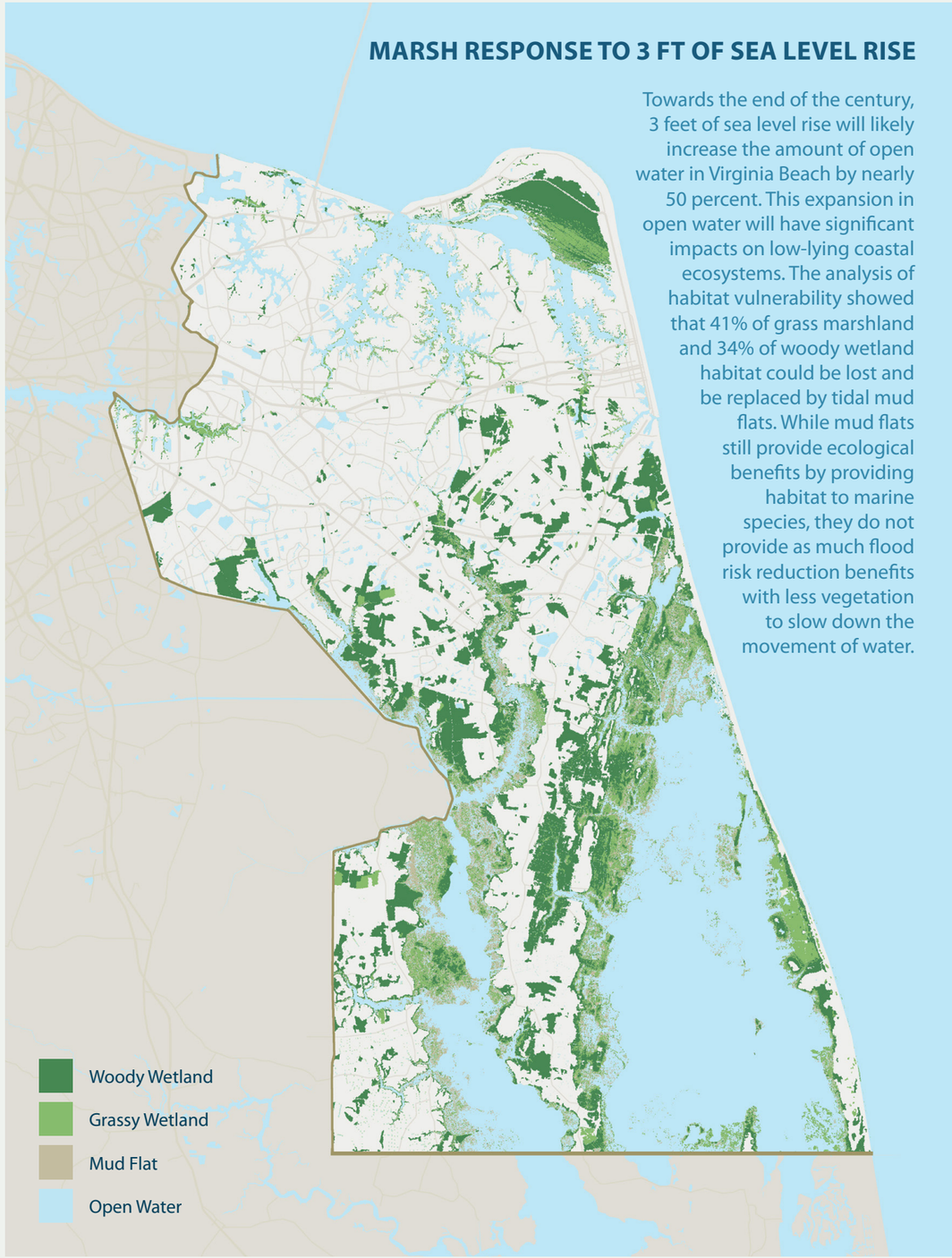
TODAY'S CONDITIONS

Despite degradation of habitat due to erosion and increased flooding, there are still large areas of connected habitat, including more than 10 thousand acres of coastal marshes, 32 acres of woody wetlands, and two thousand acres of mud flats.



MARSH RESPONSE TO 3 FT OF SEA LEVEL RISE

Towards the end of the century, 3 feet of sea level rise will likely increase the amount of open water in Virginia Beach by nearly 50 percent. This expansion in open water will have significant impacts on low-lying coastal ecosystems. The analysis of habitat vulnerability showed that 41% of grass marshland and 34% of woody wetland habitat could be lost and be replaced by tidal mud flats. While mud flats still provide ecological benefits by providing habitat to marine species, they do not provide as much flood risk reduction benefits with less vegetation to slow down the movement of water.



Flood Impacts

Unless significant actions are taken, flood events will have wide-ranging impacts on our infrastructure, economy, and overall well-being.

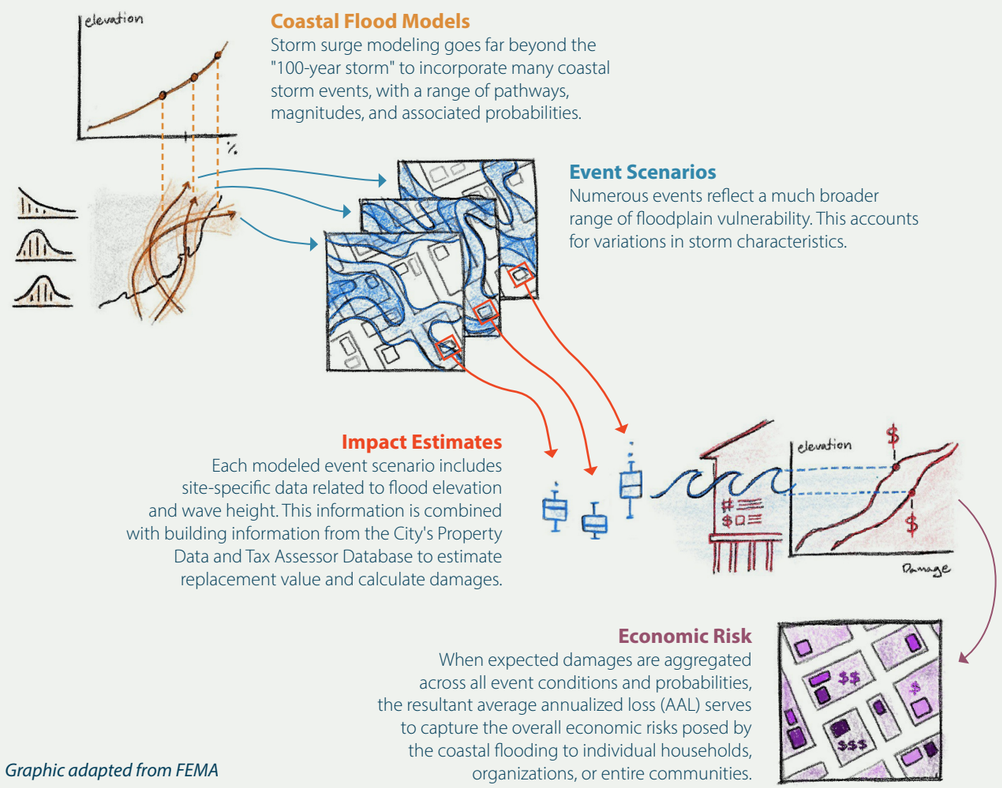
As a major tourist destination on the east coast and home to vital ecological, agricultural, and military assets, Virginia Beach is a significant driver of the national and state coastal economy. Throughout the City, flooding has already resulted in damages to buildings and infrastructure, affected housing stock and home values, disrupted economic activities, and created community health and safety risks. These impacts can be both direct and indirect, acting on individuals and buildings, as well as the complex systems people rely on. Some impacts are easier to measure and quantify than others, and not all impact types detailed in this section were quantified in the study's economic analysis. In those cases, anticipated impacts are described in a qualitative fashion.

Impacts in this section focus on coastal flooding, while keeping in mind that other factors such as stormwater flooding, groundwater, and habitat shifts play an important role.

The Cost of Inaction

An economic flood risk model was developed to help the City understand the impacts of existing, and future increases in coastal flooding. This model used the City's tax assessor database and GIS property data, along with a range of coastal flood conditions for today, the 2040's, and the 2070's. These data sets were input into the FEMA flood loss computer model Hazus. Expected flood losses are calculated in the software by comparing the flood elevation for a range of conditions to each building in the City. If flooded by a particular condition, the software then estimates the damages to the building. Also, by classifying each building's use type, such as residential, or specific commercial use, the software estimates damages to building contents. Next, the model estimates additional costs to the building owners, such as how long they may be out of the building due to the level of damage, and costs for a hotel during that time. For commercial buildings, estimates are made for the loss of use for estimated time to repair the building.

Basics of Coastal Economic Flood Risk Analysis



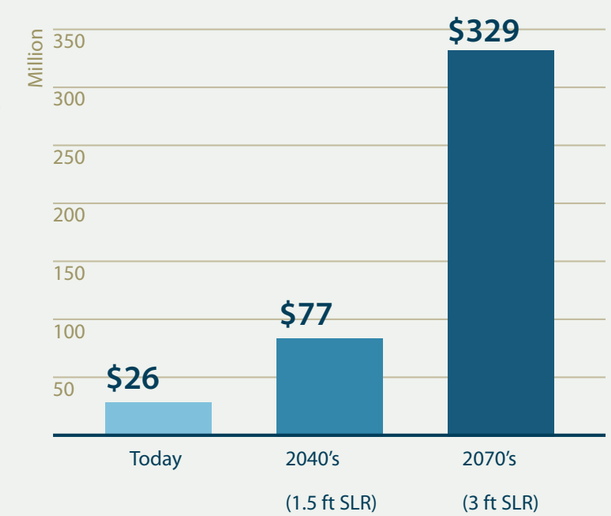
Graphic adapted from FEMA

Loss estimates associated with different flood levels are then proportioned based on the frequency of the flood type with which they are associated. For example – lower flood levels cause smaller amounts of damage, but these type events happen frequently, so they have a high weight. Flood levels that may occur with large hurricanes and their associated damages are weighed low, because they do not occur very often. The outcome of these calculations is called an Average Annualized Loss estimate. This number represents the expected coastal flood loss to the City for any given year. A good analogy is with car insurance – car insurance companies charge you a certain amount every year, knowing the odds that you will be in a certain number of minor and major accidents over a certain period of time determines your payment level.

The Average Annualized Loss estimate is then compiled for the entire City, for each sea level rise condition, and shown on geographic maps. This information helps the City understand how much risk it faces if it does not act, and also where the highest risks are located within the City. These data inform where strategies would be most effective. The Average Annualized Loss estimate is also used in comparisons to the cost of strategies to understand the return on investment.

Given the current understanding of the existing and potential impacts of sea level rise, Virginia Beach needs to identify the best course of action to prepare for the future. If not addressed, sea level rise poses a substantial threat to Virginia Beach. Under a 'Do-Nothing' or "No Action' scenario, annual average flood-related losses, including broader societal impacts, would increase almost three times from present day conditions with 1.5 feet of sea level rise in the 2040s. This equals a growth in annualized losses from $26 to $77 million. A tipping point occurs in the transition from the 1.5 to 3 foot sea level rise scenario that drastically increases losses. By the 2070s, annualized losses are expected to increase by 12 times over today's conditions, to $329 million. These numbers illustrate the scale of the challenges the City faces.

Average Annualized Losses from Coastal Flooding under Sea Level Rise (SLR) Conditions



Where are Losses Occurring?

The annualized loss estimates were developed at the building level. The values were then summarized at different levels to help the City understand where the losses were occurring.

WATERSHEDS

Today, about 74 percent of the City's exposure to coastal flood loss is in the Lynnhaven Watershed. The Southern Rivers Watershed has the next highest exposure, representing 17 percent of the annualized loss value for the City. The Elizabeth River and Oceanfront follow at 7 and 2 percent, respectively.

This distribution of loss stays mostly the same for the 1.5 foot sea level rise scenario. By the 3 foot scenario, the loss profile shifts, with the Southern Rivers Watershed (45 percent) and Lynnhaven Watershed (48 percent) having roughly the same exposure.

For the 3 foot scenario, the Elizabeth River and Oceanfront have relatively minor exposure at 4 and 3 percent. These exposures reflect the current development in the City. Continued development in areas subject to present-day and future flooding would further increase flood risk in the City.

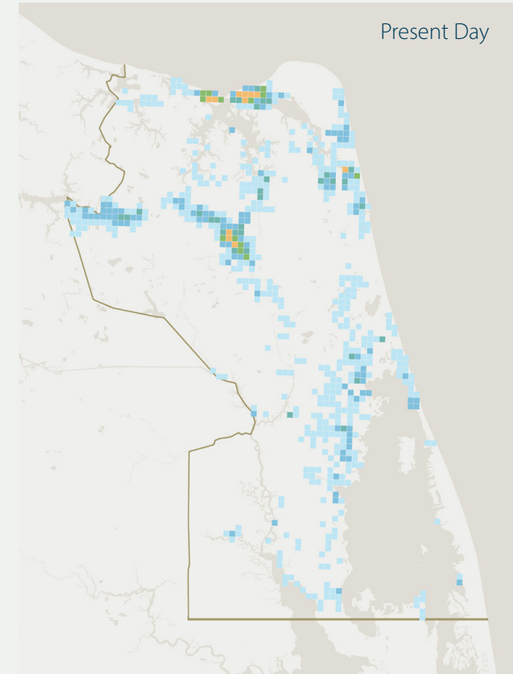
NEIGHBORHOODS

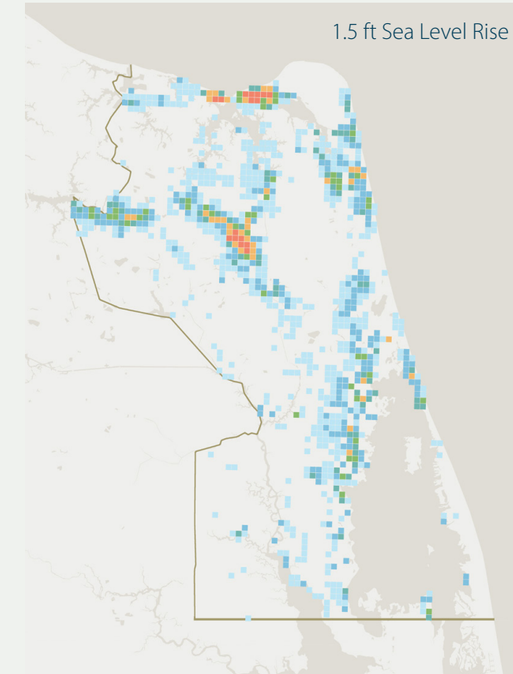
A grid-type visualization was made to see where the flood exposure in the City was concentrated, and how it would change with sea level rise. This information is shown in the series of graphics on the following page. Although the areas of losses expand in the City, the areas with high risk stay roughly the same as sea level rises.

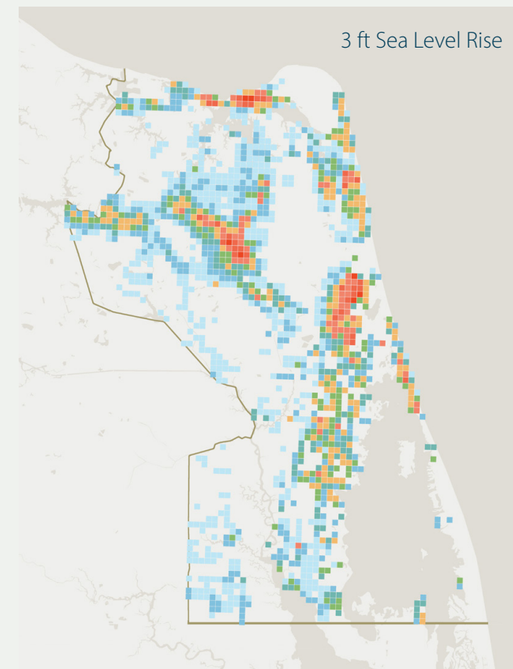
It was determined that almost 90 percent of flood risk is concentrated in seven areas in Virginia Beach and include the following:

- East and West of the Lesner Bridge along Shore Drive, including parts of the Ocean Park, Lynnhaven Colony, Cape Story by the Sea, Broad Bay Colony, Marina Shores, Cape Henry Shores, Mariners Landing, and Bay Island neighborhoods
- Laskin Road corridor, as it crosses Great Neck Creek and Little Neck Creek
- Elizabeth River Waterfront, including areas of the Arrowhead, Carolanne Farms, Fairfield, Avalon Terrace neighborhoods
- Neighborhoods of Windsor Woods, Princess Anne Plaza, Pecan Gardens, The Lakes, Scarborough Square, and Magic Hollow
- Atlantic Shores, Ocean Lakes, and Lagomar
- Bay side of Sandbridge, such as Back Bay Meadows, and South Sandbridge
- Pungo, especially the area west of Muddy Creek Road
- North End, Resort Area, Birdneck Point, and Princess Anne Hills

These areas were used to focus development of adaptation strategies.







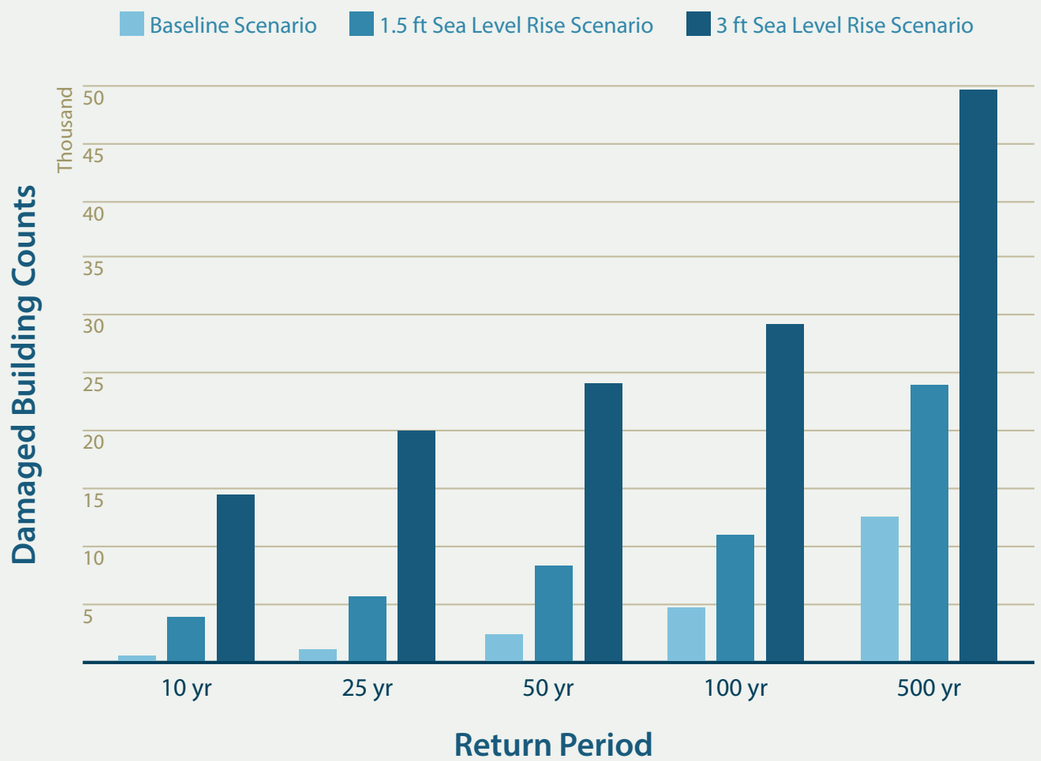
Average Annualized Losses

- 0 - $10k
- $11k - $50k
- $51k - $100k
- $101k - $200k
- $201k - $500k
- $501k - $1,000k
- $1,001k - $2,000k
- < $2,000k

Physical Damages

Coastal flooding can cause significant physical damage to buildings and infrastructure. During powerful coastal storms that generate high storm surges, forceful wave action and fast flowing waters can push against the sides of buildings and infrastructure. Fast moving waters are capable of destroying solid walls and dislodging buildings with inadequate foundations. Damages can be even greater if flood waters pick up sediment or debris.

Flood-borne debris produced by coastal flood events and storms may include decks, steps, portions of or entire houses, vehicles, boats, fences, and a variety of other objects. The force created by waves breaking against a vertical structure is often 10 or more times higher than the force created by high winds during a storm event. Even without visible waves, floodwaters can still be damaging if they enter a structure or waterlog a structure for an extended period of time.



Buildings

Coastal flooding can damage both the building itself as well as the personal contents inside. The Sea Level Wise impact assessment leveraged FEMA's Hazus Flood Model to estimate building and content damage under various flood events and sea level rise scenarios. The model combines depth of flooding associated with different coastal storm events with building attributes such as first floor elevation, year built, building structural and contents value, and estimated replacement cost to estimate damage. The analysis also calculated the expected cumulative impact across all potential storm frequencies, or average annualized loss.

The analysis found that during a large storm event today, approximately 10% of buildings across the City could be damaged. However, with sea level rise, the number of buildings impacted increases dramatically. 25% of buildings could be damaged with 1.5 feet of sea level rise and more than 65% of buildings are vulnerable citywide to flood damages under 3 feet of sea level rise.

Critical Infrastructure

Coastal flooding poses a significant risk to critical infrastructure, such as roadways, hospitals, schools, and police and fire stations. Damaged or flooded roadways, bridges, tunnels, and other transportation infrastructure can disrupt commutes and impede emergency operations vehicles. Flood damage to energy, internet, and telecommunications utility infrastructure can cause long-term outages and disruptions to service. Furthermore, many infrastructure systems are interdependent, which can lead to cascading effects as damage to one system might have broad-reaching impacts on other reliant systems.

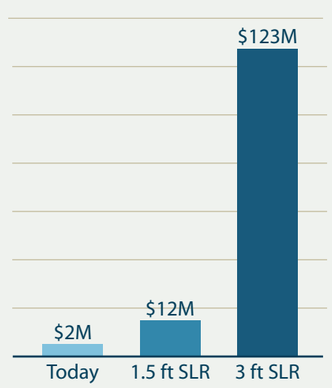
Indirect Economic Impacts

In addition to repair and reconstruction costs associated with physical damages, flooding can lead to indirect consequences for the City's economy. Persistent or devastating damages to residential and commercial buildings can lead to displacements as residents and businesses may decide to move. The Hazus flood model included an evaluation of displacement. It found that the economic impact of flooding on displacement increases significantly with sea level rise.

Displacement and business closure can lead to job loss, and weaken the economy overall. Furthermore, losses in revenue, income, and displacement can also lead to reductions in tax revenue collected by the City, which in turn leads to a lower level of public service provision.

Virginia Beach's primary economic sectors are tourism, military, and agriculture. Each of these areas plays an important role in our ability to take care of our citizens, our infrastructure and our future. They are also each threatened by the risks posed by sea level rise and recurrent flooding. Sea Level Wise did not perform a detailed economic loss analysis for these elements. Anticipated impacts are described in a qualitative fashion as they are important to keep in mind while developing adaptation strategies.

Expected Building, Content, and Displacement Cost under Sea Level Rise (SLR) Conditions



Tourism

Virginia Beach is home to many attractions that make it a top travel destination on the East Coast. Over 15 million visitors from across the country and the globe come to Virginia Beach every year to experience world-class restaurants, craft breweries, music festivals, beaches, and state and local parks.

Key to Virginia Beach's touristic appeal is the expansive natural areas and waterways. Virginia Beach is home to multiple parks of local, regional and national importance that attract people to live in and visit the City. These include First Landing State Park, Back Bay National Wildlife Refuge, and 293 city parks and park facilities, encompassing over 7,000 acres including neighborhood and community parks, signature parks, natural areas, waterway access, trail linkages, open space preservation areas, and athletic facilities.

However, sea level rise puts vulnerable natural ecosystems at risk, including coastal marshes and woody wetlands, threatening beloved natural areas and the habitats of fish, birds, and other wildlife. Furthermore, interventions to reduce flood risks can impact natural areas and assets both positively and negatively. While some flood reduction techniques may impede natural landscapes and waterways, others may serve to strengthen natural assets and the ecosystem services they provide. Flood events can also damage buildings and infrastructure that support tourism, including hotels, entertainment centers, museums, and transportation networks. Impacts on the City's natural assets and tourism-related infrastructure can lead to a reduction in visitors and tourism revenue.

Military

Hampton Roads and Virginia Beach are home to multiple military commands and support services. The military's presence dates back to the early 20th Century and has come to be a defining character of our City, influencing its growth, economy, and land-use patterns. Virginia Beach proudly hosts three military installations. Camp Pendleton is a premier training facility for the National Guard and other associated agencies. Naval Air Station Oceana is the Navy's East Coast Master Jet Base and, along with the Dam Neck Annex, employs over ten thousand active Navy personnel and forty-five hundred civilians.[17] The Joint Expeditionary Base Little Creek-Fort Story employs over eighteen thousand military and civilian personnel and is the major east coast operating base supporting Overseas Contingency Operations.[18]

The long-term threat from increased flooding and sea level rise will place additional risk on infrastructure that has a critical role in Department of Defense readiness. This includes both direct threats to military installations and facilities, as well as major roadway corridors and community assets that military personnel rely upon on a daily basis.

Agriculture

The importance of agriculture to Virginia Beach's economy is evident throughout the City. Our rural area is home to major grain handling facilities that use container exporting through the Virginia Port Authority. Virginia Beach is the largest strawberry producer in the state and ranks highly in both grain production and equine population. Farm markets, roadside stands, and "you-pick" farms are not only important economically; they foster Virginia Beach's agricultural heritage, tourism, and quality of life. The annual local economic impact of agribusiness in Virginia Beach is more than $136 million.[19]

Sea level rise, increasing flood events, and higher water tables impact many of Virginia Beach's rural areas, threatening agricultural industry and food security in the region. Increasingly recurrent flood inundation events, including regular wind-driven flooding, can damage crop yields, cause destructive erosion, and lead to salt contamination of soil. Furthermore, as sea level rise lifts the coastal water table and shifts it further inland, changes in groundwater salinity and compaction of soils can reduce the productivity of agricultural land. Long-term water management issues may also arise with aquifer salinization, leading to the abandonment of wells and the need to look for alternative fresh-water supplies to support agriculture and other industries.

Social Implications

In Virginia Beach, for every 1.5 feet of sea level rise, the percentage of people at risk to coastal flooding in the region will double from present conditions. Under current, baseline conditions, 6.5% of the total population is at risk to a coastal flood hazard. Under future 1.5-foot and 3-foot sea level rise conditions, the portion of the population at risk will rise to approximately 12.5% and 26% respectively. In addition to physical and economic impacts, flooding impacts the health, safety, and social well-being of Virginia Beach community members.

	Today's Conditions		With 3 ft of Sea Level Rise	
	Exposed Population	% Exposed Population*	Exposed Population	% Exposed Population*
People of color	24,654	17%	68,571	49%
Children (under five years old)	6,055	21%	15,636	54%
Elderly (65 years and older)	11,941	26%	26,628	57%
Institutionalized people	122	4%	443	15%
People with limited English proficiency	2,925	19%	7,666	50%
People with limited income	11,525	22%	28,609	54%
People with disabilities	9,192	23%	22,610	57%

Health Hazards

Flood events can pose physical health hazards and disrupt the provision of critical medical services. Directly, both major and minor flood events can increase cases of physical injuries and illnesses, ranging from minor to severe. Wet and flooded roads are hazardous for pedestrians, bicycles, and cars, often leading to grievous falls and collisions. Overloaded sewer infrastructure from flood events can decrease water quality and increase the likelihood of waterborne illness, as raw sewage or otherwise contaminated substances can seep into streets and waterways. Flood inundation in buildings can increase the growth of mold and other fungi, which exacerbate respiratory illnesses such as hay fever and asthma. Standing water can provide habitat for mosquitoes or other disease-carrying organisms to breed, leading to increases in vector-borne disease. Indirectly, the disruption of essential electrical, communication, and transportation infrastructure from flooding can also impede access to and delivery of critical medical services.

Damages and costs incurred from extreme or recurring flood impacts can also lead to increased stress and anxiety, with significant implications for mental health. Flooding events that directly harm people, property, and community infrastructure can be stressful, shocking, and traumatic. Extreme flood events can also result in the displacement of individuals from their homes and places of work, leading to loss of income and critical social infrastructure. Recovery from a flood event is a burdensome and often expensive process, which can further exacerbate or lead to stress-related disorders such as anxiety and depression.

Socially Vulnerable Populations

Although sea level rise and recurrent flooding have the ability to affect all Virginia Beach residents, some are more likely to feel the consequences than others. Social vulnerability refers to the higher sensitivity that exists within some social groups when compared to the general population. Socially vulnerable populations are those that are either predisposed to suffer harm during a flood event or otherwise lack the resources to effectively adapt and cope with the ultimate impacts. Key attributes that make a group vulnerable to the impacts of an emergency include a higher likelihood of social isolation, a high number of existing stressors before an event happens, limited access to information and services, and the limited ability to handle economic hardships such as displacement, disruption of livelihood, and loss. Socially vulnerable populations can also include residents in which the responsibility for their care and well-being has been transferred to another party, such as residents residing in nursing homes. When conducting a demographic-based analysis of social vulnerability, particularly vulnerable groups can include people of color, children under five years old, the elderly over 65 years old, institutionalized people, people with limited English proficiency, people with limited income, and people with disabilities.

In the Virginia Beach region, the elderly and disabled populations experience a marginally disproportionate risk to coastal flood hazards. The elderly and disabled populations show the largest populations at risk to future flood hazard areas within the Lynnhaven and along the border of the north and southern regions of the City.

PART III

ADAPTATION FRAMEWORK

Multiple Layers of Adaptation

The Adaptation Framework presents a holistic method for addressing flood risks across the City, and consists of four complementary layers. Each layer presents a specific approach to flood risk management—working through the lenses of natural mitigations, engineered defenses, adapted structures, and prepared communities.

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.

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.

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.

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.

Integrating Policy and Planning

Policy and planning actions taken by the City of Virginia Beach play a key role in implementing all of the layers in the Framework.

Policy and planning is a consistent thread throughout the Framework and integrated within each of the layers and objectives.

These elements help to describe processes behind desired outcomes, and overall complement the ***what*** with the ***how***.

What

Each layer aims to achieve concrete outcomes that improve Virginia Beach's overall flood resilience:

- **Natural Mitigations** lessen the magnitude and extent of flooding events through open space nature-based features.
- **Engineered Defenses** prevent the passage of floodwater into inhabited areas through large-scale defense systems.
- **Adapted Structures** limit the damage to buildings and infrastructure through siting, design, and retrofits.
- **Prepared Communities** minimize the social and economic impacts to residents through education and financial planning.

How

In order to achieve those outcomes, the City can employ a number of policy and planning tools:

- **Comprehensive and strategic planning** to guide long-term community development across sectors.
- **Budgeting and financing** to fund project planning and implementation using internal and external sources of capital.
- **Community outreach** to engage and educate residents and businesses around adaptation options and efforts.
- **Building codes and standards** to guide the design of buildings and other structures to meet adaptation needs.
- **Partnerships** with other public, private, and non-profit entities to accomplish goals outside of the City's jurisdiction.
- **Research and analysis** to employ the most up-to-date scientific and engineering knowledge available.
- **Land use planning and zoning** to govern how land can be developed and where structures can be built.
- **Incentives and support programs** to encourage the adoption of voluntary actions by private citizens and entities.
- **Program and project management** to allocate resources to oversee actions and achieve adaptation objectives.

City-Wide Objectives

Each layer consists of high-level strategic objectives to guide adaptation efforts. Objectives contain a range of techniques with distinct benefits and challenges when it comes to feasibility, effectiveness, costs, and impacts. This array of adaptation options leads to flexibility in implementation as objectives and techniques can be tailored to suit the needs and priorities of specific areas.

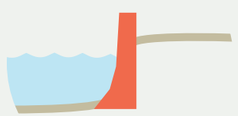
Techniques presented within each objective are drawn from the many technical reports produced throughout the Sea Level Wise effort. Techniques are both physical methods as well as policy, planning, and programmatic approaches for achieving the objectives.

Preserve Environmental Assets

Protect and expand green infrastructure networks through land conservation and renaturalization programs.

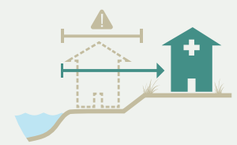
Increase Natural and Nature-Based Features

Invest in the restoration, enhancement, and construction of natural and nature-based infrastructure that mitigate the impacts of flooding.



Pursue and 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.



Regulate Building and Development

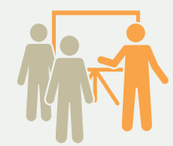
Require responsible siting, design, and construction practices for new and substantial redevelopment that are reflective of the area's current and future flood risks.

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.



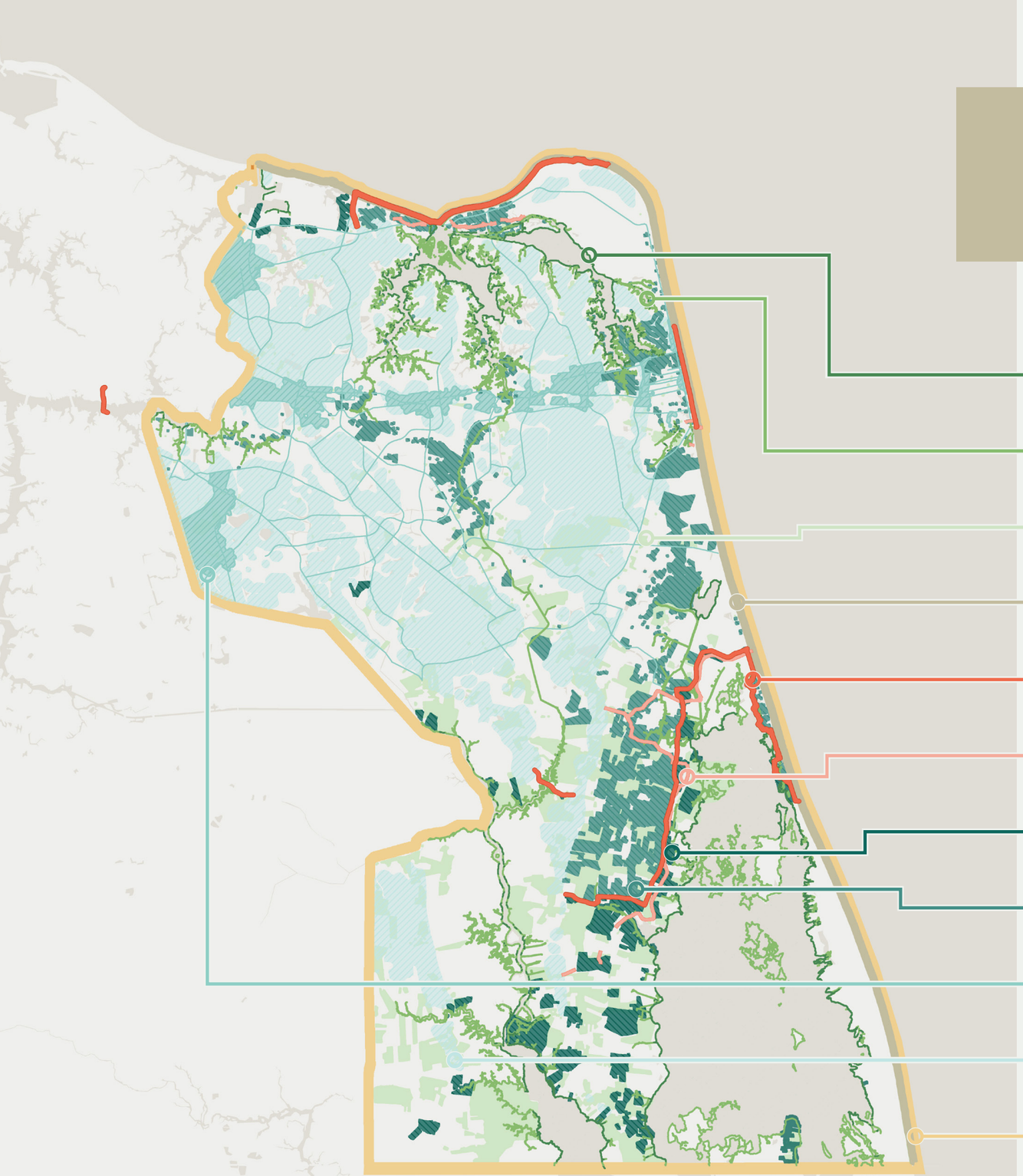
Grow Educational Outreach

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.

Envisioning an Adapted Virginia Beach



- Living Shoreline and Enhanced Revetment Areas
- Marsh Restoration Areas
- Land Conservation Focus Areas
- Beach and Dune Renourishment Areas
- Potential Large-scale Engineered Defenses
- Potential Neighborhood-scale Engineered Defenses
- Structure-Level Mitigation Focus Areas Outside Engineered Defenses
- Structure-Level Mitigation Focus Areas Inside Engineered Defenses
- 'High and Dry' Strategic Growth Areas for Concentrated Development
- 'High and Dry' Areas for Potential Adapted Development
- Social and Economic Preparedness is a theme throughout the entire City

This Vision Map presents an overview of the key focus areas and potential project locations within each layer. Objectives are expected to be implemented over time through a combination of physical and programmatic actions taken by the City and its constituents.

Complementary Applications

Some presented objectives and techniques have wide-reaching applicability across the City. Others, however are interdependent, and their application should be assessed in parallel with complementary efforts and objectives.

For example, large- and neighborhood-scale engineered defenses are expected to provide substantial protection for large numbers of structures At the same time, structures currently in flood-prone areas should be encouraged to take on risk-mitigating actions such as structural elevations, floodproofing, or voluntary acquisition. While structure-level mitigations will always be important for managing residual risks, the construction of the engineered defenses would impact the costs and benefits of making such adaptation investments. In the Vision Map presented here, structure-level mitigation focus areas are therefore differentiated by those inside and outside the expected protection area.

NATURAL MITIGATIONS

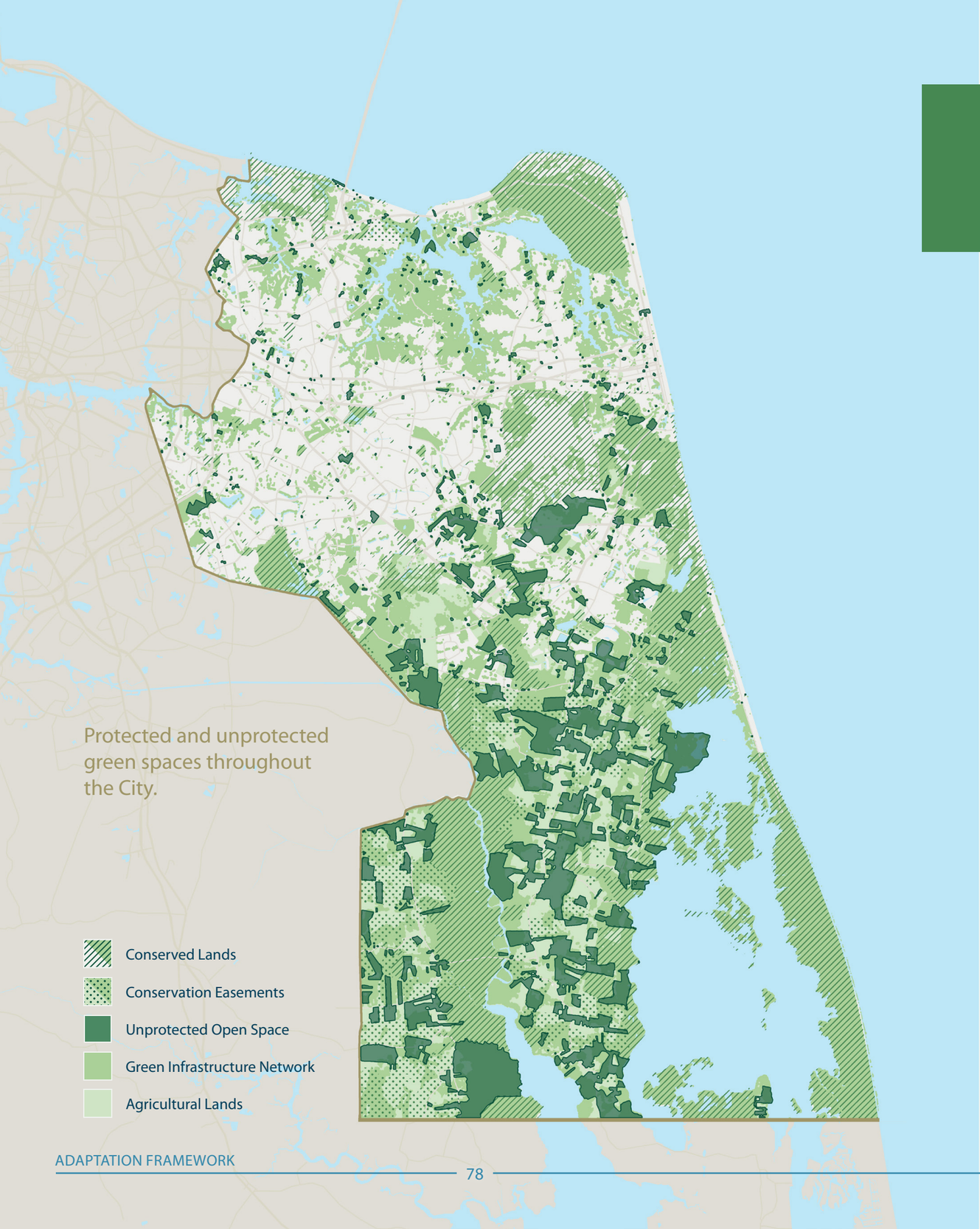
Natural features, both in the water and on land, can directly reduce the magnitude of flooding across the City by decreasing wave action, stabilizing landscapes, and absorbing excess floodwater.

Green infrastructure is the network of ecological features and open spaces that connects the built and natural environments. Ecological features in the landscape can provide flood reduction benefits, while also serving to enhance the environment, economy, and human welfare. Natural and nature-based features in the landscape can help with stormwater management, wave action reduction, and groundwater replenishment.

Naturalized landscapes also provide many ecological benefits including habitats for native species, erosion reduction, water and air quality improvement, and carbon sequestration. Virginia Beach's natural landscapes are one of the City's greatest economic assets as natural waterways, scenery, and recreational space drive residential and touristic appeal.

For example, not only do coastal wetlands reduce waves and stabilize shorelines, but they also lead to cleaner waterways, enhanced recreational areas, and more protected habitats for threatened or endangered species.

The level of flood protection provided by ecological features will vary across geographic areas due to the type and severity of the flood hazard. In the case of some low-intensity flood events, natural landscape elements may be a viable alternative to traditional hard-infrastructure with equal or greater flood reduction benefits. For higher-intensity flood events (such as coastal storm surge), natural features alone may not provide enough protection. However, they can instead act as a complementary defense system and help to prolong the useful life and function of the primary structural measures while also providing an array of ecosystem services.



Preserve Environmental Assets

Protect and expand green infrastructure networks through land conservation and renaturalization programs.

Virginia Beach already boasts an expansive green infrastructure network of public and privately owned wetlands and open spaces. With increasing development trends and pressures, it is vital that Virginia Beach facilitates the long-term maintenance and expansion of this green infrastructure network that provides flood mitigation benefits. This can be done both through the preservation of existing natural buffers and open spaces as well as through the acquisition and renaturalization of developed land.

The Virginia Beach Department of Parks and Recreation, Federal and State Governments, and The Nature Conservancy together own and manage most of the protected open space throughout the City, largely in flood-prone areas. Similarly, the City's Agricultural Reserve Program allows farmers to conserve valuable agricultural lands in the southern portion of the City, with over 9,700 acres currently enrolled. In addition to these already protected lands, the City can employ numerous financial and regulatory tools to expand green spaces with a focus on currently unprotected privately-owned spaces.

Resident Perspectives

89 percent of polled residents strongly supported creating incentives to encourage the use of natural features to absorb water and mitigate flooding impacts.

Land Conservation Techniques

Voluntary Acquisition

Voluntary property acquisition allows the City to acquire and demolish high-risk properties and then convert the property into open space with restrictions on any future development. Land acquisition can occur through a gift/donation, inheritance, or purchase from a willing seller. While purchasing land is an expensive option, by permanently removing structures from the floodplain, the City eliminates any future damages to these structures and reduces the potential for emergency response costs. Occasionally, cost-effective projects are eligible for acquisition under FEMA's Hazard Mitigation Assistance Grant Program.

Conservation Easements

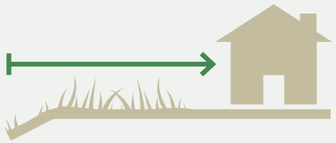
On undeveloped land, development rights can be secured through conservation or preservation easements. A conservation easement is a legal agreement between a landowner and either a land trust organization or a government entity that permanently limits uses of the land, while still allowing the landowner to continue to own and use their land, as well as sell it or pass it on to heirs. By preserving open space in the floodplain, the City can reduce future damages to adjacent homes, businesses, infrastructure, and City-owned facilities.

Development Rights Purchase

Similar to the City's Agricultural Reserve Program, the creation of a program for purchasing or transferring development rights could allow landowners in high-risk areas to sell their development rights to the City or transfer them to protected or higher ground areas. By limiting new development and redevelopment in flood-prone areas, the City can ensure that it is not worsening flood risks and preserving natural flood buffers for upland and neighboring development. The City would likely have to revisit zoning and density regulations and ordinances to establish such a program.

Strategic Growth Areas

As the City's population increases and housing and development needs continue to grow, strategic growth strategies can help concentrate new development in specifically designated areas. To promote strategic growth, the City utilizes comprehensive planning strategies such as Strategic Growth Areas, which are mixed-use developments along key transportation corridors. Similarly, the Green Line was established in 1979 and serves as an urban growth boundary, protecting rural portions of the region from increasing urban sprawl. Concentrating new development in limited geographic regions helps reduce the geographic spread of urban areas exposed to flood risks while also protecting undeveloped land, open space, and natural areas.

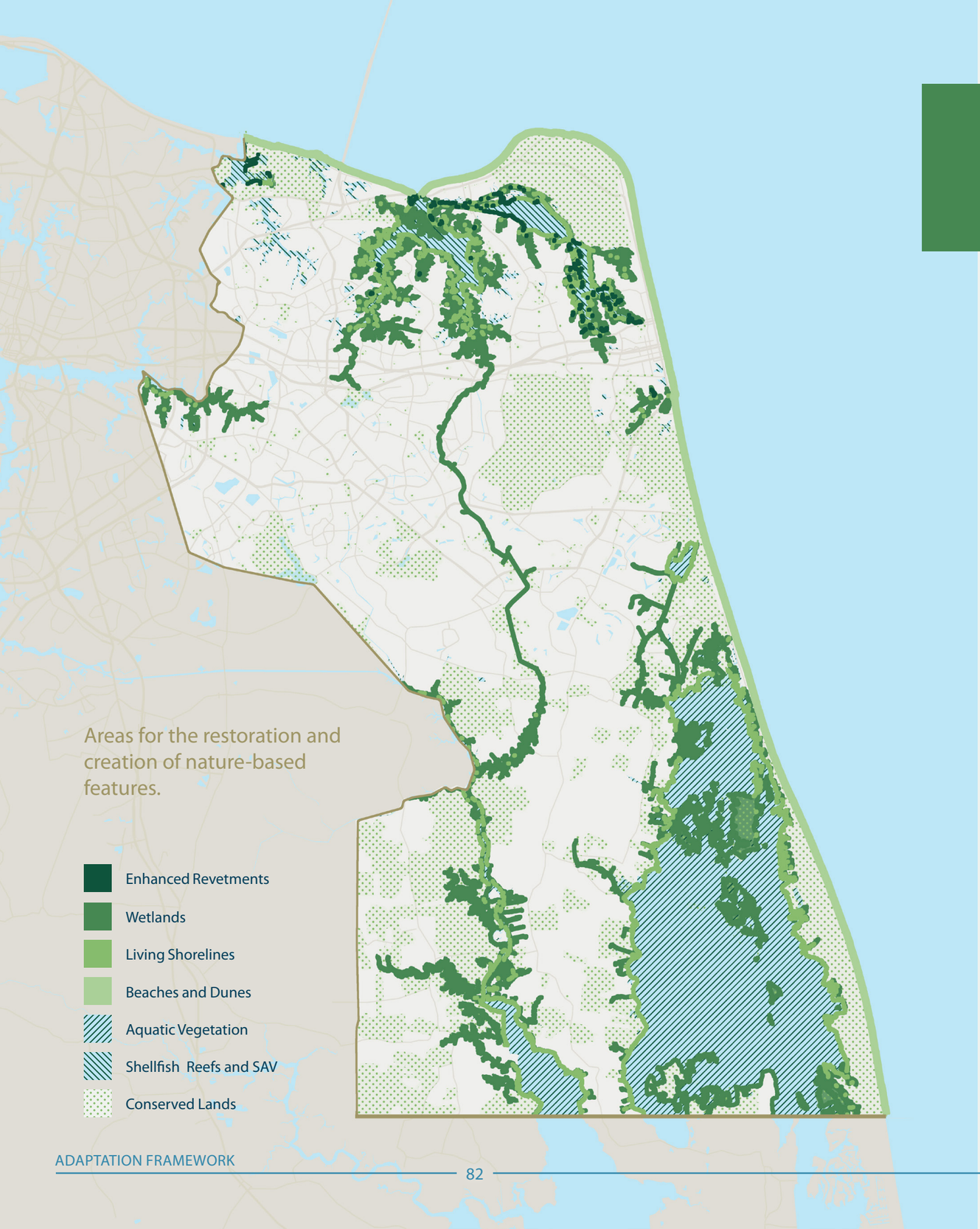


Setbacks and Buffers

Setbacks and buffers are land-use restrictions that require minimum distances between development and natural features. The Chesapeake Bay Preservation Act designates certain Resource Protection Areas, which are buffers around tidal and non-tidal wetlands, tidal shores, and other lands considered necessary to protect the quality of state waters. The Southern Rivers Watershed Management Ordinance sets a 50-foot buffer to protect wetlands and water quality from development in the area. As sea levels rise and habitats shift, the City could potentially enact a "rolling" resource protection area, where the buffer moves in parallel with landward migrating shoreline and wetlands.

Resident Perspectives

80 percent of polled residents expressed a preference for the City to focus on planning and management approaches that preserve open space through zoning.



Increase Natural and Nature-Based Features

Invest in the restoration, enhancement, and construction of natural and nature-based infrastructure that provide flood protection benefits.

In the face of rising sea levels and increasing flooding risks, natural and nature-based landscape features play a significant role in a multi-layered defense strategy. Natural features are created through natural forces, while nature-based features are human-engineered to provide flood risk protection by mimicking certain characteristics of natural features. Nature-based features can often be constructed faster and cheaper than hard-infrastructure projects, and provide additional environmental, economic, and social benefits to the surrounding areas.

Nature-based flood mitigation strategies can be employed using both non-structural and hybrid techniques. Non-structural methods focus on creating or enhancing the dominant natural features already present and contributing to flood risk reduction, while hybrid methods integrate soft or 'green' natural and nature-based measures with harder materials for added structure and stability. Many of the hybrid techniques can be classified as 'living shorelines' and present a more ecologically beneficial alternative to typical built shoreline stabilization methods, such as bulkheads. The variety of physical settings across the watersheds provides a range of opportunities for implementing natural and nature-based flood mitigation strategies.

Resident Perspectives

91 percent of polled residents strongly supported encouraging the maintenance of natural flood buffers, including living shoreline approaches for managing erosion.

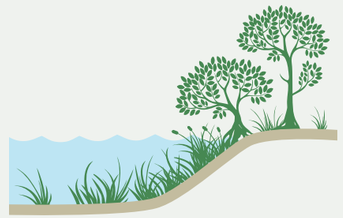
Non-Structural Protections

Beaches and Dunes

Beach nourishment is a soft armoring technique that involves pumping sand on an existing beach and dunes to raise their elevation and increase beach width. High dunes improves storm protection by preventing overtopping of the dune. Wider beaches increase the distance between the upland bank and waves and encouraging beach and dune formation. These beaches and dunes can act as a buffer for coastal flooding. A nourished beach gradually erodes away through wind and wave action so periodic nourishment is often required.

Marshes

Marshes are low-lying ecosystems that provide flood and erosion control, water purification, and food and habitat for wildlife. Marsh grasses provide vegetation-induced resistance, which can dissipate wave energy, delay storm surge intrusion, buffer tidal flooding, and reduce erosion. Restoration involves returning a degraded wetland habitat to the closest approximation of the original natural condition, while enhancement involves modifying an existing wetland by adjusting specific site conditions to improve wetland functions.



Maritime Forests

Maritime forests act as an inland buffer to surge, waves, and wind during storm events. They can tolerate strong winds, periodic or permanent flooding, moderate salinity, and sandy soils. Forest conservation and restoration provides protection from coastal erosion and helps preserve other wetlands. Similar to wetlands, forest size and connectivity are important factors in determining ecological benefits and flood hazard mitigation potential.

Aquatic Vegetation

Underwater grass beds, known as submerged aquatic vegetation (SAV), are composed of rooted flowering plants that have colonized primarily soft sediments in coastal, estuarine, and freshwater habitats. High densities of aquatic vegetation provide friction that slows down the flow of water and reduces the depth and duration of flood events. They also capture and filter sediment and polluted runoff in the water, improving water clarity while providing habitat for fish and other aquatic species.

Shellfish Reefs

Shellfish reefs are underwater aquatic habitats that have an important ecological role in salty or brackish coastal waters. These roles include filtering water, providing structured habitat for other species, and protecting shorelines from erosion by stabilizing sediments and dampening waves. Shellfish are sometimes called 'ecosystem engineers' in recognition of the multiple roles they plan in shaping the environments in which they live[20]. Shellfish reefs can be constructed by growing oysters until they reach a healthy adult size, and then planting these oysters onto sanctuary (non-harvest reefs).

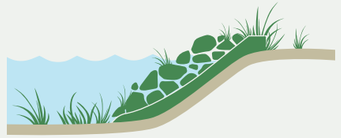
Variability in Working with Nature

When considering the use of natural and nature-based features, it is also important to recognize the dynamic and variable character of such systems. The long-term flood risk reduction and ecosystem benefits provided by natural features vary depending on responses to external events and processes such as coastal storms or urban development. For example, a newly constructed wetland could potentially be destroyed by a storm event, but could also use the sediment supply brought in by the storm to accumulate and grow. This uncertainty can be addressed through effective planning, design, and monitoring to ensure the desired level of service is upheld throughout the project's lifetime.

Hybrid Protections

Living Shorelines

A living shoreline is a hybrid technique that integrates plants or other natural elements with harder materials for added structural stability designed to break waves before they reach the shoreline. Living shorelines typically involve construction of a low-profile breakwater, commonly designed using rip-rap stone. Designs that incorporate alternative natural materials like coconut fiber logs or oysters are often referred to as "living breakwaters". The stone or natural breakwater can be constructed parallel to the existing shoreline or extended offshore to break waves further offshore or reclaim historically lost shoreline. These systems create a protected area where sediment can accumulate between the structure and the shoreline, eventually increasing the width and elevation of the marsh.



Enhanced Revetments

As part of a living shoreline strategy, the spaces in a rock or concrete revetment can be planted, resulting in an ecologically enhanced version that can be used both in open coastal locations as well as lower energy sheltered shorelines to prevent erosion of the bank and reduce wave energy. Incorporating vegetation within the revetment can help stabilize the underlying soil and provide flood storage benefits. Similar approaches can be taken to retrofit existing hardened bulkheads and revetments by incorporating vegetation.

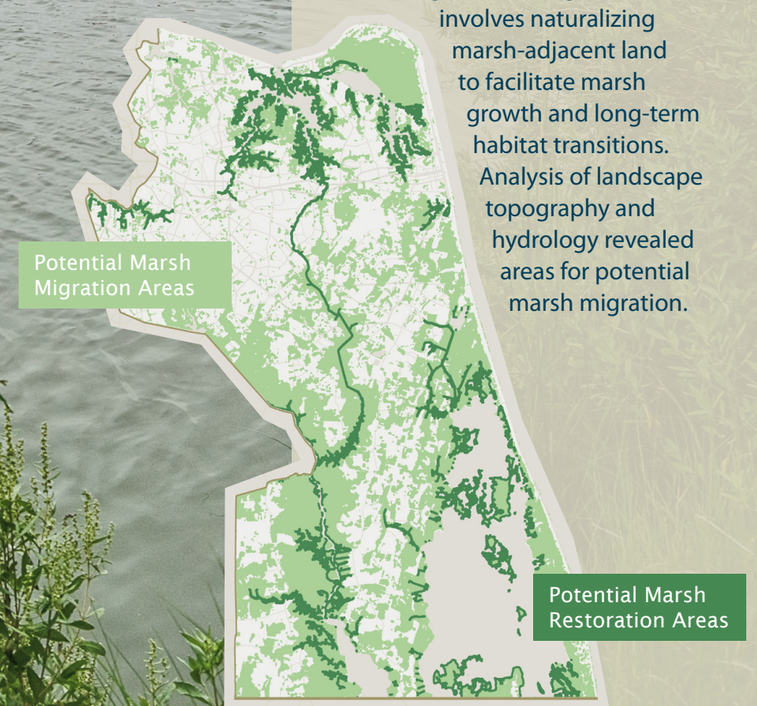
Resident Perspectives

83 percent of polled residents strongly supported an integrated approach that combines natural features with structural solutions.

Wetland Migration

Marshes exist at the interface between land and water, and are therefore threatened by changing coastal conditions. As sea levels rise, marshes will naturally attempt to migrate inland. However, hardened shorelines and upland development can restrict marsh migration, leading to significant losses in fringing coastal marshes.

Marsh migration is an important compliment to marsh restoration efforts. Strategic marsh migration involves naturalizing marsh-adjacent land to facilitate marsh growth and long-term habitat transitions. Analysis of landscape topography and hydrology revealed areas for potential marsh migration.



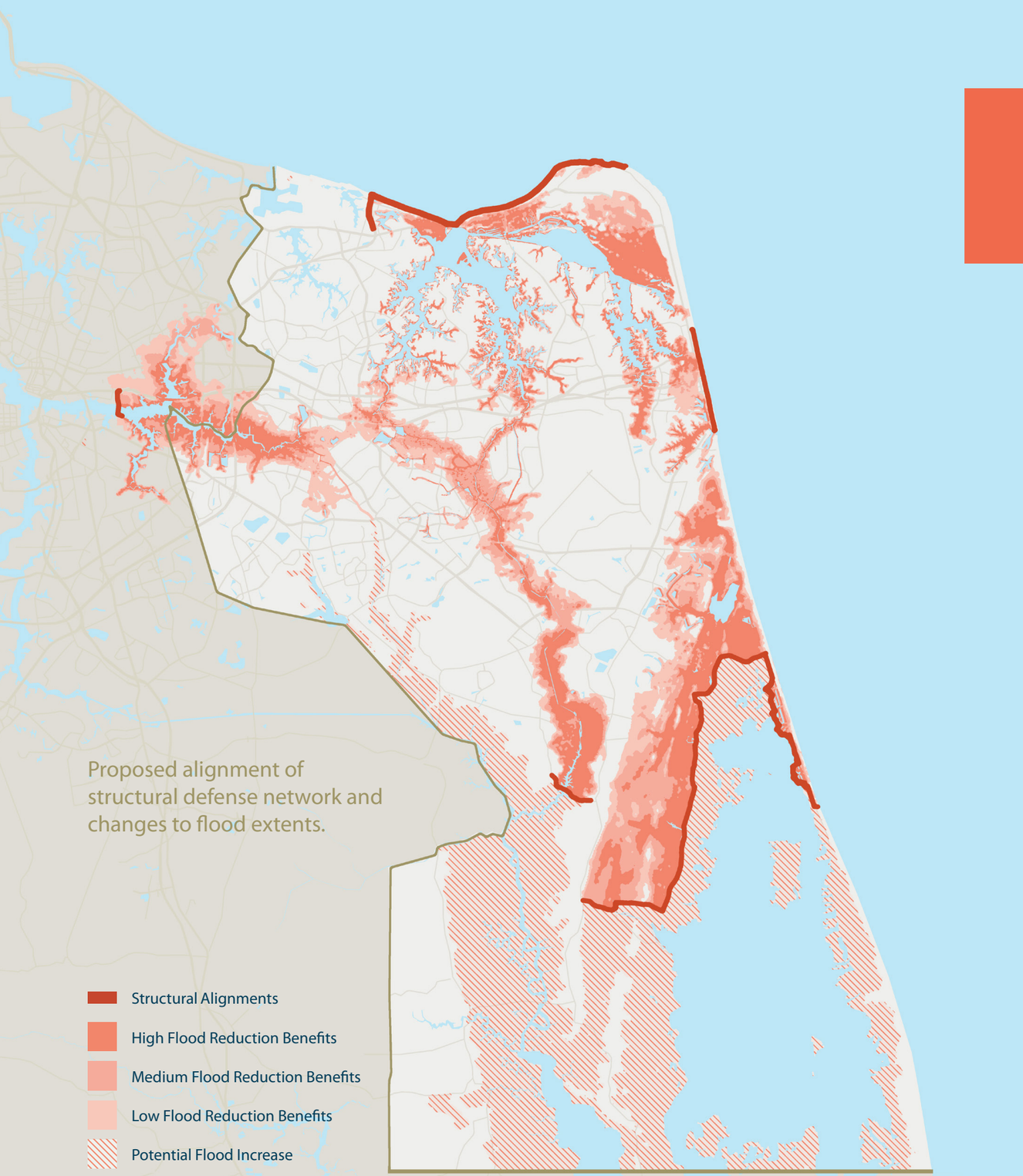
ENGINEERED DEFENSES

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

When designed on the smaller-scale, these defense systems can effectively be embedded into neighborhood coastlines and waterways. For example, roads and walkways can be raised and engineered to serve as a passive yet highly effective flood barrier integrated into the landscape.

Larger-scale structural strategies are more likely to stand out from their surroundings but can be a powerful defense system for protecting high numbers of people, buildings, and assets from coastal flooding.

Investments in flood control structures can reduce flood risks for neighborhoods and critical facilities, creating cost savings by avoiding losses during recurrent flooding or extreme storm events. However, structural solutions are expensive, with city-wide costs in the billions, and implementation comes with significant hurdles such as environmental impacts and permitting. Due to the complexity and scale, they would also require many years to effectively implement city-wide, and residual risks will always remain. Additionally, they can have adverse environmental impacts on coastal ecosystems and increase flood risks to communities outside of the flood protection area. It is therefore especially important that defensive structures are implemented alongside other adaptation layers in order to effectively manage flood risks in both near- and long-term time frames.



Pursue an Expansive Flood Defense Network

Invest in the long-term construction of a structural defense network that provides wide-reaching protection from increasingly severe coastal flood risks.

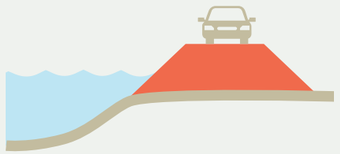
Medium- and large-scale structural systems can significantly reduce the amount of coastal floodwater entering Virginia Beach. While ambitious in scope and scale, the construction of an expansive network of protection infrastructure is one of the more effective solutions available to Virginia Beach, especially as coastal risks continue to increase throughout the century.

Structural flood defense systems can be constructed on land or in water and can provide flood protection through either passive or active means. Passive systems are immobile structures such as levees, floodwalls, and seawalls that provide a constant level of flood protection under all conditions without the need for deployment. Active systems, including in-water and inland gates, are designed to be deployed in advance of more severe flood events. They require accurate flood prediction capabilities and detailed operating instructions in order to provide effective protection during a flooding event.

A truly effective combination of passive and active structural defense elements will likely take decades to fund and implement. The design, construction, operation, and maintenance of defensive structures should be integrated into the City's capital improvement planning and budgeting processes. When assessing and prioritizing potential options, the City must consider relative cost, constructability, real estate requirements, operations and maintenance needs, impact on the functional use of waterways and traffic circulation, and ease of deployment.

These types of large-scale interventions also present particular opportunities for collaboration with other regional stakeholders. The inland nature of many of the City's coastal flood risks requires consideration of how water crosses through adjacent lands regardless of municipal borders. Consequently, some structures could be funded and constructed with support from adjacent municipalities and the military.

Inland Structural Defenses

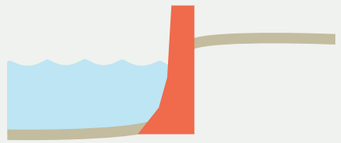


Earthen Levee

Earthen levees are free-standing embankments resistant to water passage and infiltration that can also serve dual purpose of vehicular and pedestrian access. Constructed beside a river or ocean, elevated roadways contain, control, or divert the flow of water to reduce risk of flooding. They can include grass-covered soils, sand dunes, and even stone revetments but usually require a water-resistant barrier to prevent floodwaters from seeping through the soil.

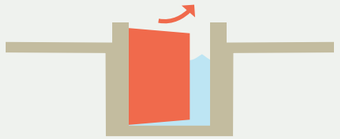
Floodwall

Floodwalls are narrow, free-standing barriers that stand between low-lying areas and neighboring waterways, inland streams, or rivers. While relatively low cost, they are aesthetically imposing, and often block access to the waterways they border.



Seawall

Seawalls are typically seen around industrial areas like ports or harbors, with the capability of supporting significant loads above the structure as well as provide protection from wave, debris, and vessel impacts. While typically costly, they allow for minimal aesthetic impact from the landward side.

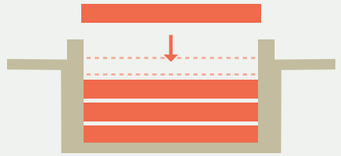


Swing Gate

The inland swing gate is stored on-site and in non-flood conditions remains open and is closed either manually or mechanically by swinging into place when needed. These structural steel gates can be engineered to withstand wave, debris and vehicular impact loads.

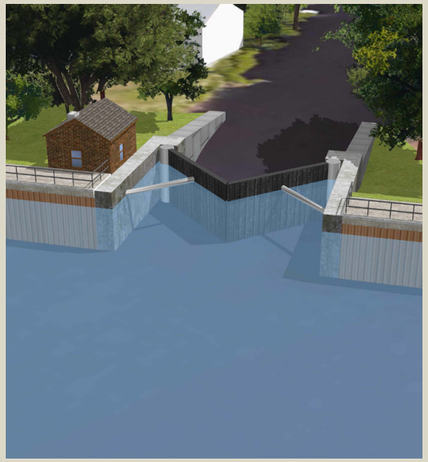
Rolling Gate

Inland rolling gates are typically constructed in-line with floodwalls to allow access to critical infrastructure areas. They appear as standard security gates when open, and remain open until the storm events. The gates run on tracks and seal with a gasket once fully closed.



Flood Log

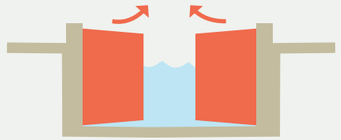
Flood logs are modular beams that can become a flood wall when stacked on top of each other. While low-cost, they require a significant long-term storage area when not in use and call for significant manpower and time commitment before the storm event to permit full and adequate deployment.



In-Water Structural Defenses

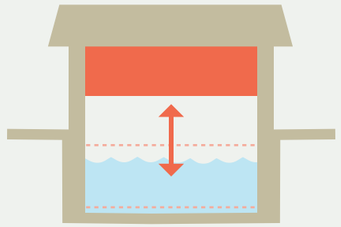
Sector Gate

Sector gates are arched structures that pivot from outside the channel inwards to close. They can be constructed at massive scales, capable of spanning large channels while having a limited impact on vessel traffic. However, they are very costly and have significant access and power requirements, and high maintenenace costs.



Miter Gate

Miter gates are a type of navigation lock with doors that remain on the side of the channel when open, and swing out and lock together to stop the passage of water when closed. With relatively simple construction and operation needs, they are a good choice for small riverine or inlet crossings but have high maintenance costs.



Vertical Lift Gate

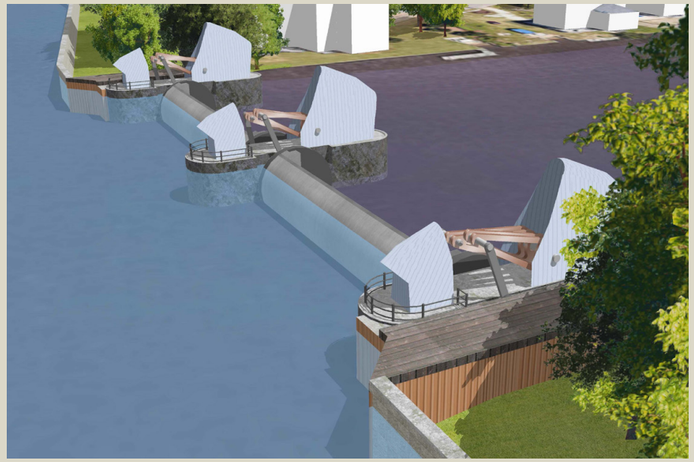
Vertical lift gates hang in the air above the water when open and come down into the water whenclosed. They have high maintenance costs, are not generally suited for high vessel traffic areas and typically deployed adjacent to existing bridge infrastructure to minimize major aesthetic impact.

Movable Gate

In-Water Movable Gates encompass a variety of flood protection systems but in general, these systems tend to lie underneath or alongside the channel when open, and when activated, pivot or slide to seal the channel in during a storm-surge event. They can accommodate large depths but have high maintenance costs. Also, storage, access, and power requirements lead to high construction costs and coordination needs.

Resident Perspectives

Risk reduction, cost effectiveness, and environmental impacts were the top three priorities identified by residents as the most important criteria for evaluating structural adaptation solutions.



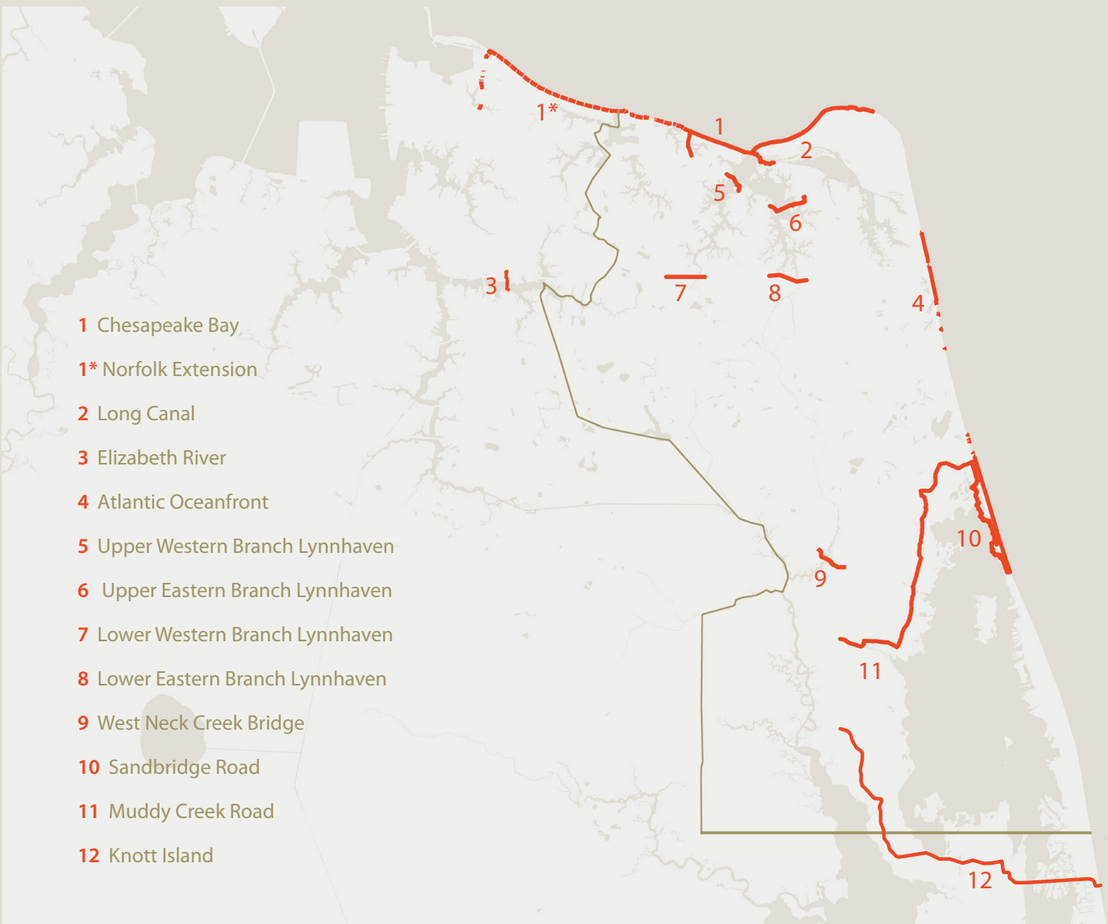
Evaluating Structural Alternatives

The integrated strategy for Virginia Beach followed a multi-step design and evaluation process involving expert knowledge, state-of-the-art evaluation tools, stakeholder engagement, and participatory decision-making.

Step 1. Potential Locations

The process began by identifying locations where large-scale structural elements could have the greatest potential to block specific flood pathways, preventing coastal floodwaters from passing into inland areas.

Twelve initial locations were identified where opportunitied existed to strategically place defense structures across low-lying land or waterways to protect large areas of the City from coastal floodwaters.



Step 2. Site Characteristics

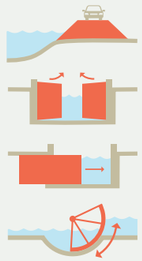
Next, each location was reviewed to understand the possibilities and constraints. This included a review of land elevations, land ownership, traffic, navigation, existing structures, utilities, and natural features. Locations were chosen that had the potential to protect large areas, but not be too disruptive for people or the environment.

Step 3. Design Level of Protection

After careful consideration, the team established that structures should be designed to a federal levee accreditation standard established by the Federal Emergency Management Agency. The use of this standard would provide for both robust protection and also discounts on flood insurance rates for policy-holders in the protected areas. This resulted in a minimum design elevation at the 100-year return period storm, for a sea level rise scenario of 3 feet above existing conditions. Finally, an additional 2 feet of design elevation (termed "freeboard") was included to meet the federal guidelines and allow for a factor of safety for uncertainty.

Step 4. Structural Toolkits

A wide range of defensive structures was identified. The selection drew from best practices around the world and included floodwalls, seawalls, various types of gates, and storm surge barriers. These structural elements were qualitatively reviewed for advantages and disadvantages. They were also scored across a range of key factors such as relative cost, proven performance, constructability, and real-estate impact to enable comparison. The top-ranking structures formed the toolkit that the engineering team used to develop conceptual designs.



Step 5. Conceptual Designs

Considering the constraints and the design elevation, the engineering team conceptualized how to implement flood protection at each site. In some locations, multiple alternatives were developed, utilizing different applications of the toolkit. Each site design was considered a piece of the overall city-wide flood protection puzzle.

Step 6. Combination Selection

The next challenge was to look at different combinations of sites to determine the best overall combination for coastal flood defense across the City. Collaborative workshops were held to identify and evaluate different combinations of the twelve sites. Each potential combination was called a flood protection alternative. Workshops included a mapping exercise to identify potential feasibility considerations such as constructability and environmental impacts. The outcome was a set of 10 initial alternatives which combined one or more of the conceptual site designs.

Step 7. Cost, Benefit, and Impact Assessment

The 10 alternatives were evaluated using either quantitative and qualitative assessments of project cost, return on investment, amount of flood reduction, potential for increased flooding to other areas, technical feasibility, and potential environmental impacts.

Costs and Benefits

For each flood protection alternative, total project costs in 2018 included estimated costs associated with designing and permitting the structures, construction, and annual operation and maintenance needs. Project benefits comprised of total estimated prevented flood damages to buildings, and impacts on their use, residents, and contents over the entire project life span. A project is considered a good return on investment when the benefits are equal to or outweigh the costs.

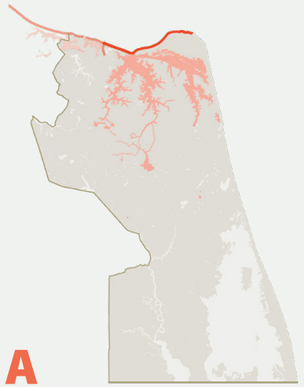
Impacts

The City employed state-of-the-art computer modeling to simulate various coastal, rainfall, and compound flood event types and assess positive and negative impacts of the structure. Each alternative also had varying levels of impact on the surrounding area. The level of protection provided by a structure is based on the amount of water it prevents from entering inland areas. However, when floodwaters are blocked from entering protected areas, that water is displaced, potentially increasing flooding concerns for areas outside of the structural system. Additionally, flood defense structures can also block the drainage of rainfall runoff, which must be minimized or mitigated with pumps that move this build up to the other side of the structure so additional flooding does not occur.

Step 8. Alternative Comparison

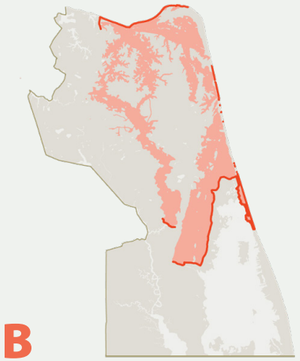
A workshop was held to review and weigh the evaluation factors for each alternative. The pros and cons of each alignment were used to remove alternatives with notable issues. Decisions were often made in light of further consideration of the cost, permitting, and construction challenges. As the group engaged in further discussion about the benefits and drawbacks, three primary strategy alternatives emerged as the most effective and feasible options.

Alternative	A1	A2	B	C
Overall Length	7.8 miles	12.4 miles	33.6 miles	34.4 miles
Flooded Area Reduction	41 square miles	46 square miles	78 square miles	85 square miles
Mitigated Structures	28,000	29,000	39,000	45,000
Design & Construction Cost	$1.13 billion	$2.31 billion	$2.22 billion	$2.42 billion



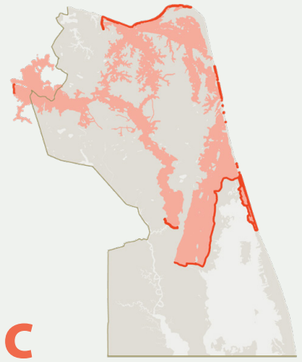
A

Alternative A represents a relatively lower-cost approach, but only protects the Northern portion of the City. There are two different arrangements for structures along the Chesapeake Bay—one (A1) retains all protection within Virginia Beach whereas the other (A2) offers a continuous line of protection extending across Little Creek into the City of Norfolk.



B

Alternative B offers a higher level of protection, blocking most of the major coastal flooding pathways into the City, except for protection from flooding coming from the Elizabeth River.



C

Alternative C offers the highest level of protection at the highest cost. This alternative extends protection into the Norfolk to protect from flooding through the Elizabeth River.

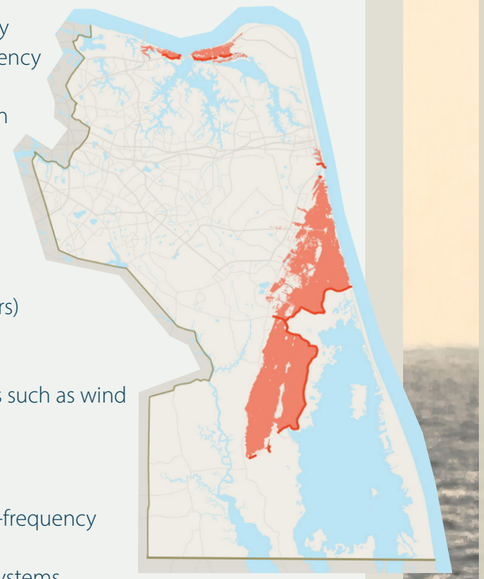
Resident Perspectives

Alternative C had the highest favorability among polled residents and forms the basis of the City's recommended engineered defense solution.

Step 9. Neighborhood-Scale Systems

The team assessed the potential to implement smaller engineered defense systems to address near-term concerns and more commonly occurring coastal storms. These neighborhood-scale interventions can protect the most vulnerable areas within the City while the extensive coastal defense systems are designed and evaluated for environmental impacts. The neighborhood strategies that are less intrusive to the built environment could have a high probability of implementation and provide flood risk reduction benefits for highly vulnerable areas.

The team performed a high level assessment to identify areas within the City that are vulnerable from combined effects of sea level rise and higher frequency coastal storm surge events. The vulnerability assessment revealed fourteen distinct areas within the City to focus on. That initial set was narrowed down based on pre-existing projects, site constraints, environmental impacts, overlap with large-scale approaches, and cost—leaving five areas where conceptual projects were developed.



Neighborhood-Scale Advantages

- Can be designed and constructed relatively quicker (usually within 5 years)
- Relatively less expensive
- Requires minimal use of deployable structures, maximizing reliability
- Protects from tidal, nuisance, and lower elevation, high-frequency events such as wind events, small coastal storms, tropical storms, etc.

Neighborhood-Scale Disadvantages

- Does not provide adequate flood protection against high-elevation, low-frequency flood events such as hurricanes
- Potential for duplication of flood risk reduction if combined with larger systems
- Does not provide any FEMA flood insurance reduction benefits.

Step 10. Complementary Protection Measures

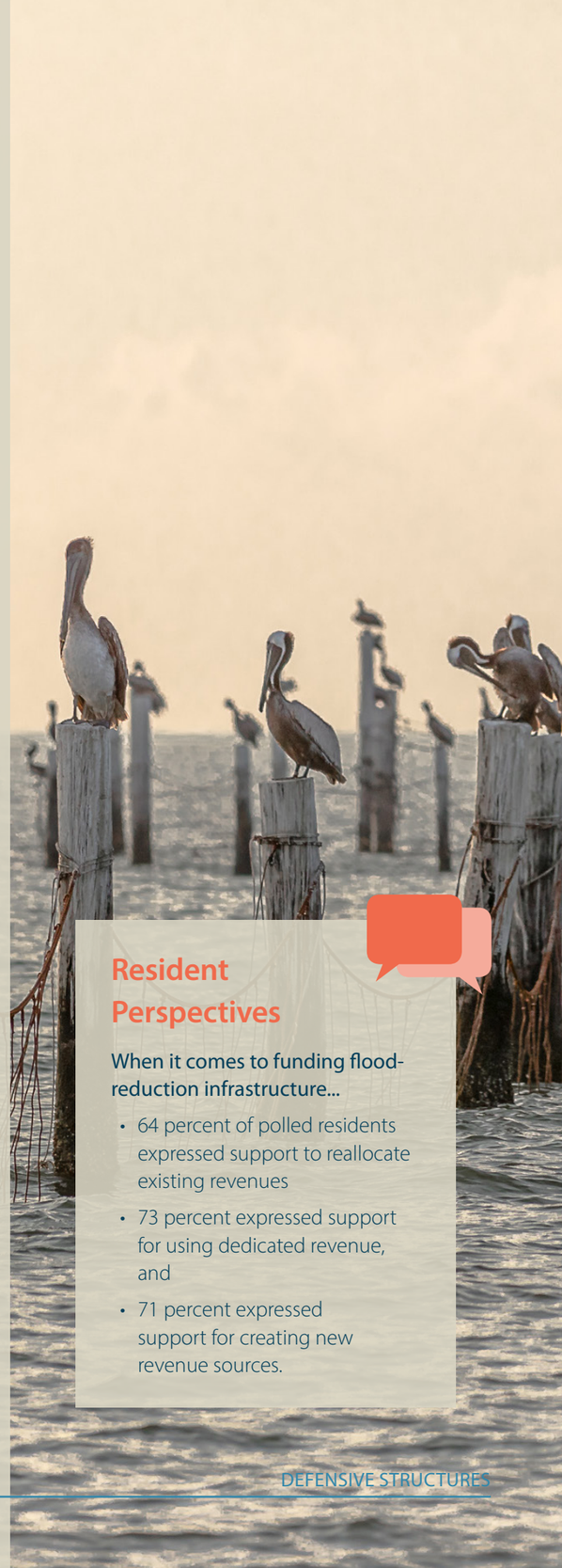
Although the combined structural defense system protects large portions of the City from coastal flooding, there are still some areas that remain unprotected. These areas are either outside of the area of protection or subject to residual risk. Furthermore, large-scale infrastructure projects are expensive and will likely require a significant amount of time to advance through a comprehensive feasibility study, final design, permitting, and construction. To provide protection in the near-term and address residual risks, the City is committed to pursuing additional strategies—including those presented in the other Adaptation Layers—that could compliment or enhance the performance of the large-scale engineered defenses.

Financing Large-scale Infrastructure

There are many funding and financing options the City can explore, including from federal, state, and private capital. While Virginia Beach is a good candidate for a variety of grant funding opportunities, the City will likely need to borrow funds (issue debt or debt financing) to invest in these substantial structural responses.

The City may rely on financing mechanisms that have successfully been used in the past, such as issuing debt via general obligation and revenue bonds. The City may also consider alternative financing mechanisms such as environmental impact bonds or green bonds. These are innovative, but untested in Virginia Beach.

Regardless of the type of debt issued, the City will need to reallocate existing revenue streams and/or generate additional revenues through new funding streams to pay off the debt. This could mean reallocating existing tax revenue (for example the sales tax or property tax) or revenue from non-obligated funds (for example the City's general funds) to pay off the debt. The City may also dedicate revenue from fee- or tax-generating facilities or amenities, such as parking facilities, to pay off debt associated with related infrastructure investments that improve drainage and stormwater management. The City may also create new revenue streams associated with increased value of land, property, or economic activity from reduced flood risk. For example, the City may impose higher sales tax rates for economic activity within a commercial area that will be better protected from flooding due to the protective infrastructure.



Resident Perspectives

When it comes to funding flood-reduction infrastructure...

- 64 percent of polled residents expressed support to reallocate existing revenues
- 73 percent expressed support for using dedicated revenue, and
- 71 percent expressed support for creating new revenue sources.

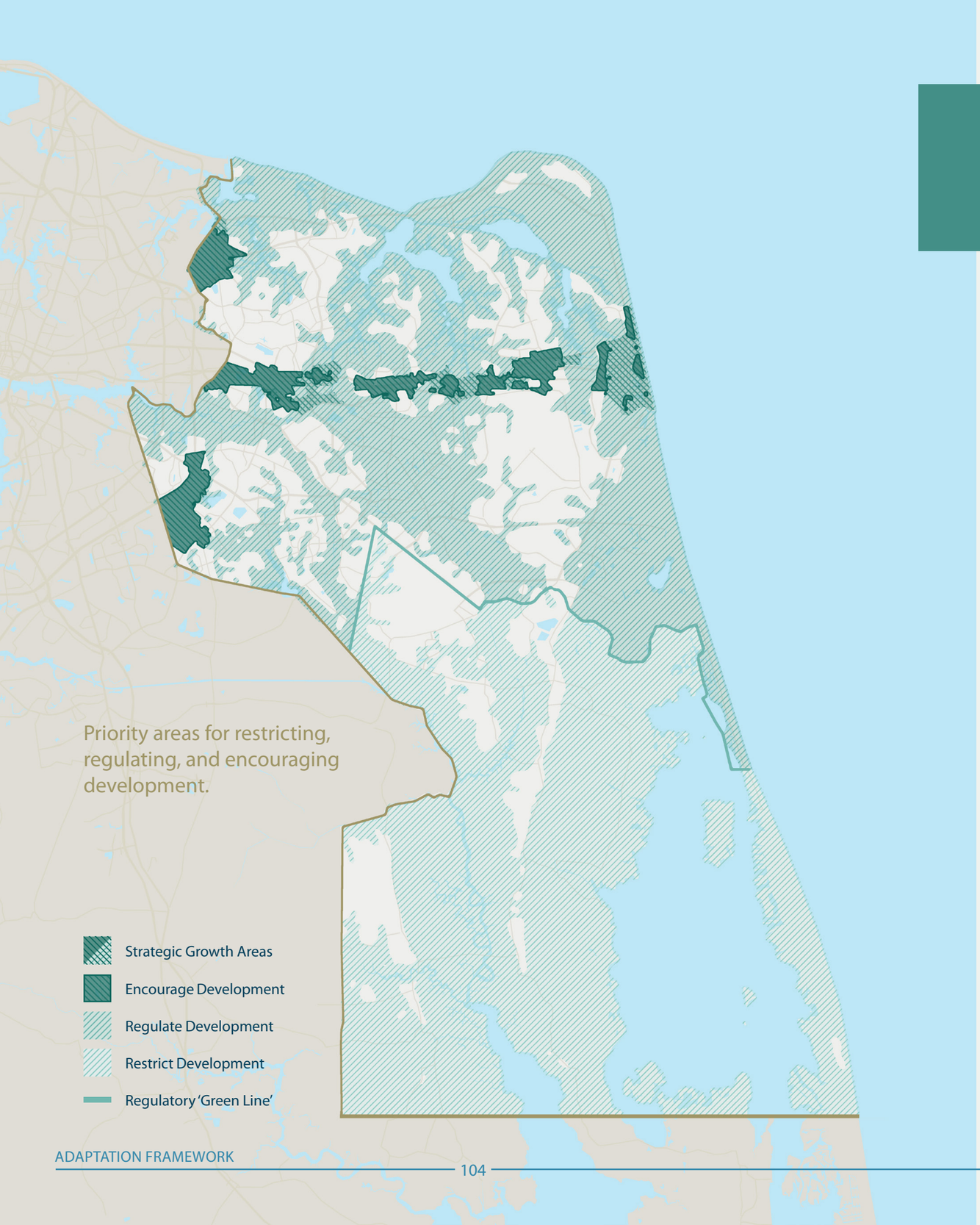
ADAPTED STRUCTURES

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

When preventative infrastructure is incomplete, inadequate, or in any way incapable of handling the magnitude of flood risks, the flood-exposed buildings and infrastructure themselves become the next line of defense. Buildings and infrastructure systems can be designed resiliently, capable of withstanding a certain level of flood impacts. In both new and existing development, flood-resilient planning and design components can be integrated through a systematic and forward-looking approach to project management, siting, and design.

The 2016 Virginia Beach Housing Needs Assessment, Market Analysis, and Re-Investment Study determined that half of the housing stock in Virginia Beach was built in the 1970s and 1980s, and therefore numerous structures in and around the City may need to be improved and/or redeveloped over the next decade. This presents an opportunity for the City to ensure that as the housing stock transitions, redeveloped structures and surrounding infrastructure systems are sited, designed, and constructed to be more resilient to the future flood risks as detailed by the most recent sea level rise, precipitation, and recurrent flooding data and research. While structural adaptation concepts are relevant for all urban and developed areas, it is of particular relevance for the designated Strategic Growth Areas (SGAs), where the City anticipates most growth and redevelopment occurring in the following decades.

New projects can be sited in areas of minimal flood exposure, and designed to handle an acceptable level of flood risks based on criticality and useful life. Existing buildings and infrastructure can be retrofitted, to minimize existing and future risks. Infrastructure assets can be proactively managed, assessing areas of greatest system-wide vulnerability and identifying areas for targeted interventions.



Regulate Building and Development

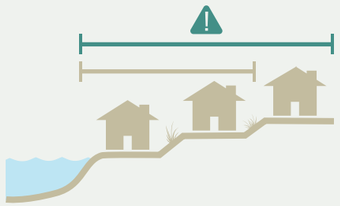
Require responsible siting, design, and construction practices for new and substantial redevelopment that are reflective of the area's current and future flood risks.

Regulating the siting and design of new development and substantial redevelopment can reduce the threat of sea level rise and recurrent flooding to residential, commercial, and publicly owned structures throughout the City. This includes restricting where developers are allowed to build, how new structures are built, and how substantially redeveloped structures are rebuilt to higher standards. Land use codes and ordinances are used to govern where and how structures are built within the City.

Both the regional planning district commission and Commonwealth of Virginia have taken actions that serve to concentrate and regulate development in response to increased flooding risks. In January 2018, The Hampton Roads Planning District Commission unanimously passed a resolution encouraging Hampton Roads localities to adopt policies that incorporate sea level rise into planning and engineering decisions. At the state-level, two executive orders have forwarded resilience planning: in 2018, Virginia Governor Ralph Northam signed Executive Order 24, "Increasing Virginia's Resilience to Sea Level Rise and Natural Hazards". This document established a Chief Resilience Officer for the Commonwealth, and directed a number of measures, including establishing unified sea level rise planning scenarios, updated freeboard standards, review of a review of vulnerable, and establishing a Coastal Resilience Master Plan. While not explicitly aimed at reducing flood risks, Virginia Beach's Strategic Growth Areas can concentrate development in places with low flood risk, or at least limit sprawl to smaller geographic footprints that can be more effectively protected by flood risk reduction interventions.

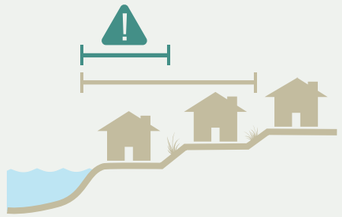
Beyond these regulatory changes, the City understands that additional changes to siting and design regulations are needed to support healthy development while encouraging the construction of safer more resilient structures City-wide. For example, the City's current building codes do not yet require applicants to consider future flood conditions that account for sea level rise and increasing rainfall. Restricting the area in which new structures and critical facilities can be built will protect new development from exposure to flood risks. New development and substantial redevelopment in flood-prone areas can also be designed to safer standards, able to withstand both current and future flood conditions.

Siting and Design Regulations



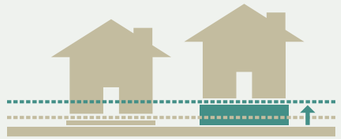
Floodplain Ordinance Update

The City's floodplain ordinance helps to govern development within the 100-year floodplain. As rainfall patterns continue to change and sea level rise increases, this 100-year floodplain no longer serves as the best boundary to estimate flood risk. All too often, areas outside of this floodplain are experiencing flooding on a regular basis. The City has the opportunity to update the ordinance to govern a larger, expanded floodplain to more accurately capture current and future flood risks. An updated ordinance can take into account important new data such as updated research and recent flood modeling, while making sure that development within the regulatory floodplain can withstand future flood conditions.



Coastal Zone Creation

With the help of FEMA Flood Insurance Rate Maps, the City can identify coastal areas which are subject to 1.5 feet or higher waves during a 100-year coastal flood event. These areas are considered high-risk coastal zones and are greatly impacted by damaging waves during storm events. Currently, the City does not single out these areas for special consideration within the floodplain ordinance. By designating this high-risk coastal area as a separate floodplain district (such as a "Coastal A-Zone" in accordance with Virginia State Building Code), the City could incorporate higher design standards and better protect the people and property within these areas.



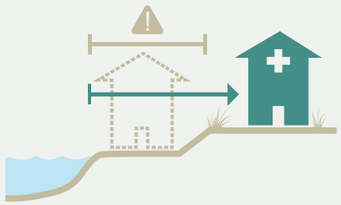
First Floor Elevation Requirements

One of the most effective tools to remove flood risk, at a reasonable cost, is to raise structures above the level of the flood water. The City could increase elevation requirements (i.e. freeboard) for new structures and substantially redeveloped structures. Freeboard is currently set at two feet above the base flood elevation by the Floodplain Ordinance, but could be raised to three feet, or above a future design flood elevation as determined by the City's research and data findings. This may require increasing the maximum building height allowed for buildings outside of the Special Flood Hazard Area so that property owners may elevate their structures.

Resident Perspectives

75 percent of polled residents expressed strong support for changing land use and floodplain ordinances and regulations, building codes, and construction standards to enhance the resilience of buildings and neighborhoods.

80 percent of polled residents supported the City establishing higher building standards and codes.



Critical Facility Location

Critical facilities are vital facilities (hospitals, schools, police stations, fire stations and emergency shelters, for example) that provide key services necessary for the community's safety and well-being. New regulations could ensure that new City-owned critical facilities are not built in high flood-risk areas. As sea level rise continues to impact the City, these facilities will remain safely out of reach from flooding and flood-impacted roadways, thereby continuing to provide critical services to the community.

Conditional Permitting

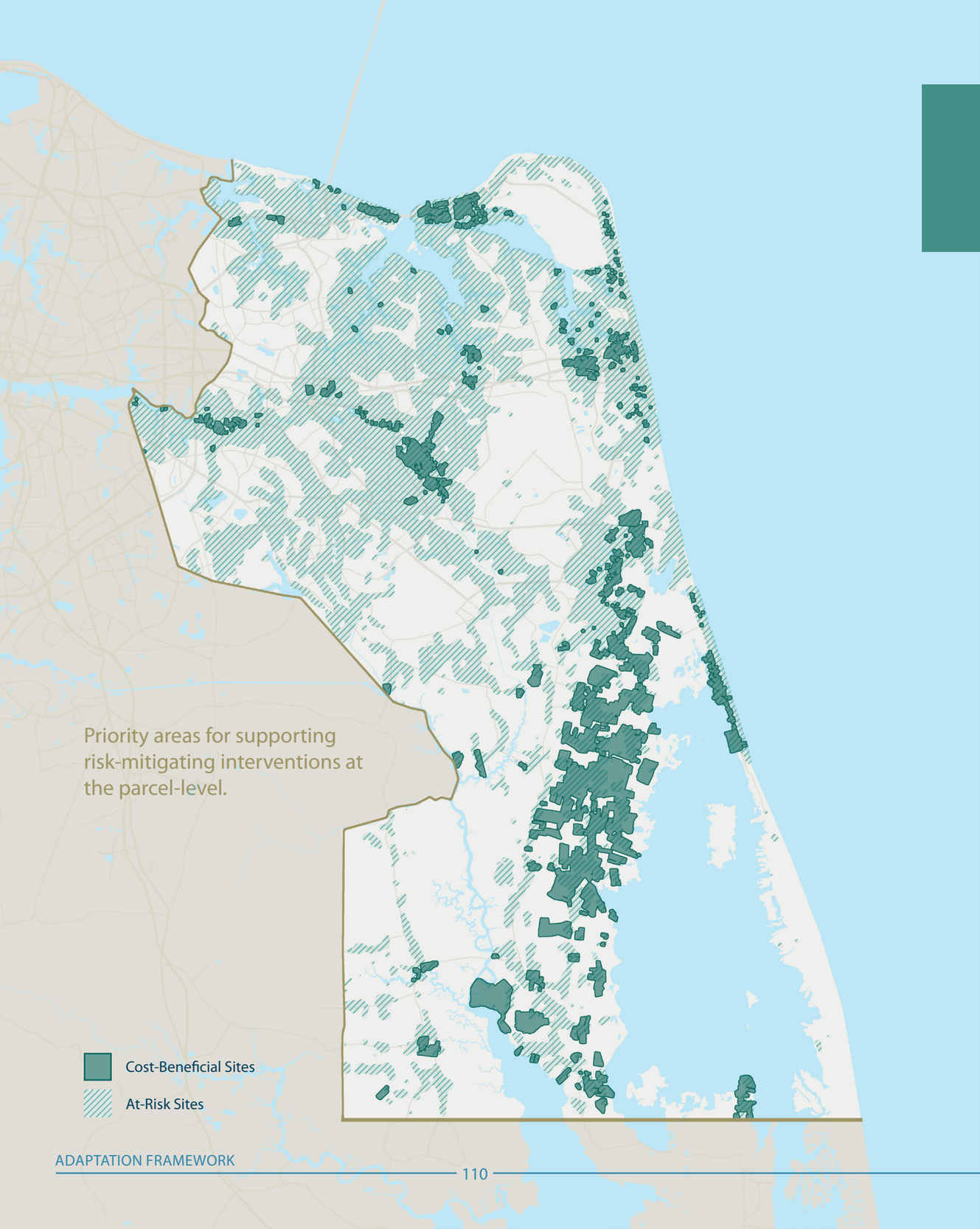
Higher design standards can be applied to most new development and redevelopment projects. New requirements can ensure that developers applying for conditional rezoning and conditional use permits utilize design practices that account for sea level rise, rainfall, and recurrent flooding projections. Design restrictions can also require all mechanical and electrical systems to be built up to new higher freeboard requirements.

Resident Perspectives

79% of polled participants expressed strong support for passing laws and regulations that dictate where new facilities and buildings can be built in vulnerable areas or areas likely to flood.

Designing Under Changing Conditions

Flood-resilient design often requires an estimation of how flood risks will change over a building or structure's lifetime. This means if a building is expected to last for 80 years, engineers should design for flooding conditions expected in 2100. However, pinpointing exact future conditions with complete accuracy is impossible. Therefore, engineers must assess what level of risk is appropriate based on how critical a building, structure, or asset is, and then design based on the best scientific projections available today. For long-term structures, designing for further future adaptation is also possible. For example, a flood wall could be designed to be raised over time as sea level rise increases.



Support Risk-Mitigating Interventions

Provide resources and incentives to encourage flood-resilient design or retrofits of residential and commercial properties.

While strong regulations can be an effective way to enforce safer standards for new development, the City can also support voluntary risk mitigation actions taken by individual residents and businesses. Retrofits to existing buildings can potentially eliminate risks from minor flood events while significantly decreasing damages experienced during major and catastrophic storm events. Flood-mitigation actions at the parcel-scale include structural elevations, floodproofing, demo/rebuild, stormwater management, and green infrastructure.

However, retrofits for residential homeowners and commercial businesses can be expensive and require a substantial financial investment. Many residents and businesses simply do not have the capital or savings with which to undertake a project such as a structural elevation. Often-times the high cost of these risk-mitigating actions is only feasible through federal grant funding that significantly reduces the cost burden. The City is already helping residents with FEMA Hazard Mitigation Program Grants and is looking to expand this type of assistance. However, federal funds are only available under specific conditions, are limited, and can take years to actualize.

City incentive programs can fund or offset the costs for community members to conduct flood mitigation retrofits on their homes and businesses. These incentives can come in numerous forms, such as direct financial assistance in the form of a grant, loan program, or tax credits. City-provided financial incentives and assistance can provide more opportunities for businesses and community members to mitigate flood risks on their property.

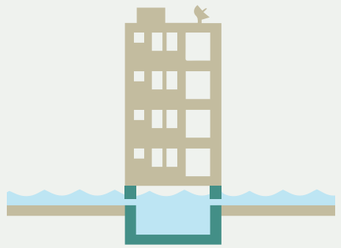
Resident Perspectives

56 percent of polled residents would prefer the City to focus on planning and management approaches that floodproof houses and reduce flood impacts.

Site-Scale Mitigation Methods

Dry Floodproofing

Dry floodproofing involves making structures substantially impermeable to floodwaters. This can be done to existing individual flood-prone structures by reinforcing walls, adding flood shields, and installing drainage systems with pumps. Unlike other individual structure measures, dry floodproofing is active mitigation that requires human intervention to be effective (i.e., at least 12 hours of warning time to install the measures and evacuate). Furthermore, because dry floodproofing measures can impose significant flood loads on structures, their application is primarily recommended for commercial and public structures in riverine floodplains that are constructed of concrete or masonry framing with slab-on-grade foundations.



Wet Floodproofing

Wet floodproofing involves modifying a structure to allow floodwaters to enter and exit without causing significant damage. This can be done through the addition of hydrostatic openings or vents, application of flood damage-resistant construction materials, elevation of utilities and key equipment, and relocation of valued contents to reduce damages and losses from inundation by floodwaters. Wet floodproofing is a relatively inexpensive mitigation option, but may involve some human activation (i.e., moving key equipment and contents to a higher level before evacuating) and requires significant post-flood cleanup. Wet floodproofing can help reduce minor or residual flood risks for flood-prone residential homes, and is generally most suitable for commercial warehouses, storage buildings, and other non-residential structures where the contents/equipment are more valuable than the structure itself.

Structure Elevation

Structural elevation involves lifting existing flood-prone homes to a safer height above anticipated flooding levels. In this process, entire structures are lifted and a permanent foundation is constructed underneath in accordance with City ordinances and current building codes and design standards. The feasibility of structural elevation depends on a structure's foundation type: homes with crawlspace foundations are typically the simplest and cheapest to elevate, homes with pile foundations are more difficult and expensive, and slab-on-grade homes are the most complex and costly. Cost-effective structural elevation projects are eligible for funding under FEMA's Unified Hazard Mitigation Assistance Program.

Photos courtesy of FEMA library

Resident Perspectives

48 percent of polled residents said they would invest in home floodproofing to improve their own resilience to flooding.

42 percent of polled residents said they would like to learn more about what they personally can do to adapt and prepare.

Mitigation-Reconstruction

Mitigation-reconstruction projects involve demolishing existing individual flood-prone homes and replacing them with new structures constructed within the same footprint and elevated above design flood levels. The new structure is designed and constructed to resist high winds and other hazards in accordance with the City ordinances, as well as the latest building codes and design standards. This is generally a good mitigation approach for addressing flood and sea level rise risks in situations where one or more existing structures cannot be feasibly elevated, but they are expensive and subject to FEMA hazard mitigation grant funding limitations.

Voluntary Acquisition

Voluntary acquisition is when the City purchases a high-risk property from a willing seller in order to allow the residents to relocate to a safer area. Once the property is acquired, the City demolishes the structure and converts the parcel into open space, which can have added flood-reduction benefits for the surrounding neighborhood. Although expensive, buyouts are a highly cost-effective option for select high-risk residential structures and are supported through FEMA's Hazard Mitigation Assistance Program. Based on City analyses, over 2,500 residential parcels across the City are good candidates for voluntary property acquisition.

Green Infrastructure

Green infrastructure and other water management strategies can be implanted on private residential and commercial property. Water management strategies come in many forms and are often one of the more affordable and technically feasible options for property owners. Strategies include rainwater harvesting, rain gardens, green roofs, bioswales, cisterns, and permeable pavements. Green infrastructure reduces and filters stormwater runoff thereby improving water quality, recharging the water table, reducing risks of saltwater intrusion, improving air quality, and providing public health benefits. Green infrastructure systems require diligent upkeep to remain effective, which property owners should consider when budgeting for long-term maintenance.

Resident Perspectives

79 percent of polled residents support the implementation of a voluntary acquisition program. The fact that the program would be completely voluntary, help at-risk homeowners, and help the City manage flooding are primary factors influencing this support.

47 percent of polled residents said they would likely consider selling their home to the government at fair market value through a voluntary residential property acquisition program.

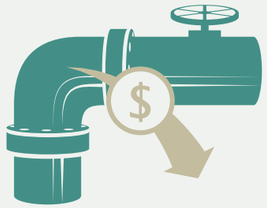
Financial Incentives and Assistance

Loan Program

A number of states, and even a few cities, have developed loan funds that provide low-interest loans to residents and businesses. The City has the opportunity to shape a loan fund to meet Virginia Beach's specific needs. Oftentimes these loans are housed in a revolving fund, which means that the interest earned on the loans would flow back into the fund and be loaned out again to community members. A City-funded loan program could fund a wide range of interventions, such as residential home elevations, outside of FEMA funded grant programs or even nature-based or green infrastructure projects at the residential level. The seed money from the fund could come from numerous sources and could be discretionary used by the city.

Property Tax Relief

The City has the opportunity to incentivize homeowners and businesses to reduce flood risk through tax relief. Tools such as tax credits, deductions, and exemptions could reduce community members' tax bills and reduce the cost burden of implementing site-scale mitigation strategies. These tools can also be used to encourage residents to install living shorelines and green infrastructure in and around their homes. This could be an incentive not only for residential homeowners but also for landlords which manage Virginia Beach's large rental market.



Fee Reductions

Stormwater fees levied on residents and businesses are critical to maintaining, updating, and improving the stormwater infrastructure in the City. These fees increased in 2019 to help fund upgrades and help address flooding issues. The City can offer residents incentives in the form of reduced stormwater fees, especially for residents who reduce impervious surface areas or install green infrastructure on their properties. Reduced fees could be a significant incentive and encourage the community to invest in flood mitigation measures.

Flood Insurance Rate Reduction

Investing in site-scale mitigation strategies such as a home elevation could significantly decrease flood insurance costs through the National Flood Insurance Program (NFIP). The NFIP takes mitigation measures that property owners have implemented in mind when analyzing the cost of the flood policy premium. For example, once a home is elevated, a new elevation certificate can be obtained and the flood insurance premium re-evaluated. Home elevations not only reduce the risk of flooding by moving the lowest level of a house or business above the base flood elevation but can potentially save homeowners and businesses thousands of dollars in flood insurance costs.

City-Funded Grants

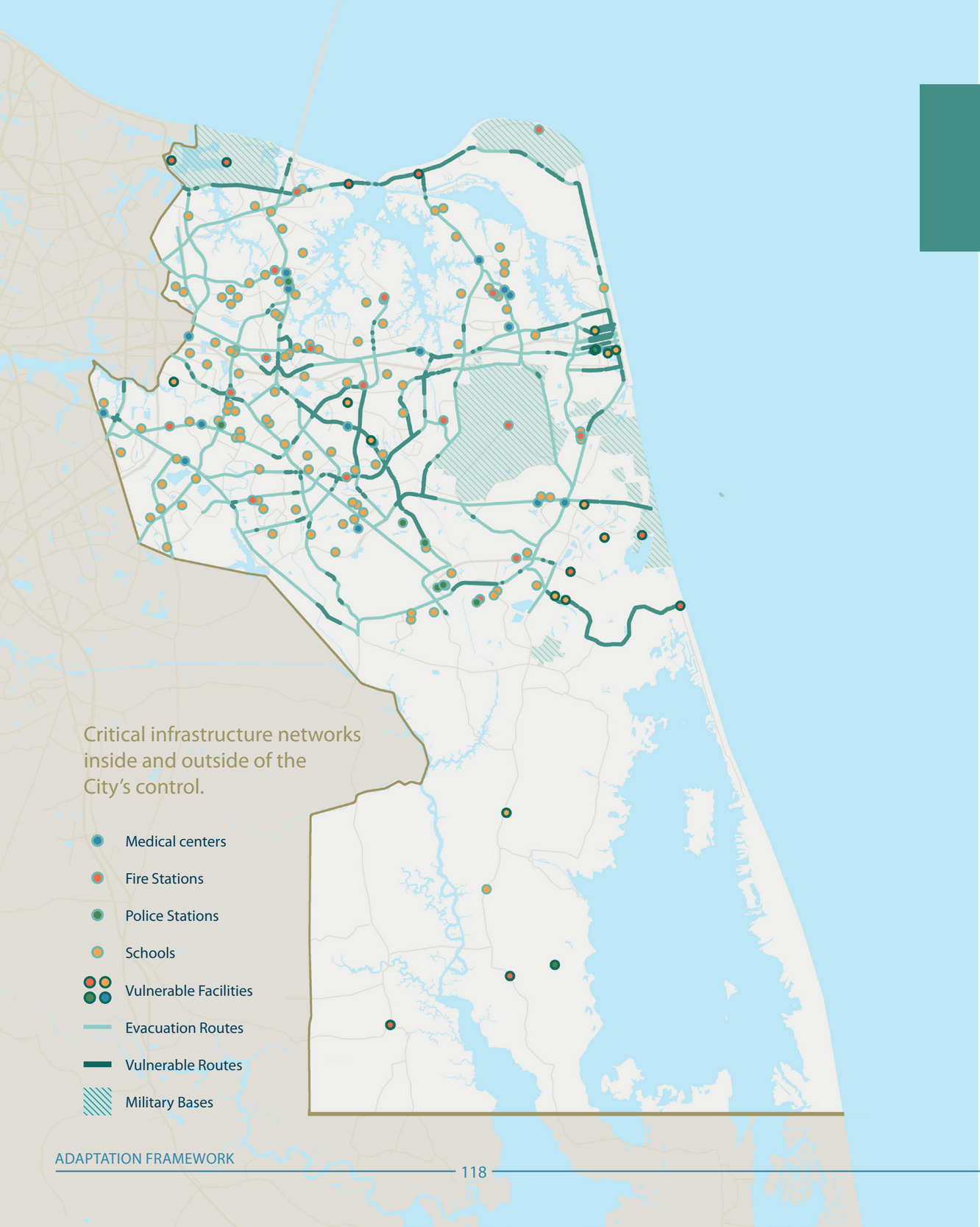
City-funded grants are yet another available tool to incentivize home and business owners to mitigate and reduce their flood risk. Grants, unlike loans, do not have to be paid back. This largely alleviates the cost burden from the grant recipient, either a home or business owner. A grant program such as this is a unique tool but also comes with significant costs to the City. Unlike a revolving loan program, which theoretically once funded, can be self-sustaining – once grant funds have been used, the City does not receive any of that money back. The return on investment for the flood mitigation that is implemented with those funds may make grant funding worthwhile.

Federally Funded Grants

Federally funded grants will likely continue to be the most utilized source of funding to encourage risk mitigating strategies at the residential level. Millions of dollars are distributed every year through agencies such as the Federal Emergency Management Agency and the Housing and Urban Development Agency. These agencies have the ability to distribute large sums of money, but as previously mentioned, they can have an extremely long timeline to project completion.

Resident Perspectives

Over 80 percent of polled participants are in support of the City providing financial assistance to support parcel-level actions, indicating willingness to implement these strategies given funding mechanisms are available.



Minimize Infrastructure Vulnerabilities

Engage with local and regional infrastructure and utility agencies to better understand independent and cascading vulnerabilities and make proactive investments.

Many infrastructure and utility services are vulnerable to disruption from significant flood events. Infrastructure related to telecommunications, internet, electric power, oil, natural gas, potable water, sanitation, and transportation are all important for keeping residents safe and businesses functioning. Buildings like fire stations, police stations, emergency shelters and hospitals also play a critical role safeguarding residents' well-being. Critical infrastructure assets in particular are assets that, if incapacitated or destroyed, would have a detrimental impact on the function of the City's operations as a whole. Floodwaters can physically damage or otherwise limit asset functionality, leading to operational disruptions and service outages with direct and indirect impacts that can range from minor to severe.

Infrastructure and utility systems are often interdependent, and so damages to one asset can disrupt other services, with impacts that cascade throughout the region. For example, if a wastewater treatment plant floods, it can contaminate the region's potable water systems, threatening the health and safety of residents throughout the service area. At the same time, during a storm event, electrical power and gas lines are often disrupted, which would further impact the ability of residents to both learn about potential water contamination challenges as well as take the recommended precautionary steps of boiling water.

It is in Virginia Beach's best interest to promote resilience among the utility companies, governments, and infrastructure networks that exist outside of City ownership. The City of Virginia Beach manages an extensive array of assets including all City-owned facilities as well as roadways, bridges, curbs, gutters, sidewalks, stormwater pipes, swales, roadside and off-road ditches, public beaches, and traffic lights and signs. However, these infrastructure networks are complemented by regional systems that cross municipal boundaries. For example, Virginia Beach is dependent on the City of Norfolk for public drinking water, and Hampton Roads Sanitation District (HRSD) for sanitary sewer treatment. Both public and private agencies will need to make investments to retrofit or replace existing infrastructure systems to withstand future flood impacts and may need guidance to do so in an efficient and effective way.

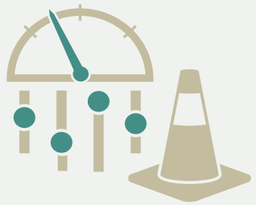
Infrastructure Management Techniques

Prioritized Asset Investments

In order to effectively manage immediate and long-term infrastructure vulnerabilities, the City can require the consideration of future flood risks in all capital investment decision-making and procurement processes. Assessing the physical flood exposure, independent and cascading vulnerability, and criticality of assets or systems can lead to a prioritization of higher-risk assets. This prioritized understanding of higher-risk assets can inform asset management and provide investment decision-making alternatives, which include maintenance, replacement, and construction schedules.

Resilient Construction Standards

With an enhanced understanding of risks, the City can set siting and design standards to guide the construction of all new City-owned infrastructure assets and facilities. Standards would incorporate flood-related projections over the course of the asset's useful life to ensure that the City is building wisely to account for future risks. Varying requirements can account for the asset type, setting higher requirements for those deemed most critical to City services. These standards can further guide the retrofit of existing infrastructure as necessary.

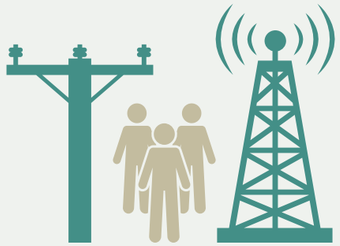


Operation and Maintenance

Standard operations and maintenance practices for all City-owned assets can be further developed to incorporate updated flood risk information and cascading vulnerabilities. The proactive maintenance and operations of all City-owned assets to enhance flood resilience can ensure that critical facilities stay online during a disaster event and the critical services can be maintained. Enhanced monitoring technology, early warning systems, emergency operations planning, and supplemental insurance can further serve to aid infrastructure resilience.

Cross-Jurisdictional Collaboration

Some neighboring cities, regional agencies, state agencies, and federal government entities have authority over infrastructure systems that Virginia Beach residents rely on. Although the City does not have direct control over this infrastructure, coordination can be undertaken to understand and support the ways these entities are incorporating sea level rise adaptation into infrastructure management. The City of Virginia Beach can continue to coordinate with partner agencies, sharing Sea Level Wise data, findings, and other resources to support flood adaptation work within these systems and collaboratively build a more resilient region.



Public-Private Coordination

Private utility providers play a huge role in regional infrastructure networks—including Dominion Energy, Virginia Natural Gas, Cox Communications, Lumos Network, and Verizon. Future risks are something independent utilities might not focus on unless otherwise supported or mandated. The City can help inform external agencies and companies of their flooding risks and vulnerabilities by communicating findings and sharing resources from the most recent sea level rise, precipitation, and recurrent flooding research. The City can also continue to encourage private utilities and service providers to engage on issues related to sea level rise and increased flooding events through their participation in working groups and inclusion as stakeholders in City decision-making and planning processes.

Regional Commitment

With so many integrated components, critical infrastructure resilience works best as a collaborative multi-jurisdictional effort. The City can lead the call for a Memorandum of Understanding with relevant companies and agencies in the region. The Memorandum would be a formal way of committing to coordinated flood adaptation efforts. In it, all signing participants would officially recognize their increasing flood risks and pledge to incorporate sea level rise and recurrent flooding considerations into their continuity and asset management planning.

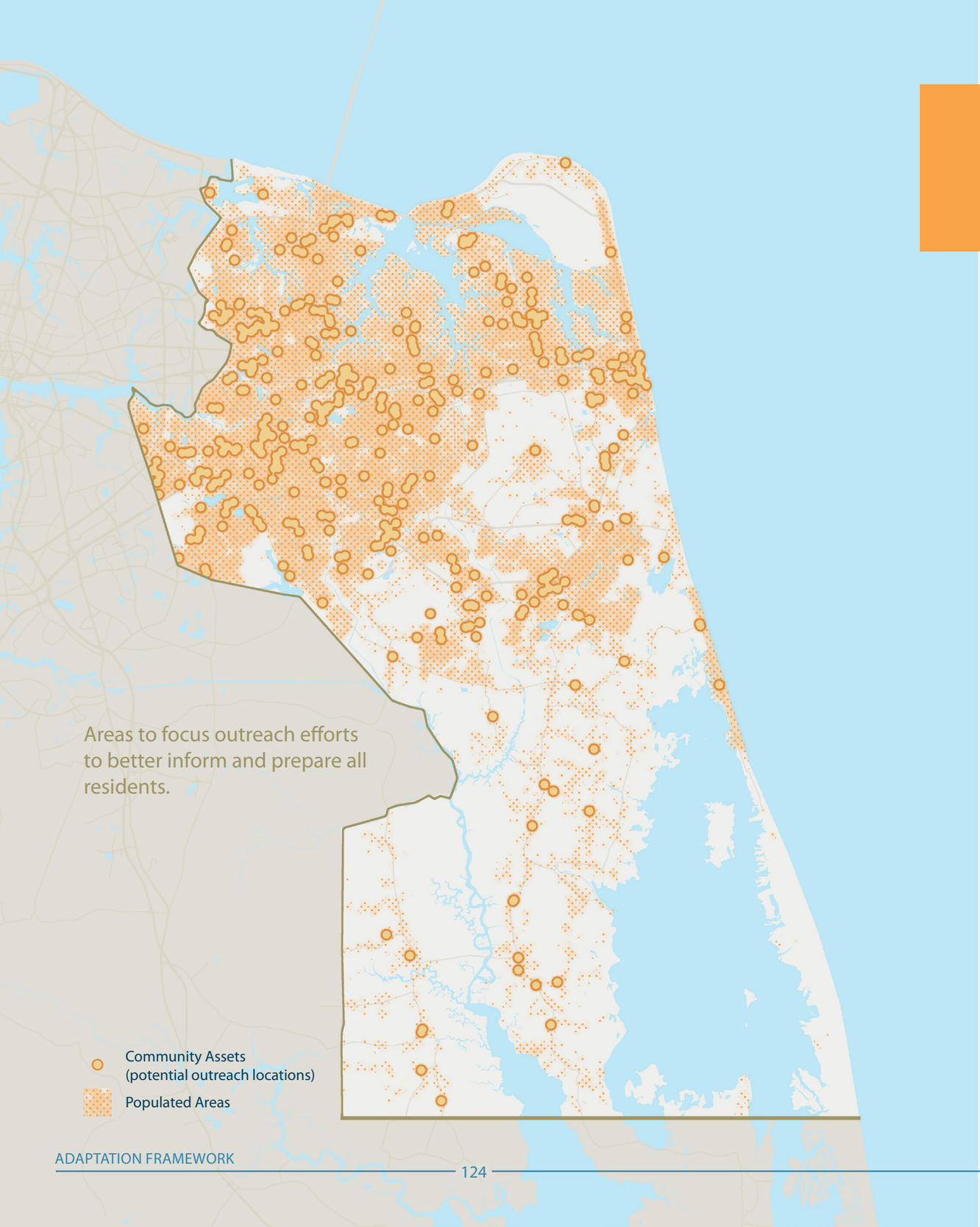
PREPARED COMMUNITIES

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.

Even with layers of ecological protection, defensive structures, and resiliently designed buildings and infrastructure, there will always be residual risks. Taking proactive steps to prepare for the impacts of sea level rise and flooding helps mitigate that remaining risk. Preparedness plays a critical role in keeping residents safe during flood events and allowing communities to physically, economically, and socially recover in the aftermath.

With a clear understanding of the risks, residents are empowered to make more educated and informed decisions. Residents interested in buying a new home, for example, would benefit from access to information about a property's current flood hazard exposure, as well as about how such exposure may change over the life of a mortgage. For residents currently exposed to flooding hazards, knowing the extent of their risk and the suite of risk-mitigating options available to them can help them to take concrete steps towards minimizing their flood risks.

Having the capacity to recover and adapt after flooding takes forethought and planning. Financial instability and lack of access to financial capital to cover impact costs can be detrimental to individual and community recovery after a flood event. Measures to ensure resilience in key economic sectors as well as insure against damage and recovery costs are therefore essential elements in a robust preparedness strategy.



Grow Educational Outreach

Develop programs and tools to inform vulnerable residents about their flood risk and facilitate access to mitigation, preparedness, and recovery resources.

Through expansive public education and outreach centered on flood risk and preparedness, Virginia Beach can continue to bolster community resilience and ensure that the residents are better at preparing for, responding to, and recovering from flood events.

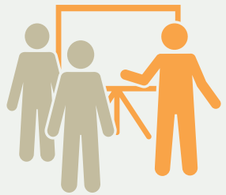
Direct flood risk outreach and education takes place through a variety of avenues including community-based organizations, institutions, academia, non-profits, professional associations, and the private sector.

The City's outreach and engagement should be community-wide, with a particular focus on reaching vulnerable populations, such as the City's youth, the elderly, people with disabilities, and minority and low-income populations.

Resident Perspectives

Only 39 percent of polled residents identified as well informed or very well informed regarding flooding causes and risks, indicating a need for further educational outreach.

Engagement Methods



Educational Workshops

Community flood mitigation workshops can highlight new and innovative ways in which homeowners can mitigate and adapt to flood risk. These workshops could potentially showcase specific programs that are in place to help usher homeowners and businesses through flood mitigation grant and loan processes. Educational workshops should serve geographically diverse neighborhoods and can even cater to specific vulnerable populations. For example, workshops focusing on youth and families can focus on installing green infrastructure such as rain barrels and gardens, and provide emergency preparedness information regarding what to do if one finds themselves in a flood event. Workshops should provide resources in different languages, ensuring that all community members have access to flood information.

Business Outreach

When flooding causes businesses to close their doors, they are not able to provide vital services to community members. Shuttered businesses, whether closed for a few days or permanently, can greatly impact resident's job stability, income, and even City tax revenue. These impacts trickle down throughout the City, and underline the importance of investment in disaster and continuity planning. Flood-preparedness education and resources catered specifically to local businesses should be done in coordination with the Virginia Beach Department of Economic Development and the Hampton Roads Economic Development Alliance. This outreach and engagement will not only help area businesses prepare for and recover from flood events faster, but will also promote City-wide economic resilience and ensure area residents have access to services and job stability.

Community Partnerships

The City should continue to partner with local nonprofit organizations to educate homeowners on options such as conservation easements and saltwater intrusion. There are significant opportunities to engage with younger residents through partnerships with schools, youth organizations, and through public spaces such as the Virginia Aquarium and Marine Science Center. The growing elderly population in Virginia Beach provides an additional opportunity for educational outreach through partnerships with retirement communities, senior centers, nursing homes, community gathering places, and religious centers that house and interact with elderly community members on a regular basis. Religious organizations and non-profits that work with elderly and minority populations, in particular, are well-positioned partners who can spread awareness and help educate community members about flood preparedness, response, and recovery.

Consultation Services

The City could explore offering consultation services through private sector experts or through City staff who have expertise in flood mitigation and adaptation. These consultations could provide homeowner flood-protection counseling, continuity planning for area businesses, and offer expertise in terms of applying for grants and loans to fund larger-scale flood mitigation. Hands on problem solving to mitigate flood impacts, with a knowledge expert on flood risk and mitigation, could help homeowners and businesses better understand their unique individual risk, and develop a plan to reduce their vulnerability.

Community Flood Science

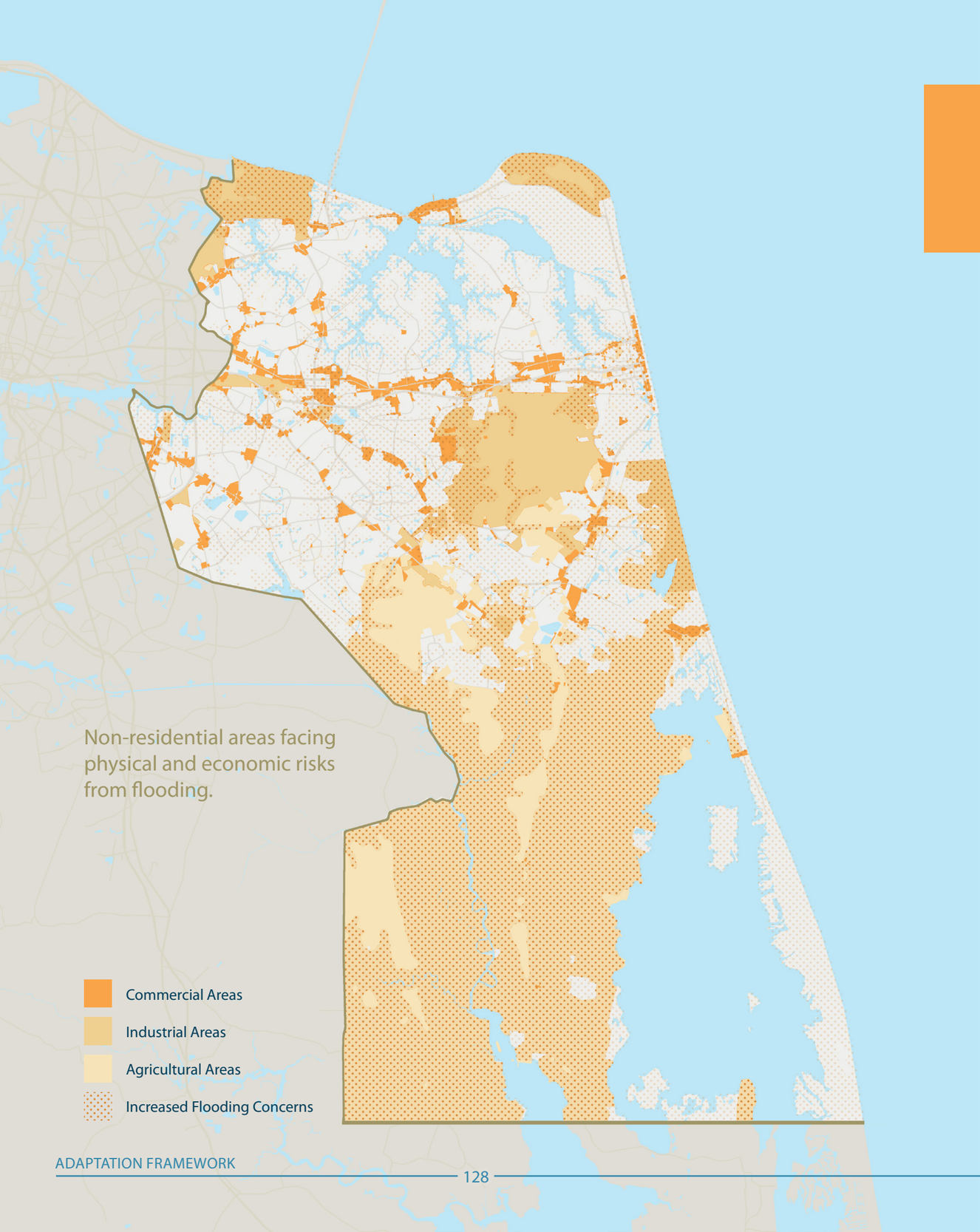
In the past, the City has had success with involving the community in mapping and documenting flood events in their neighborhoods. The Action-oriented Stakeholder Engagement for a Resilient Tomorrow map provides an interactive public engagement process that was conducted in collaboration with a team from Old Dominion University's Resilience Collaborative.[21] This participatory mapping resulted in a community map that could be built upon in the future, calling on Virginia Beach residents to continue to document the flood events, as well as successful adaptation and mitigation efforts that community members are undertaking.

Public-Facing Resources

The City recognizes the importance of easily accessible online resources relating to flood hazards and homeowner mitigation strategies. Currently, the City has a website dedicated to sea level rise and hopes to eventually create a one-stop-shop portal, which residents may visit to learn about their individual flood risk. This portal would house all of the City's flood resources in one convenient location. The City also wants to use this portal to raise awareness about ways to reduce flood insurance premiums and the benefits of the CRS program (page 130). The vast amount of research, modeling, and data that the City has collected in its study of flood risks over the last few years could also be housed here, translated into straight-forward, readable summaries that communicate the findings of pertinent research.

Resident Perspectives

Residents expressed preferences for receiving information about flood risks and response through public meetings, e-mail, government websites, and social media.



Promote Economic Resilience

Bolster flood resiliency of the City's economic engines through access to planning resources, technical guidance, and financial support.

Economic resilience is an important component of promoting the overall safety and success of Virginia Beach. The term economic resilience refers to the capacity of Virginia Beach's private and public businesses to bounce back and continue to thrive after a flood event. By prioritizing economic resilience, the City can mitigate the impacts of these shocks and stressors on the Virginia Beach job market.

Storm events, recurrent flooding, and sea level rise have the ability to impact not only business revenue, but wages and household income. These impacts reverberate throughout the community and trickle down to increased poverty, lost tax revenue, and reduced City services. These impacts underscore why protecting economic engines and promoting economic resilience from flood events is a top priority for the City.

While protecting already established industry sectors is important to the economic prosperity of the City, Virginia Beach also realizes that establishing new economic sectors that promote sustainability and green growth are equally important. By supporting the establishment of a resilience services industry, the City is promoting healthy economic growth that is inherently sustainable, fosters the opportunity for economic growth in a new service industry offers to jobs, and increases the Virginia Beach tax base.

Virginia Beach's key economic sectors—tourism, military, and agriculture—are the economic engines of the community. These sectors employ thousands of people, but also support public infrastructure and services through taxes. Protecting these sectors from the impacts of sea level rise and recurrent flooding is vital to maintaining the City's long-term growth and success. Virginia Beach is well-positioned to continue to foster economic resilience, which will both attract new private sector business and maintain a healthy business community despite recurrent flooding and sea level rise.

Resident Perspectives

29 percent of polled residents identified the availability of technical assistance as a factor that would most influence their undertaking of flood-adaptations to a home or business.

Economic Resilience Techniques

Flood Insurance Expansion

Flood insurance is a key component of residential and community-wide preparedness. In the aftermath of a flood event, insurance provides financial resources to support individuals with flood-impacted property rebuild and recover. Flood insurance is highly recommended for all residential and commercial properties located in high flood risk areas, and is required for those properties with federally backed mortgages. This requirement is most often fulfilled through purchasing a flood insurance policy through FEMA's National Flood Insurance Program. The City should encourage all at-risk community members to purchase of flood insurance for their buildings and contents, regardless if it is required or not. Insurance outreach and engagement can be supported by FEMA regional staff members and marketing materials may be available through FEMA.

Community Rating Improvement

The City of Virginia Beach was recently accepted into the National Flood Insurance Program Community Rating System (CRS). CRS provides incentives to communities that engage in optional floodplain management activities—offering insurance premium discounts for City actions that reduce risk. Each activity the City engages in raises the community's overall score, thus reducing insurance premiums for all residents, and potentially leading to expanded flood insurance coverage. The City can maintain and improve its CRS rating through activities that relate to informing the public, adjusting mapping and regulations, reducing potential flood damages, and strengthening overall flood preparedness.

Cultural Asset Protection

The City's distinct mix of recreational areas, waterways, museums, shopping centers, and residential neighborhoods are a primary attractor to residents, businesses, and tourists alike. These cultural assets are key to the City's economy and financial well-being. The City can prioritize investments in flood mitigation and defense infrastructure that protects valuable cultural assets and areas. Additional investment in stormwater and transportation infrastructure both tangentially support the tourism and commercial businesses as well, reducing flooding on area roads and making travel into and out of City easier.

Resident Perspectives

For polled residents without flood insurance, 73 percent don't think or don't know if their property is at risk for flooding.

27 percent of polled residents without flood insurance say that flood insurance is too expensive.

Military Coordination

The military plays an extensive role in the Virginia Beach economy. From employing residents to supporting businesses in the area, the military installations in and around the City touch almost every resident. As many residents move to Hampton Roads from afar for military jobs, the City can help educate service members on how best to access local resources to prepare for recurrent and extreme flood events. Roadway access to Navy facilities during recurrent and moderate flood events is of particular importance to military interests. Regional and Navy collaboration can therefore focus on improving access to critical military installations during and after flooding events. More broadly, since the City's economic health is closely tied to the Navy, all opportunities to work together on flood risk reduction strategies will benefit the broader Virginia Beach community, reduce future financial losses, and promote economic resilience.

Agricultural Preservation

Through rural preservation programs, low taxes, and increased flood protection, the City plans to help safeguard the rural south's agricultural economic output. Both flood defense and nature-based strategies offer protection to the Back Bay and the Southern Rivers Watershed. Implementation of these strategies will help reduce impacts to the long-standing agricultural community.

Green Job Growth

The resilience services sector is a place for innovative economic growth within the City. The development of this sector could bolster and support local job creation while promoting flood mitigation. Currently, the City boasts one of the most successful workforce development programs in the nation. Through collaboration with local educational institutions and area colleges, this workplace development structure can be leveraged to support the training and cultivation of skills needed to support resilient services. Resilience services could include training, certification, and apprenticeships in resilience and sustainability jobs such as green infrastructure installation and maintenance; flood retrofitting; home elevations; utility and mechanical elevation; living shoreline design, installation, and maintenance; solar installation and maintenance; and energy efficiency upgrades.

Resident Perspectives

Residents identified the availability of private contractors to do the work as a factor that would influence their undertaking of flood-adaptations to a home or business.

PART IV

WATERSHED STRATEGIES

Watershed Approach

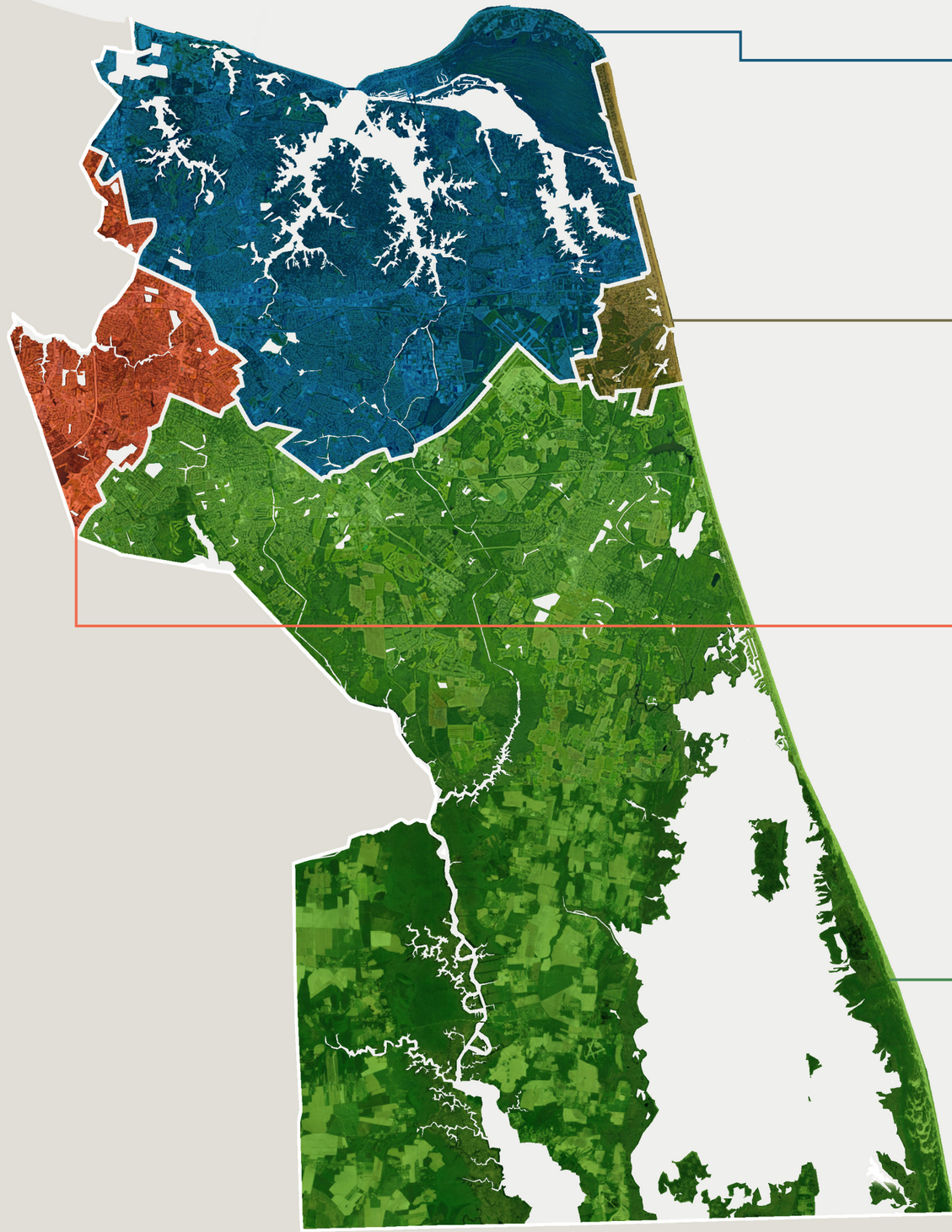
Virginia Beach's four major watersheds pose distinct flooding challenges and opportunities.

Flood risks can look very different throughout the diverse geographic areas of Virginia Beach. The City has a mix of urban and rural land uses, high and low-density development, and coastal and inland flood sources. Watersheds present natural boundaries for taking a more precise look at water-based issues.

A watershed defines the geographic land area that drains into a particular body of water, such as a river, bay, or ocean. The City of Virginia Beach is divided into four major watersheds: Elizabeth River, Lynnhaven River, Oceanfront, and Southern Rivers. Each major watershed is also composed of a sub-set of smaller drainage areas, known as drainage basins. Virginia Beach has thirty-one drainage basins forming the boundaries of these four major watersheds.

Virginia Beach sits on one of the largest drainage divides on the east coast. The Lynnhaven River and Elizabeth River Watersheds are situated in the northern part of the City and drain into the Chesapeake Bay. The Southern Rivers Watershed drains to the south into the Albermarle-Pamlico Sound. The Oceanfront Watershed drains directly into the Atlantic Ocean. Ultimately, they all drain into the Atlantic Ocean by taking different courses.

Watersheds cross municipal boundaries, which sometimes complicates efforts to manage water. Upstream and downstream changes to water management can have far-reaching consequences and must be evaluated. This is why watersheds are a crucial tool for assessing and addressing the wide range of flood risks across the City.



Lynnhaven

Flooding in the Lynnhaven Watershed comes from either the Chesapeake Bay through Lynnhaven Inlet or internally from the numerous surrounding bays and rivers — including Lynnhaven River, Lynnhaven Bay, Broad Bay, and Linkhorn Bay.

Oceanfront

The Oceanfront Watershed faces flood risks directly from the Atlantic Ocean (if dunes are overtopped), through Rudee Inlet, and from floodwaters from Lynnhaven Inlet coming into Linkhorn and Broad Bays.

Elizabeth River

The Elizabeth River provides a flood pathway from the Chesapeake Bay, through Norfolk and Chesapeake. As sea levels rise, flood pathways begin to merge with flooding driven from the North Landing River during times of southerly winds, generating more widespread flooding.

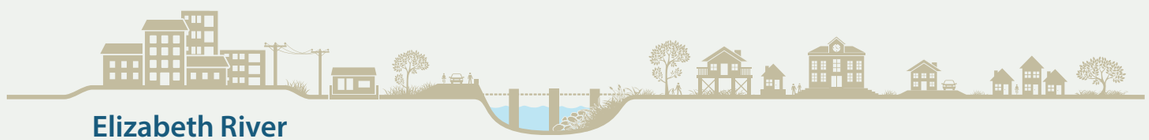
Southern Rivers

With miles of beachfront, inland bays and rivers, and extensive low- lying lands, the Southern Rivers Watershed is particularly susceptible to repetitive flooding. Southerly winds frequently bring water up from North Carolina into Back Bay and North Landing River, flooding the surrounding areas.

Applying the Adaptation Framework

For planning purposes, a watershed-level view of the City allows for a more locally grounded and customizable approach to adaptation. Each Watershed Strategy lays out the specific flood drivers and risk types distinct to that watershed, and uses techniques identified in the Adaptation Framework to identify specific areas for action. Projects presented in the Watershed Strategy chapters are crafted to fit with specific neighborhood characteristics and protect key environmental assets, economic drivers, and community priorities.

Adaptation also requires evolving over time as circumstances change. Although some applications can be implemented immediately, others may take years to complete.

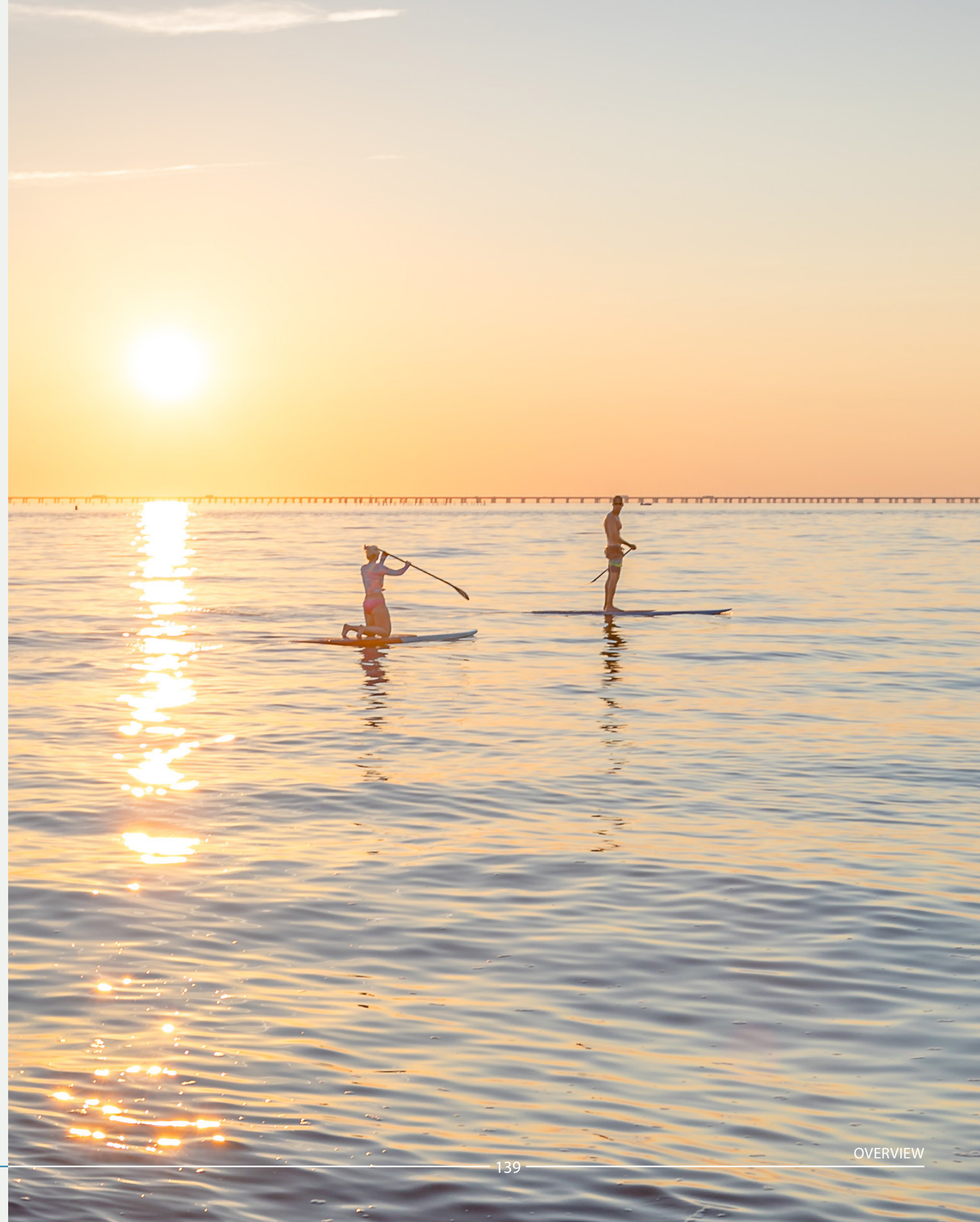


Elizabeth River

Lynnhaven

Oceanfront

Southern Rivers



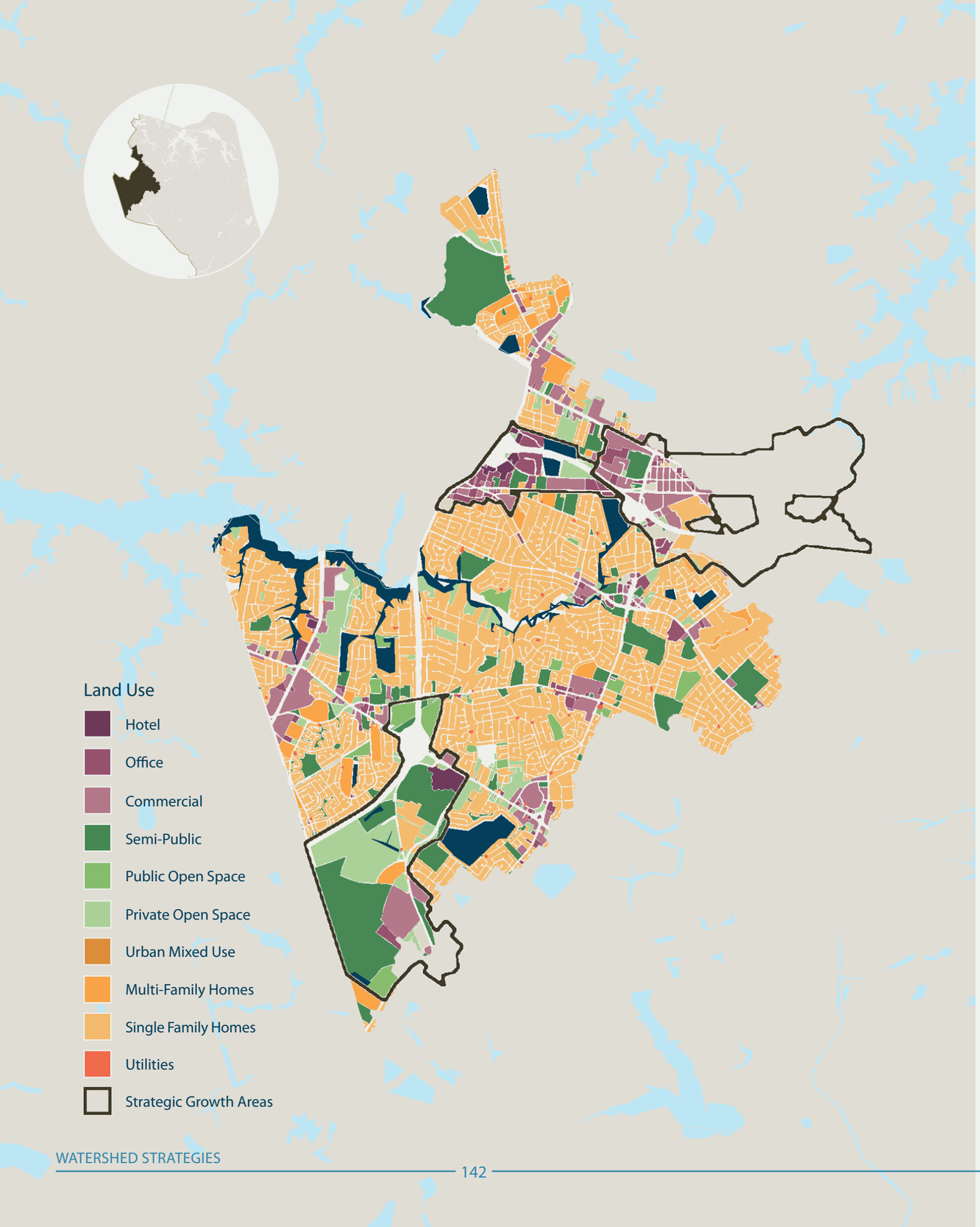
ELIZABETH RIVER

The Elizabeth River Watershed is on the west side of the City, and shares boundaries with the cities of Norfolk and Chesapeake. The Elizabeth River is home to a thriving community that enjoys recreational amenities along the tidal urban river and creeks.

There has been steady population growth in this watershed, especially within and surrounding three of the City's Strategic Growth Areas (SGAs) which fall within the watershed's boundaries.

Although land elevations in the Elizabeth River Watershed are higher than other areas in Virginia Beach—with only 3% of the total land area under 3 feet elevation—increased urbanization, degradation of naturalized landscapes, and aging infrastructure contribute to flood exposure and vulnerability in this area. More than 80% of homes were built in the 1970s or earlier, leading to an older overall building stock with many homes built to lower codes or standards than in place today.[22]

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 Elizabeth River Watershed.



Elizabeth River Watershed

Community Context

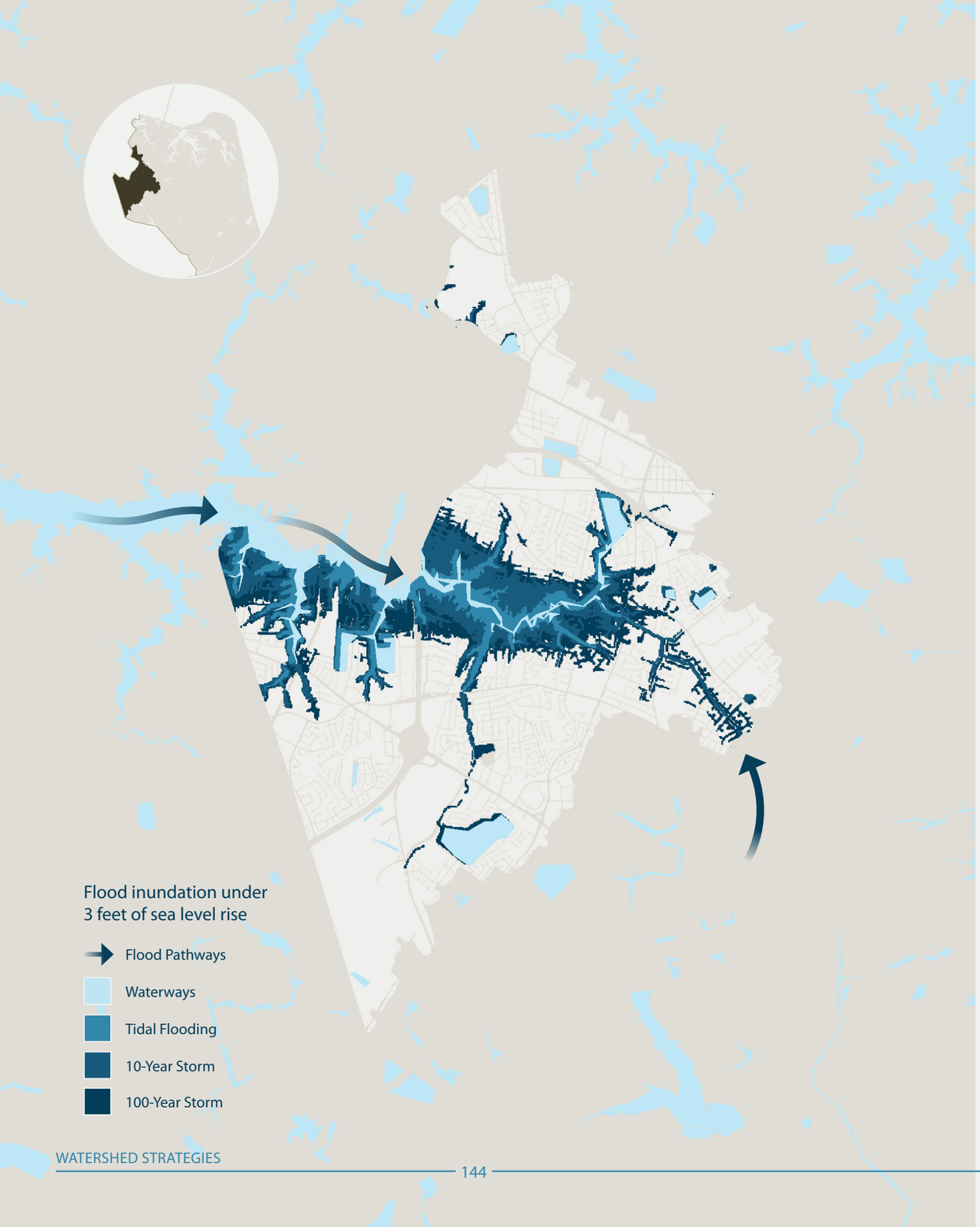
Waterways: The Eastern Branch of the Elizabeth River is a thriving urban river that flows from Virginia Beach through Chesapeake and Norfolk.

Natural Resources: The Eastern Branch of the Elizabeth River is fringed by tidal marshes and wetlands, which provide habitats to a diversity of birds, fish, and wildlife. As an urban river, water pollution has historically threatened species diversity in the watershed, notably leading to substantial declines in the native oyster population. In the past, oysters were so abundant along the Eastern Branch that they were used to form the foundation of "Shell Road", which is now called Indian River Road in Virginia Beach. Significant work has been underway for the last several decades to restore the health of this urban river, including marsh and oyster restoration projects, which require continued coordination and support across all three cities. Public parks and recreational amenities along the waterfront are important to the communities surrounding the Eastern Branch in Virginia Beach. Although there are a few access points available to community members along the waterfront, they are scattered and are insufficient to serve the size of the community. One of the goals of the Eastern Branch Environmental Restoration Strategy is to improve public access along this branch, including extending the Elizabeth River trail into Virginia Beach to link together river access points, urban parks, and other points of interest.

Residential Population: The Elizabeth River Watershed is dominated by low-density residential neighborhoods. The residential population in the watershed has grown by about 7% in the past decade. The watershed's population is 59,108 with 22,426 households. In 2019, the median income was $67,910 with a per capita income of $31,227. Residents are 58% white, 28% black, 9% Hispanic, and 5% Other. As of 2019, 58% of residents own their home, 37% of residents are renters, and 5% are vacation rentals.[23]

Economic Industries: Further away from the waterfront edge are mixed-use areas with commercial and industrial centers that focus on retail and services. Together, these industries employ more than 60% of residents in the Elizabeth River Watershed.

Strategic Growth Areas: Three SGAs fall within the boundaries of the watershed, including Newtown, Pembroke, and Centerville. Visions for these areas include new or reconfigured commercial and residential corridors that maximize the use of exiting urban land uses.



Elizabeth River Watershed

Flood Pathways and Extents

Pathways: The Eastern Branch of the Elizabeth River is the most important flood entry point into the watershed. It provides a connection to the main stem of the Elizabeth River which connects to the James River, then eventually, to the Chesapeake Bay. Tidal creeks extending from the main stem of the river connect inland areas to the waterfront. Other flood entry points could develop with even higher sea levels. The Elizabeth River could be potentially flanked by the flood waters coming through the North Landing River during periods of sustained southerly winds. The Intracoastal Waterway provides a connection between the Currituck Sound and the Southern Branch of the Elizabeth River. However, it is a narrow channel that does not convey a lot of flood water.

Tidal Flooding: High tide flooding impacts a small amount of land today within the watershed. Given the relatively higher land elevations in the watershed, the growth of the future high tide floodplain is mostly constrained to the lowest lying areas directly adjacent to the river. High tide flooding with 1.5 feet of sea level rise only impacts less than half a square mile of land. With 3 feet of sea level rise, just over half a square mile of land becomes permanently inundated during high tide.

10-Year Storm: A moderate storm event today impacts less than a square mile of land. With 1.5 feet of sea level rise, the amount of flooding from a 10-year storm is anticipated to increase, extending into some residential areas and low-lying roadways. A moderate storm event with 3 feet of sea level rise could flood almost 2 square miles of land, representing almost 60% more land area flooded as compared to today.

100-Year Storm: During a large storm event, there is just over a square mile of flooded land that extends into multiple residential neighborhoods and low-lying roadways. With 1.5 feet of sea level rise, flooding from a 100-year event extends even further into the watershed through the tidal creeks that allow flood waters to penetrate into some of the commercial and industrial areas and low-lying roadways. A large storm event with 3 feet of sea level rise could result in even more extensive flooding, impacting almost 3 square miles of land.

Elizabeth River Watershed

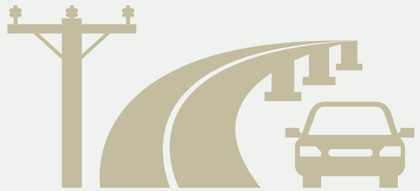
Notable Impacts

Impacts on Buildings

Elizabeth River has over 5,000 buildings exposed to coastal flooding under long-term sea level rise projections. If not addressed, average annual flood losses to buildings, contents, and associated displacement of occupants is approximately $843,000 under today's conditions, but jumps to $9.3 million with 3 feet of sea level rise.

Flood Exposure of Buildings

	Now	1.5 ft SLR	3 ft SLR
# Buildings	1,801	2,739	5,100
# Residents	9,644	13,027	26,664
Expected Building, Content, and Displacement Costs	$843,600	$2.86M	$9.32M



Impacts on Infrastructure

Today, there is only 1 community facility and less than half a mile of critical evacuation routes exposed to coastal flood risks. With 3 feet of sea level rise, 9 facilities and approximately 2 miles of critical evacuation routes become threatened by coastal flooding.

Vulnerable Critical Facilities

	Now	1.5 ft SLR	3 ft SLR
Fire Stations	0	0	2
Schools	1	4	7
Miles of Critical Roads	0.4	0.7	2.2

Impacts on Habitats

Some coastal habitats are able to keep pace with sea level rise or migrate into undeveloped areas whereas other habitats are at risk of being lost due to drowning or being blocked by development. Towards the end of the century, 3 feet of sea level rise will likely increase the footprint of the Elizabeth River within Virginia Beach by 16%. This expansion in open water will have significant impacts on coastal wetlands surrounding the river. The analysis of habitat vulnerability showed that 11% of grass marshland could be lost. Tidal flats could increase by 74% due to conversion of grass marsh and woody wetland habitat could increase by 4% due to migration into undeveloped areas. With less vegetation to slow down the movement of water, the tidal mud flats do not provide as much benefit for flood risk reduction.

Changes in Acres of Habitat

	Now	1.5 ft SLR	3 ft SLR
Woody Wetlands	369	357	383
Grass Marsh	173	174	155
Tidal Flat	20	13	35
Open Water	577	627	667

Impacts on People

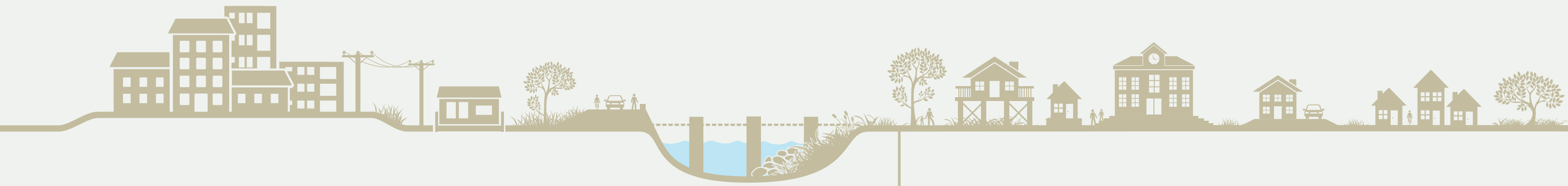
Today nearly 10,000 residents live in homes vulnerable to flooding, but that number could triple as sea level rise leads to an expanded floodplain. By the end of the century, over 26,000 people in the Elizabeth River Watershed could be exposed to coastal flood hazards. Out of those residents exposed to future flooding, over 70% may experience increased vulnerability due to physical and socioeconomic factors. These populations may require greater assistance and support from the City regarding supporting mitigation and preparedness.

Vulnerable Populations Exposed to Flooding

	% Today	% at 1.5 ft SLR	% at 3 ft SLR
People of Color	8%	13%	35%
Children (<5)	13%	19%	42%
Elderly (>65)	26%	31%	55%
Limited English	12%	17%	46%
Limited Income	9%	13%	32%
Disabled	17%	24%	49%

Elizabeth River Watershed

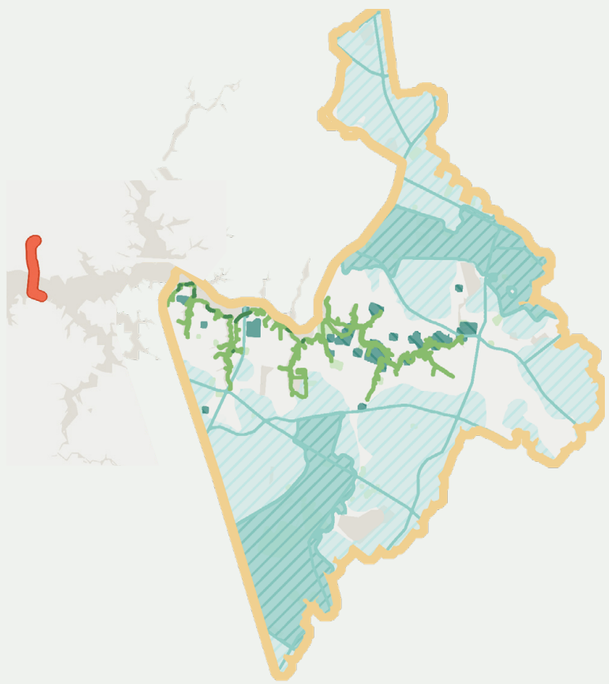
Adaptation Vision



The layered flood protection system for the Elizabeth River Watershed could provide long-term protection from rising sea levels and coastal flooding, and create social, environmental, and economic benefits.

The measures proposed within this chapter, 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.

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.



Natural Mitigations

- Living Shoreline
- Marsh Restoration and Creation
- Land Conservation

Engineered Defenses

- Elizabeth River City-Wide Alignment

Adapted Structures

- Commercial Floodproofing
- Floodplain Regulation
- Resilient Roadways
- Responsible Development
- Building Elevation

Prepared Communities

- Residential Community Education
- Flood Insurance Expansion
- Business Outreach and Education

Elizabeth River Watershed

Living Shoreline

The shorelines of the Elizabeth River that are west of Interstate 64 are exposed to higher wave power than those on the east side of the highway. These shorelines could benefit from a mixture of different living shoreline projects that incorporate structural components such as rocks, coconut fiber logs, or oysters, for additional protection and stability. Because the Elizabeth River is a tidal river connected to the Chesapeake Bay, the salinity is high enough to support oysters. Living shorelines that include oyster habitat, such as oyster castles or reef balls, would help support the goal to restore historically lost oyster bed habitat and improve water quality in one of the river's most polluted stretches.

The western Elizabeth River shorelines are lined with a combination of natural or undefended shorelines as well as shoreline defense structures (such as bulkheads and riprap revetments). Several homeowners who own land that abuts the River have converted their shorelines from hard defensive structures into living shorelines. The Living River Restoration Trust and the Elizabeth River Project provide assistance to homeowners to help in the design, financing, and construction of living shorelines.

In addition, there is a significant opportunity to undertake large-scale living shoreline projects on undeveloped private open-space land and city-owned park areas, providing a natural form of protection from strong waves to a larger area. These projects could serve as additional "blueway" stops along the Elizabeth River Trail that will likely be extended into the Eastern Branch of the Elizabeth River by the year 2024, providing improved public access to the waterfront. The construction costs for living shoreline projects vary widely depending on the shoreline length, level of protection needed, and the costs for materials and labor.

Average construction costs for projects with sand fill and/or stone structures typically range from $150 – $500 dollars per foot. These estimates do not include permitting costs or upfront construction costs. Construction of all living shoreline projects identified in the Elizabeth River Watershed could range from $650,000 to $2.2 million; however, additional cost estimation and analysis is required to determine actual costs.

COST

$$$$

TIMELINE

near-term mid-term long-term

BENEFITS

- Offers broad ecosystem services
- Provides erosion control
- Reduces flooding during smaller storm events
- Improves water quality
- Beautifies the waterfront area
- Enhances habitats for wildlife and aquatic species

Elizabeth River Watershed

Marsh Restoration

The Elizabeth River's narrow Eastern Branch winds into the western part of Virginia Beach, creating tidal creeks that ebb and flow with the ocean tides. As the tide flows in and out, large muddy tidal flats develop. The tidal creeks and flats provide a thriving habitat for birds, aquatic life, and marsh plants that call this once deep-water shipping route home. The Virginia Beach community utilizes this area for recreation and nature watching and has worked hard, in conjunction with non-profits and the City, to protect and conserve this area.

Although much conservation work has been undertaken by community members, non-profits (such as the Living River Restoration Trust, the Nature Conservancy, and the Chesapeake Bay Foundation), and the City of Virginia Beach, there is still a significant opportunity to continue pursuing marsh restoration in this area of the River. Additional marsh restoration will foster new habitat and helps maintain interconnected habitat. Marsh restoration in this area will provide multiple benefits aside from new habitats and enhancement of natural resources: the new marshland will reduce erosion and reduce the power of waves as they push up river during storm and tidal events.

COST

$$$$

TIMELINE

near-term mid-term long-term

BENEFITS

- Prevents erosion of the river banks
- Improves water quality
- Beautifies the waterfront area
- Recreational opportunities.
- Creates additional habitat
- Connects habitat

Elizabeth River Watershed

Land Conservation

Some of the marshlands and habitat along the Eastern Branch of the Elizabeth River are already protected under conservation easements, which are agreements in which landowners voluntarily protect and conserve a piece of land from ever being developed.

These protected pieces of shoreline foster marsh expansion and enhance the overall green infrastructure of the river's bank. There is an opportunity for other landowners and residents of properties that border the River to conserve the natural assets of the waterway through conservation easements. A conservation easement would be a voluntary option for residents or even commercial property owners.

Given the expected growth within the three SGAs that are located in the Elizabeth River Watershed, there will be increased development pressures on the area. By conserving open space along the river, vital natural assets to the community will be preserved for future generations, while ultimately helping to absorb flood waters and precipitation.

Setbacks and buffers for new or substantial redevelopment along the Elizabeth River can be used to both conserve land and move development out of high risk flood zones that border the river.

COST

$$$$

TIMELINE

near-term mid-term long-term

BENEFITS

- Tax benefits for the landowner conserving the land
- Conservation of habitats
- Water sink during flood and storm events
- Beautifies the waterfront area and offers additional natural assets

Elizabeth River Watershed

Elizabeth River City-Wide Alignment

The Elizabeth River is used as a primary navigation channel and has been identified as an important location to provide flood protection through the City-Wide Structural Alternative Flood Protection analysis that was conducted. The proposed defensive structure, known as the Elizabeth River Alignment, would actually be located in the City of Norfolk and would also provide benefits to the cities of Norfolk and Chesapeake, as well as Virginia Beach.

The Elizabeth River Alignment would be conceptually located at the site of Atlantic Intermodal Services (the old Ford Plant), across from Grandy Village in Norfolk. A storm surge barrier, which could utilize an in-water circular gate, would cross the Eastern Branch of Elizabeth River at this location. The gate would be tied to a new seawall on the south side of the river. This gate type would minimize the impact on commercial traffic in the channel while providing flood protection. The gate would tie to high ground on the north side of the river using a floodwall with deployable gates at Westminster Avenue and Kimball Terrace. This alignment will offer a strong line of protection but will not impact military or identified park land.

The proposed gate location is an alternative to the location identified by the City of Norfolk's USACE Coastal Storm Risk Management Feasibility Study. The Norfolk USACE study was limited by the federal study authorization, and could not evaluate approaches that benefited areas outside of the City of Norfolk. As such, the Norfolk study proposes a surge barrier on Broad Creek, downstream of the location proposed here. The location proposed here would have comparable costs but benefit Norfolk, Chesapeake, and Virginia Beach. The City has had initial conversations with Norfolk, Chesapeake, and USACE on considering assessing the benefits of relocating a surge barrier from Broad Creek to the Elizabeth River, as shown here.

A theoretical cost share was determined by the amount of floodplain reduction in Norfolk, Virginia Beach, and Chesapeake, resulting in a 37% share of costs for the City of Virginia Beach. With this cost-share of the gate, costs to the City would be approximately $196 million.

COST

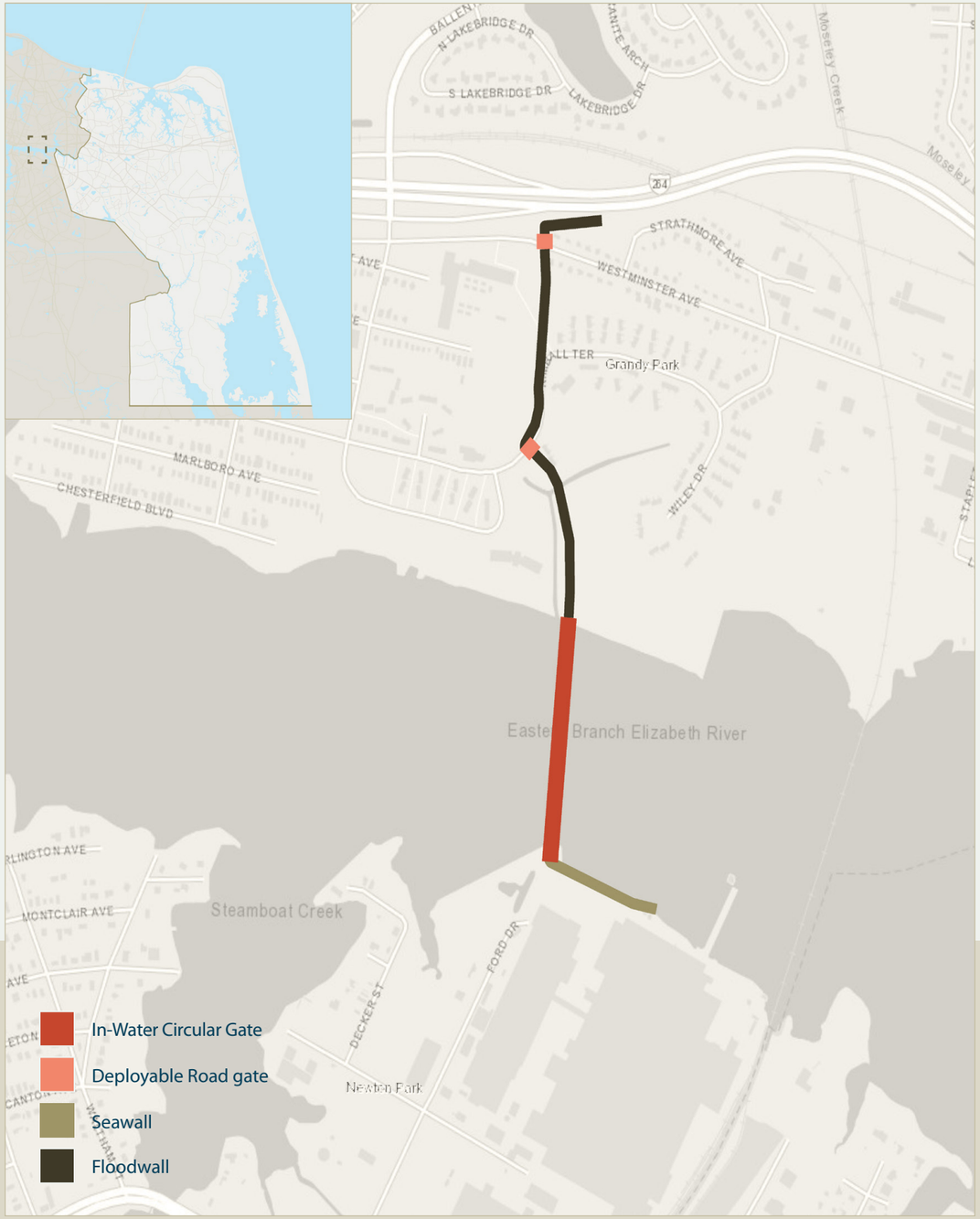
$$$$

TIMELINE

near-term mid-term long-term

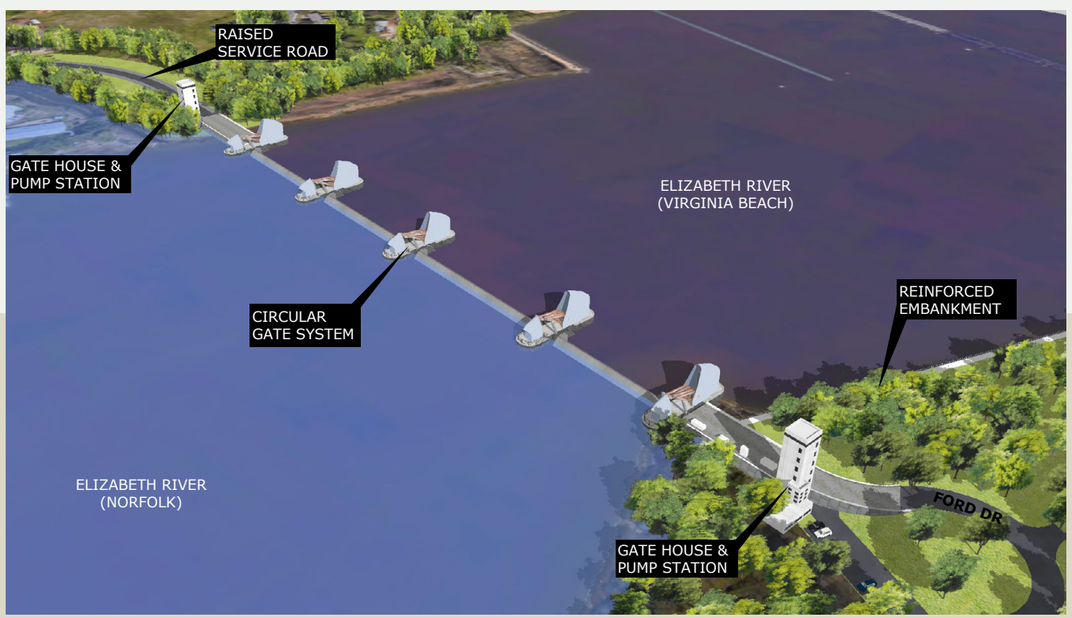
BENEFITS

- The gate would offer benefits to the Cities of Virginia Beach, Norfolk, and Chesapeake if constructed.

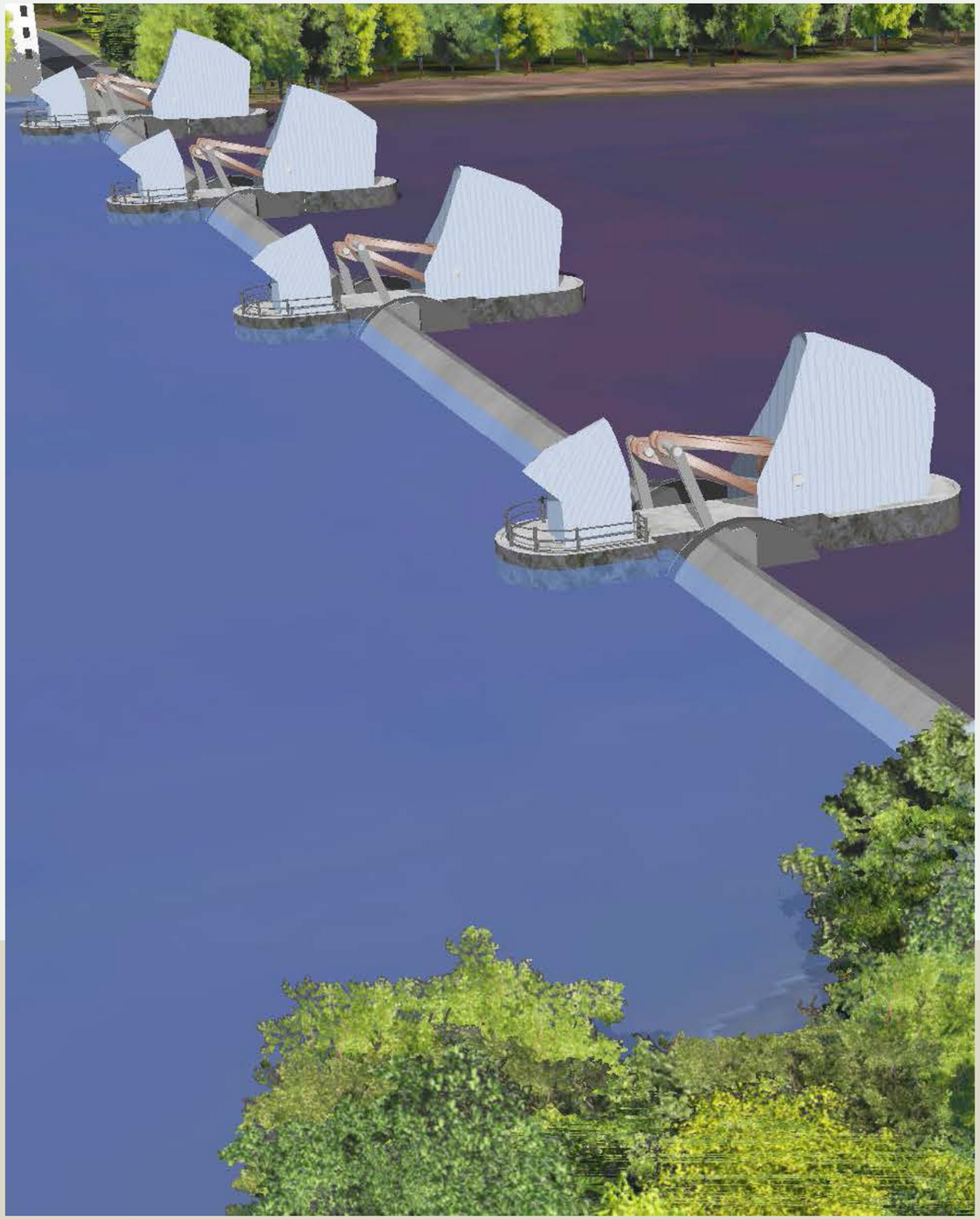


Elizabeth River alignment with circular gate, road gates, seawall, and floodwalls.

Elizabeth River existing conditions



Elizabeth River structural protection system under flood condition



Elizabeth River structural protection system under flood condition (enlarged view)

Elizabeth River Watershed

Commercial Floodproofing

A study of Individual Building and Site-Level Flood Risk Strategies found that floodproofing was a cost-beneficial solution for a total of 19 commercial buildings in the Elizabeth River Watershed. Floodproofing these buildings ranged from moderately cost- effective to highly cost-effective and would serve to protect the commercial and economic interests of these structures from the impacts of flooding.

For some of these structures, both wet and dry floodproofing were found to be a good solution, but the strategy with the higher return on investment is recommended. There are 9 buildings suitable for wet floodproofing that would amount in $410,239 in cumulative costs and 10 buildings suitable for dry floodproofing that would amount to $1,030,980 in cumulative costs.

COST

$$$$

TIMELINE

near-term mid-term long-term

BENEFITS

- Wet floodproofing would result in $582,640 cumulative benefits and a benefit-cost ratio of 1.4.
- Dry floodproofing would result in $2,729,297 in cumulative benefits and a benefit-cost ratio of 2.6.

Elizabeth River Watershed

Floodplain Regulation

In consideration of sea level rise, the City is exploring changes to the definition of the "regulatory floodplain" that would expand the land area to which regulations apply to either the 500-year floodplain or the "future 100-year floodplain."

These changes to floodplain regulations across the City would impact development in areas that fall within this new regulatory floodplain.

Under an expanded "future 100-year floodplain" with 3.0 feet of sea level rise, there would be an additional 1.6 square miles in the regulatory floodplain.

COST

$$$$

TIMELINE

near-term mid-term long-term

BENEFITS

- Reduced vulnerability to flood risks for new development and substantial redevelopment
- Safer long-term growth
- Preservation of life and property

Elizabeth River Watershed

Resilient Roadways

The vulnerability of Virginia Beach's road network and community facilities to critical flood pathways should be recognized and addressed by the City's efforts to improve resilience to coastal flooding. The identified roads are essential and represent key conduits for the tourism, service, and defense industries, or accessibility to key community resources such as fire and emergency stations, hospitals, and police stations. In addition to accessibility concerns, some of these community facilities themselves becomes increasingly vulnerable to damage during storm events.

The City should seek to address these vulnerabilities through existing or new road improvement projects. South Military Highway, Providence Road, Indian River Road, South Witchduck/Kempsville Road, and Princess Anne Road are all important routes for evacuation, commuting, and accessibility to key resources. Sections of Princess Anne Road, South Military Highway, Indian River Road, and South Witchduck/Kempsville Road become vulnerable to flooding with higher sea levels. Accessibility to several schools, mostly concentrated in the Kempsville area, also becomes an issue.

The proposed Elizabeth River structural protection system would protect these critical routes and access to community assets from coastal flooding during large storms. The City should consider roadway improvements to reduce the vulnerability of these critical routes.

COST

$$$$

TIMELINE

near-term mid-term long-term

BENEFITS

- Reduced risks of flooded critical infrastructure assets such as roads, bridges, and highways
- Increase accessibility to critical community assets
- Increased safety of people and property
- Increased safety of evacuation and emergency response routes

Elizabeth River Watershed

Responsible Development

The Elizabeth River Watershed contains three of Virginia Beach's SGAs, and a significant portion of the watershed contains areas that are relatively safe from flood risks. In the coming years, a good portion of Virginia Beach's growth, both residential and commercial, will be focused in this region in the coming years. These factors underscore the importance of responsible development in order to protect the City's growth from increased flood risk due to the Elizabeth River.

Specifically, "high and dry" areas should be identified and designated as locations for responsible development, be that residential, commercial or mixed-use. The SGAs located in this watershed should extend their planning time horizon and vision to incorporate the identified flood risks and think strategically about how that impacts the community. SGA locations and boundaries could even be altered to ensure that new development is not located in an area that may be prone to flooding in the near- or even long-term future. Developers who are responsible for developing both commercial and residential properties in this area should be given support and specific guidance regarding how to assess flood risk given new data and research for the watershed.

Responsible development in the Elizabeth River Watershed also includes preserving the tree canopy, setting minimum canopy requirements for new development in the watershed, reducing impervious pavement, and promoting storm water based fee incentives.

As this portion of the City grows, new critical assets and facilities, such as fire stations, schools, and hospitals, may be constructed to service the watershed's growing population. These critical assets and facilities should be developed with increased flood risks in mind. New critical facilities and assets in the Elizabeth River Watershed should be built outside of the future 100-year floodplain for the 3 foot SLR scenario when feasible, and if not, should be built with flood resilience and future flood scenarios in mind.

COST

$$$$

TIMELINE

near-term mid-term long-term

BENEFITS

- Reduced risks of flooded critical assets
- Reduced vulnerability to flood risks for new development and substantial redevelopment
- Safer long-term growth
- Preservation of green infrastructure

Elizabeth River Watershed

Building Elevation

The Elizabeth River Watershed is home to 16 residential properties where home elevations would be both beneficial and cost effective. These homes could be raised to a 3 foot freeboard, depending on changes to the zoning ordinance.

Although the Elizabeth River Watershed has the fewest number of homes in the City that would benefit from an elevation, this opportunity should not be overlooked. These homes are specifically located in SGAs that overlap with flood risks from the Elizabeth River, and elevating them could prevent flood losses in the future as sea level rise and recurrent flooding impact those areas along the River. The cumulative project costs of raising these residential properties would be $2.8 million, with each structure costing, on average, $176,000.

COST

$$$$

TIMELINE

BENEFITS

- $3.4 million in cumulative benefits
- Benefit-cost ratio: 1.2

Elizabeth River Watershed

Business Outreach and Education

The Elizabeth River Watershed has a strong business community that provides area residents with a wide range of services and products, while also providing the City with vital sales tax revenue. Outreach and education targeted towards the business community is vital in reducing economic losses brought about by flood events. The City should focus on educating and collaborating with the Elizabeth River business community to create continuity plans and emergency operations. The City can also educate businesses on the importance of flood insurance to cover the losses and help businesses regain their footing following a flood event. The City can also work with the Department of Economic Development to help foster conversations and bring additional awareness about flood risks to the business community.

Coordination efforts to advance these activities can be made through the various business organizations in the City. In fact, the City has already met and discussed the sea level rise and flooding issues with several such organizations, including the Minority Business Council, the Realtor's Association, and others.

COST

$$$$

TIMELINE

BENEFITS

- Reduced vulnerability of industrial and commercial businesses to flood risks

Elizabeth River Watershed

Flood Insurance Expansion

Flood insurance is vitally important to recovering from a flood event. A major component of preparing the community for increased sea level rise and recurrent flooding, is ensuring that residents and businesses have the means to recover from a flood event.

The overall flood insurance policy penetration in the Elizabeth River Watershed is 7%. This is 4% lower than the overall flood insurance penetration rate across the City, which is approximately 11%. The majority of the population that holds flood insurance policies in the watershed reside in neighborhoods next to the Elizabeth River.

The City should focus on increasing flood insurance penetration within areas in the Elizabeth River Watershed that have the highest residual risk – which is the risk that remains after applying a flood insurance deductible.

The most under-insured neighborhoods in the Elizabeth River Watershed today include:

- Carolanne Farms
- Arrowhead
- Fairfield
- Avalon Terrace
- MacDonald Park

The City should focus on increasing flood insurance penetration within the watershed through targeted outreach via numerous channels (radio, newspaper, digital ads, etc.) while providing educational background on the importance of flood insurance and who exactly should buy it. Partnership with FEMA can also provide ready-made marketing materials and data to reach high potential insurance buyers.

COST

$$$$

TIMELINE

near-term mid-term long-term

BENEFITS

- Provides CRS benefits for the City
- Allows residents and businesses to recover faster following a flood event

FLOOD INSURANCE STATISTICS

- 54% coverage inside Special Flood Hazard Area
- 5% coverage outside Special Flood Hazard Area
- 257 total claims
- $ 3,211,130 total losses reported from claims

Elizabeth River Watershed

Residential Community Education

The Elizabeth River Watershed is home to a wide range of residents who bring both demographic and cultural diversity to the community.

Education regarding flood risks and how to mitigate flooding at home is vital to reducing the risk of the watershed as a whole, but especially the risk of vulnerable community members.

A large percentage of residents who live within the Elizabeth River Watershed are increasingly vulnerable to flood risk due to factors such as age, income, physical and mental disabilities, and ethnicity.

The Elizabeth River Watershed is home to numerous community gathering places such as public schools, community and recreational centers, and 27 city parks. These community assets are well positioned to provide flood risk education throughout the watershed. The City should continue to partner with non-profits such as the Elizabeth River Project to do educational outreach to kids and young adults regarding marsh restoration, living shorelines, and the importance of natural assets – not only for beautification purposes but also for flood risk reduction benefits.

Flood education can be conducted from the perspective of helping individual homeowners and renters in Elizabeth River understand the risk to their structures, properties, and contents (such as what flood zone is your home located in?). Alternatively education can take the form of mitigation actions to help reduce the flood risk overall, or even go so far as to educate the public on what to do in the case of a flood.

All of these components can be highlighted through various outreach and engagement channels, and cater to the entirety of the City.

The City should ensure that outreach is accessible to vulnerable populations, whether that takes the form of printing materials and providing information in languages other than English or crafting materials that cater to community members with specific disabilities such as hearing or eyesight impairment.

COST

$$$$

TIMELINE

near-term mid-term long-term

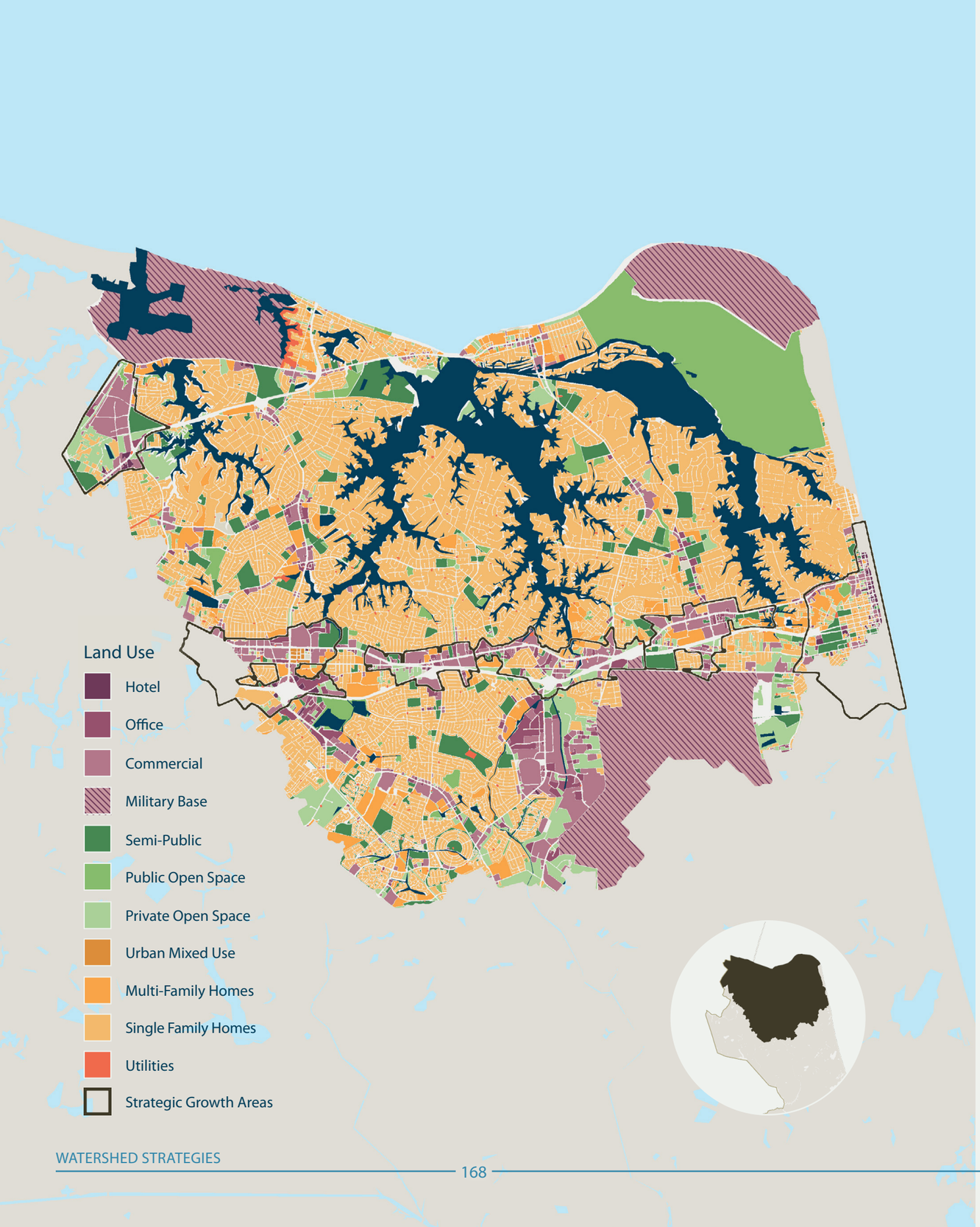
BENEFITS

- Residents have a better understanding of their individual flood risks and more general understanding of what to do in a flood scenario

LYNNHAVEN

The Lynnhaven Watershed is the second largest watershed in Virginia Beach, comprising approximately 81 square miles in northern Virginia Beach. This watershed contains a quarter of the City's residents, a substantial portion of the City's businesses, and five of the City's SGAs. This vital region connects the City to Chesapeake Bay, contains critical community infrastructure and transportation routes, and is home to important military installations including Joint Expeditionary Base Little Creek-Fort Story, and Naval Air Station Oceana.

Over the last 40 years, this historically agrarian community has undergone extensive development in both commercial and residential areas. However, the loss of naturalized landscapes has only served to make flooding worse, as development has formed on manufactured land and has surrounded the numerous water ways, rivers, tributaries, and bays that make up this region. 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.



Lynnhaven Watershed

Community Context

Waterways: Lynnhaven's waterways include Little Creek Inlet, Lynnhaven Inlet, Lynnhaven Bay, Eastern Branch Lynnhaven River, Western Branch Lynnhaven River, Linkhorn Bay, Broad Bay, Little Neck Creek, Thalia Creek, and London Bridge Creek.

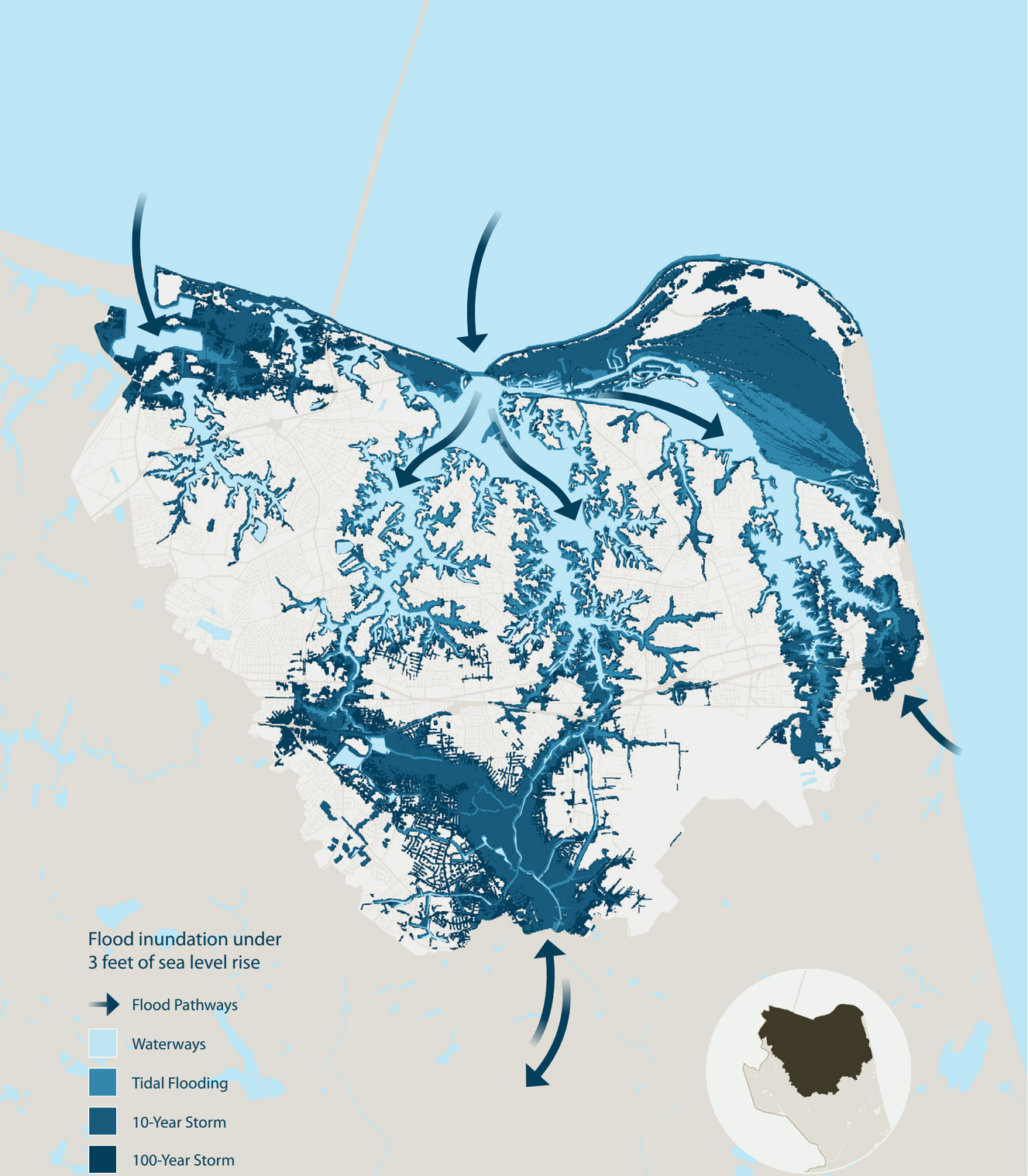
Natural Resources: The Lynnhaven River is the largest tidal estuary in Virginia, including 150 miles of shoreline, as well as hundreds of acres of marsh, mudflats, and shallow water habitats.[24] Historically this area was known for its oysters, but pollution and runoff from nearby industrialization and development have resulted in substantial declines in the oyster population. Over recent years, the community has worked hard to return the watershed to its previous glory, investing in improving water quality, essential habitats, and community accessibility. Five federal and state endagered species occur or potentially occur in the Lynnhaven River Watershed, including species such as the hawksbill, Kemp's Ridley and leatherback sea turtles, and the roseate tern.[25] The estuary also serves as an essential habitat for not only fish, but also shellfish, and is important for both commercial and recreational fishermen.[26]

The City is dedicated to preserving natural resources and preserving and enhancing naturalized landscapes, as seen through the purchase and preservation of Pleasure House Point. Today, 15.6 square miles within the watershed have been conserved and placed in easements. In addition to the restoration and conservation work being completed by the City within Lynnhaven, federal agencies, such as the U.S. Army Corp of Engineers, are also heavily involved in restoration work within the watershed, including a phased restoration project, that, when finalized will create 31 acres of new reef habitat, restore 38 acres of wetlands ,and 94 acres of submerged aquatic vegetation.[27]

Residential Population: The Lynnhaven Watershed is a densely populated region of the City. Over the past 40 years this area transitioned from an agrarian community to a bustling commercial center and residential area which is home to five strategic growth areas. The watershed's population is 235,320 with 94,157 households. In 2019, the median income was $68,500 with a per capita income of $38,406. Residents are 69% white, 20% black, 7% Hispanic, and 4% other. Regarding ownership, 53% of residents own their home and 47% of residents are renters.[28]

Economic Industries: The Lynnhaven Watershed is an economic driver for the City, with a number of commercial, industrial, and military complexes. While the oceanfront area commands a significant portion of the tourism industry, the Lynnhaven Watershed is also a popular stop for visitors, and boasts numerous condos and rental properties that cater to tourists. Boating is a strong part of the Lynnhaven economy. The military also has a strong presence in this part of the City, with Naval Air Station Oceana and Joint Expeditionary Base Little Creek-Fort Story located within the watershed.

Strategic Growth Areas: Lynnhaven Watershed is home to five SGA's within Virginia Beach: Pembroke, Burton, Rosemont, Lynnhaven and Hilltop. Both Lynnhaven and Hilltop are constrained by waterways, floodplains, wetlands, and aircraft noise, due to their location near the Naval Air Station Oceana military complex. These areas will be drivers of growth and development in Virginia Beach for years to come.



Lynnhaven Watershed

Flood Pathways and Extents

Pathways: The Lynnhaven Watershed contains two flood pathways into the City of Virginia Beach. The Lynnhaven Inlet is the most meaningful flood pathway - dispersing water from the Chesapeake Bay into the Lynnhaven estuary. This includes numerous surrounding bays and rivers — including Lynnhaven Bay, the western and eastern branches of the Lynnhaven River, Broad Bay, and Linkhorn Bay. Coastal floodwaters entering through the Lynnhaven Inlet flow into the Oceanfront Watershed and can flood the backside of the Resort area. They also flow further south, through both Thalia and London Bridge Creeks to the south of I-264, and can penetrate as far south as Dam Neck Road on West Neck Creek in the Southern Watershed. Little Creek Inlet is the second pathway for floodwaters into the City within the Lynnhaven Watershed. At present, such flooding is mostly contained in a relatively small area; however, in the future, this pathway will grow, and floodwaters are expected to overtop and flow into Chubb Lake, Lake Bradford, and the Little Creek Reservoir. The Lynnhaven Watershed can also receive floodwaters from the Oceanfront and Southern River Watersheds. Waters from the Southern Rivers Watershed can flow into Lynnhaven from West Neck Creek.

Tidal Flooding: High tide flooding only impacts a small amount of land today. However, residents in the Lynnhaven Watershed are familiar with tidal flooding that occurs several times a year during extreme high tides, such as during King Tides. Sections of Shore Drive and other low-lying areas have been repetitively flooded during these conditions. These events provide indicators of areas that will experience more frequent flooding with higher sea levels. With 1.5 feet of sea level rise, 1.5 square miles of land is anticipated to be permanently inundated during daily high tides. An additional 2 square miles of land becomes vulnerable to permanent inundation towards mid-century with 3 feet of sea level rise.

10-Year Storm: A moderate storm event today impacts approximately 7 square miles of land, mostly concentrating within the low-lying neighborhoods on either side of Shore Drive, including Bay Island. With 1.5 feet of sea level rise, an additional 4 square miles of land will be impacted, with flooding reaching further south through both Thalia and London Bridge Creeks past I-264. With 3 feet of sea level rise, a 10-year storm event will result in even more extensive flooding, expanding into an additional 5 square miles of land. This flooding will impact the outer boundary of the Joint Expeditionary Base Little Creek - Fort Story, and create more widespread flooding in neighborhoods on both sides of Shore Drive and the center of the City.

100-Year Storm: During a large storm event today, the amount of flooded land is similar to the area impacted during a moderate storm event with 1.5 feet of sea level rise. Flooding during a large storm towards mid-century becomes more of a concern, as there is potential for flood waters entering into Rudee Inlet to overtop the central resort area and flow into Little Neck Creek. This merging of flood pathways generates more extensive flooding, especially near Joint Expeditionary Base Little Creek – Fort Story. Flooding entering through Little Creek Inlet also becomes more substantial, impacting a significant amount of land on Joint Expeditionary Base Little Creek - Fort Story. The total amount of flooded land in the Lynnahven watershed increases to 24 square miles, with other notable growth in the floodplain towards the center of the City.

Lynnhaven Watershed

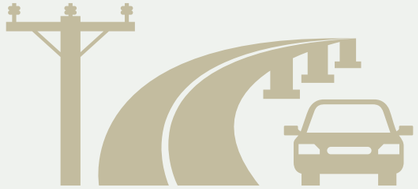
Notable Impacts

Impacts on Buildings

The Lynnhaven Watershed contains the highest building stock value, which represents over 53% of the City's total value. This area has almost 26,000 buildings exposed to coastal flooding with 3 feet sea level rise projections. If flooding vulnerabilities are not addressed, average annual flood losses to buildings, contents, and associated displacement of occupants is approximately $8.8 million under today's conditions, but jumps to $129.9 million with 3 feet of sea level rise. Lynnhaven Watershed has the largest potential annualized loss, out of the four watersheds.

Flood Exposure of Buildings

	Now	1.5 ft SLR	3 ft SLR
# Buildings	8,236	13,260	25,979
# Residents	63,568	86,661	133,129
Expected Building, Content, and Displacement Costs	$8.77M	$33.97M	$129.89M



Impacts on Infrastructure

Today, there are 4 community facilities and almost 4.5 miles of critical evacuation routes that are exposed to coastal flood risks. With 3 feet of sea level rise, 20 facilities and more than 27 miles of critical evacuation routes become threatened by coastal flooding.

Vulnerable Critical Facilities

	Now	1.5 ft SLR	3 ft SLR
Fire Stations	2	2	5
Medical Care	0	1	2
Schools	2	6	13
Miles of Critical Roads	4.4	9.7	27

Impacts on Habitats

Some coastal habitats are able to keep pace with sea level rise or migrate into undeveloped areas whereas other habitats are at risk of being lost due to drowning or being blocked by development. Towards the end of the century, 3 feet of sea level rise will likely increase the footprint of open water in the Lynnhaven River watershed by 16%. This expansion in open water will have significant impacts on coastal wetland habitat. The analysis of habitat vulnerability showed that 14% of woody wetland habitat could be lost. Tidal flats could increase by 39% due to conversion of woody wetlands. Because of the large amounts of protected land in the Lynnhaven River watershed, including First Landing State Park and Pleasure House Point Natural Area, grass marsh habitat could increase by 3% due to migration into these undeveloped areas. However, marsh islands in the middle of Lynnhaven Bay as well as fringing marsh along more developed shorelines are expected to sustain substantial losses.

Changes in Acres of Habitat

	Now	1.5 ft SLR	3 ft SLR
Woody Wetlands	3,677	3,494	3,159
Grass Marsh	873	866	901
Tidal Flat	184	137	256
Open Water	7,072	7,607	8,291

Impacts on People

Today more than 60,000 residents live in homes vulnerable to flooding, but that number will more than double as sea level rise leads to an expanded floodplain. By the end of the century, over 130,000 people in the Lynnhaven Watershed could be exposed to coastal flood hazards. Out of those residents exposed to future flooding, over 70% may experience increased vulnerability due to physical and socioeconomic factors. These populations may require greater assistance and support from the City regarding supporting mitigation and preparedness.

Vulnerable Populations Exposed to Flooding

	% Today	% at 1.5 ft SLR	% at 3 ft SLR
People of Color	26%	36%	58%
Children (<5)	27%	37%	58%
Elderly (>65)	28%	37%	57%
Institutionalized	9%	9%	28%
Limited English	27%	37%	58%
Limited Income	29%	42%	62%
Disabled	29%	40%	61%

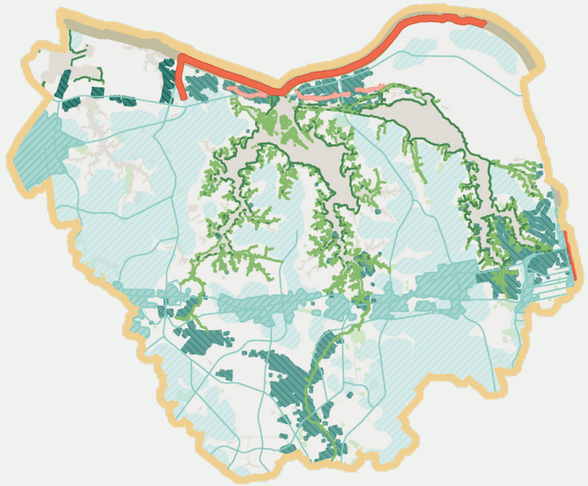
Lynnhaven Watershed

Adaptation Vision

The Lynnhaven Watershed represents a large portion of the flood risk within the City. Through both nature based and built systems, working in tandem, this portion of Virginia Beach will continue to thrive despite rising sea levels and increasing rainfall.

If implemented, Lynnhaven Inlet will be outfitted with a storm surge barrier that will consist of a combination of movable gates and seawalls. This structure will significantly reduce the influx of coastal flood waters entering into the City from the Chesapeake Bay.

Structural interventions alone will not totally protect the Lynnhaven Watershed. Additional 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. The City should also continue to pursue policy and regulatory actions such as expanding the definition of the floodplain to ensure that lives and property are adequately protected in the watershed.



Natural Mitigations

- Beach and Dune Nourishment
- Ecological Revetments
- Land Conservation
- Living Shoreline
- Marsh Restoration and Creation
- Shellfish Reefs and Oyster Restoration
- Seagrass Restoration

Engineered Defenses

- Chesapeake Bay City-Wide Alignment
- West of Lesner Bridge Neighborhood Alignment
- East of Lesner Bridge Neighborhood Alignment

Adapted Structures

- Commercial Floodproofing
- Floodplain Regulation
- Mitigation Reconstruction
- Resilient Roadways
- Responsible Development
- Building Elevation

Prepared Communities

- Business Outreach and Education
- Flood Insurance Expansion
- Residential Community Education

Lynnhaven Watershed

Beach and Dune Nourishment

There are approximately 11 miles of beachfront within the Lynnhaven Watershed, facing the Chesapeake Bay. These beaches, including Chesapeake, Ocean Park, and Cape Henry, have been nourished using sand from the Lynnhaven Inlet maintenance dredging project.

These beach nourishment projects have been largely successful, providing both additional storm protection and recreational areas. Looking forward, continued nourishment of these beaches will require more sand than is currently available from the dredging at Lynnhaven Inlet.

The City is exploring alternative sources for sand including nearby borrow sites in the Chesapeake Bay and federal navigation channels along the Atlantic oceanfront. This strategy recommends exploring sustainable sources for sand to nourish these beaches and continued investment to maintain wide beaches that protect property from storm surge and provide beaches for tourism.

Beach nourishment projects in the Lynnhaven Watershed are funded from the State Beach Nourishment Funding Program, special tax districts, funding from the City of Virginia Beach's annual budget, and the Project Cooperation Agreement between the City of Virginia Beach and USACE (allows for a 65%-35% cost share between USACE and the City of Virginia Beach). In 2016, Virginia Beach proposed annual contributions between $1.2 to $2.5 million for the next six years to the restoration fund.

COST

$$$$

TIMELINE

near-term mid-term long-term

BENEFITS

- Expand the width of beaches and increasing recreation areas
- Offer enhanced protection storm events
- Accelerate dune growth and habitat enhancement

Lynnhaven Watershed

Ecological Revetments

The Lynnhaven Watershed currently has some revetments (much like a retaining wall or barrier) along the marsh edges. Planting additional revetments could be a potential mitigation tactic throughout the broader watershed, especially in open water areas or areas that experience high wave heights.

The City could also explore renovating traditional revetments to incorporate different materials and add forms of vegetation that could grow on top of or over the structure.

Revetments come in many different forms, and the City should explore innovative ways to incorporate more living shoreline aspects into existing structures. These living shoreline elements will not only help mitigate the impacts of sea level rise and flooding, but will also benefit water quality and provide habitats for fish and wildlife.

COST

$$$$

TIMELINE

near-term mid-term long-term

BENEFITS

- Reduce the impacts of sea level rise and flooding
- Potential to reduce the intensity of waves
- Enhance fish and wildlife habitats
- Bolster water quality
- Aesthetically pleasing and reduces the visibility of hardened structures

Lynnhaven Watershed

Land Conservation

The City has long sought to conserve land in the Lynnhaven Watershed, most notably by the purchase and subsequent protection of Pleasure House Point, one of the largest undeveloped tracts of land in the Lynnhaven Watershed. Additionally, the City has preserved 15.6 square acres within the watershed.

The City should continue to advocate for land conservation and preservation within fragile areas of the watershed.

Voluntary acquisition of residential homes opens up land space and provides a significant opportunity for the City to not only protect its residents from recurrent flooding and sea level rise, but also conserve and protect green space within the watershed.

There are an estimated 1,146 land parcels within Lynnhaven that could potentially be a candidate for voluntary acquisition by the City. It would cost roughly $341 million, or an average of $297,100 per parcel, to acquire all of this land within the watershed. The City should continue to explore voluntary acquisition as a means to both conserve and improve the green infrastructure network and reduce the risks to residents from sea level rise and storm surge.

COST

$$$$

TIMELINE

near-term mid-term long-term

BENEFITS

- Create additional open space land
- Enhance the green infrastructure network and bolster the naturalized landscape
- Provide additional recreational space for watershed residents
- Relocates owners from high-risk properties

Lynnhaven Watershed

Living Shoreline

Although the proposed Chesapeake Bay structural protection system will be much more effective at mitigating large storm surges, there is still opportunity within the Lynnhaven Watershed to construct living shorelines.

Living shorelines along the banks of tidal bays, rivers, and creeks would provide a first line of defense during flood events and slow the water's advance so that neither the structures nor the land feel as much of an impact. Offshore breakwaters could be constructed to break up wave energy and reclaim historically lost fringing marsh.

The majority of shorelines in the Lynnhaven Watershed are on private lands. Of the approximately 32 miles of shoreline suitable for construction of living shorelines, only 2.5 miles border existing conserved lands or easements. The City can consider living shoreline projects along city-park property or collaborate with these landowners to identify sites and design large-scale living shoreline protection systems.

Homeowners or businesses with waterfront property armored with bulkheads or other hardened shorelines can explore the possibility of converting these into living shorelines. The City should continue to partner with non-profits, organizations and groups such as Lynnhaven River NOW and the Chesapeake Bay Foundation to provide assistance to homeowners to help in the design, financing, and construction of living shorelines where feasible.

The construction costs for living shoreline projects vary widely depending on the shoreline length, level of protection needed, and the costs for materials and labor. Construction of all living shoreline projects identified in the Lynnhaven Watershed could range from $25.3 – $84.5 million.

COST

$$$$

TIMELINE

near-term mid-term long-term

BENEFITS

- Offer broad ecosystem services
- Provide erosion control
- Reduce flooding during smaller storm events
- Improve water quality
- Beautify the waterfront area
- Enhance habitats for wildlife and aquatic species

Lynnhaven Watershed

Marsh Restoration and Creation

Although there are opportunities in each of the four watersheds in Virginia Beach to restore, enhance, and create new wetland areas, the Lynnhaven Watershed offers an extensive opportunity which should be a priority for the City.

Analysis has shown that the Lynnhaven Watershed will be particularly susceptible to the loss of both fringe and marsh island systems as sea levels continue to rise around Virginia Beach. The marsh islands in the middle of Lynnhaven Bay are especially important given that they slow down the movement of water in the bay. Techniques such as beneficial use of dredge material can be used to ensure the marsh islands are able to keep pace with rising sea levels.

There is an opportunity for the City to continue to collaborate with Lynnhaven River NOW, the Nature Conservancy, and USACE to advance strategies to reduce erosion and protect the fragile marshland within the watershed. The USACE Norfolk District and the City are currently partnering on a $34 million Lynnhaven River Basin Ecosystem Restoration Project to restore approximately 38 acres of wetland over the next few years. The City can use lessons-learned from this project to undertake more extensive wetland restoration in the Lynnhaven Watershed.

COST

$$$$

TIMELINE

near-term mid-term long-term

BENEFITS

- Opportunity to collaborate with non-profits, federal, and state partners to achieve wetland restoration
- Many restoration projects can be done in small increments

Lynnhaven Watershed

Shellfish Reefs and Oyster Restoration

The Lynnhaven has been and will continue to be well suited for emerged and semi-emerged shellfish habitats. While this particular application may not be effective for reducing high intensity waves, it will help bolster the living shoreline habitat diversity.

The restoration of shellfish and oyster habitats, along with restoring the water quality for the Lynnhaven River and Bay, has been a priority from the federal, state, and local level for many years.

Lynnhaven River NOW has been highly successful in implementing shellfish reefs and oyster restoration with community help and involvement. The City should consider bolstering involvement and support of these programs.

COST

$$$$

TIMELINE

near-term mid-term long-term

BENEFITS

- Restore habitats and species
- Improve water quality
- Bolster the shellfish and oyster industry / commercial and recreational fishing

Lynnhaven Watershed

Seagrass Restoration

The Lynnhaven Watershed is a key area in which aquatic vegetation restoration could provide numerous benefits, not only at reducing the power of waves but also improving water quality.

Researchers have been studying vegetation restoration in the Lynnhaven Watershed for decades, and new ways of transplanting and growing seeds have provided hope that this will be a viable option in the future.

If recent vegetation restoration pilot projects prove successful, there are huge flood benefits that will come from the ability of this vegetation to slow down the flow of water.

The Lynnhaven River Basin Ecosystem Restoration Project aims to restore over 90 acres of seagrass beds, focusing on restoring populations of eelgrass and widgeon grass in areas where these grasses were historically abundant.

The City should continue to monitor the research and progress of funded studies and programs such as this, and if proven successful, continue to support aquatic vegetation restoration throughout the watershed.

COST

$$$$

TIMELINE

near-term mid-term long-term

BENEFITS

- Decrease the flow of water
- Increase water quality
- Reduce the power of waves
- Increase habitats

Lynnhaven Watershed

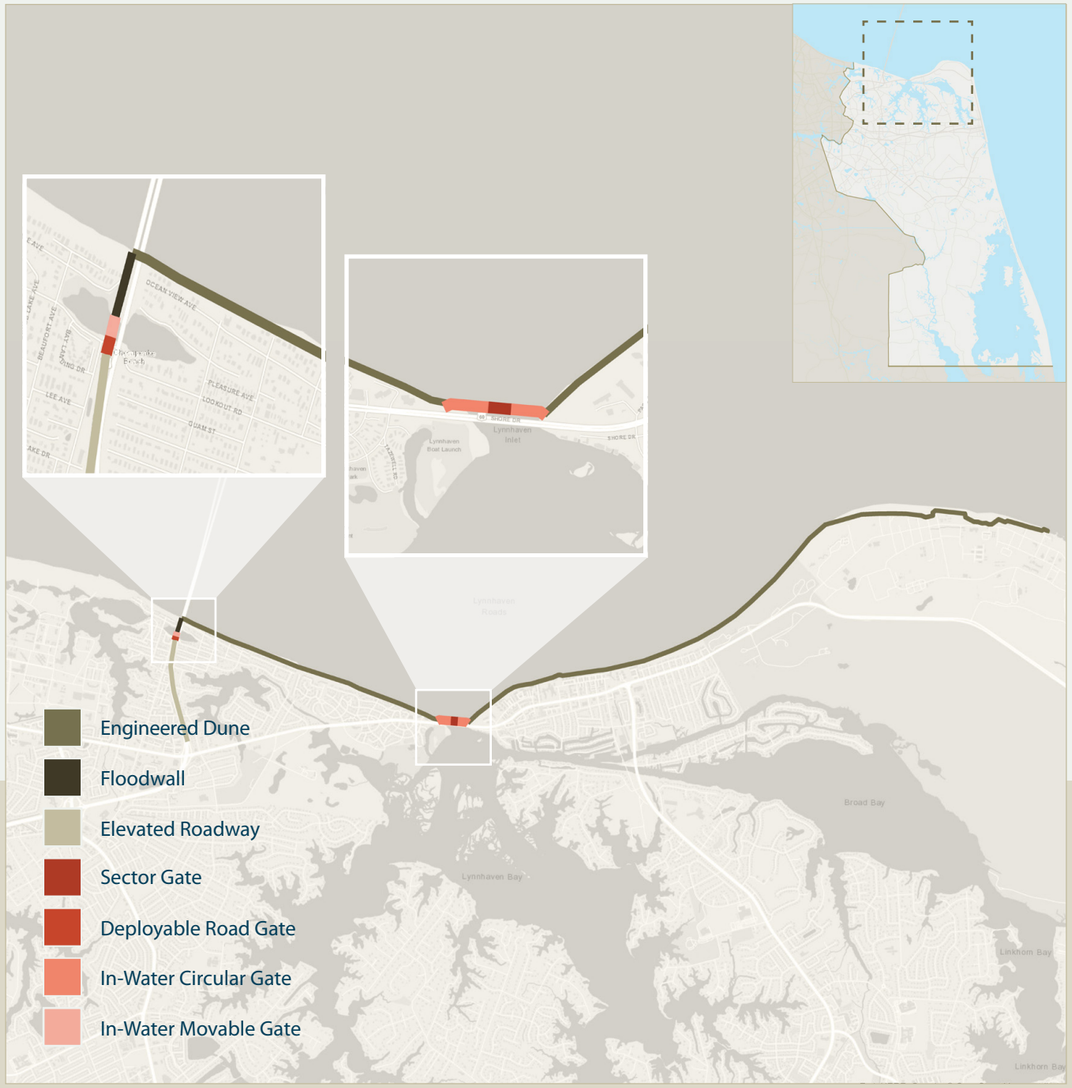
Chesapeake Bay City-Wide Alignment

As previously mentioned, Lynnhaven Inlet is the primary gateway of coastal flood waters into the interior of the City. In reflection of this, a storm surge barrier at the Inlet is included in all of the downselected City-wide flood defense alternatives. Such a gate would be placed north of the Lesner Bridge and is conceived to be a hybrid design incorporating a central sector gate to address navigation needs in the Federal Channel. The sector gate would be flanked by in-water movable gates, with tie-in seawalls. The design elevation for this structure would be approximately 18 feet (NAVD88 datum). This elevation may increase when considering the effects of wave runup and overtopping.

Additional infrastructure, or enhancement of existing lines of protection, would be required to the east and west of Lynnhaven Inlet. This includes raising the beach and dune elevations, and potentially fortifying the dunes with sheet-pile or rubble-mound cores to meet flood certification requirements. The design elevation of this line of protection would be approximately 16 feet (NAVD88 datum).

Both the eastern and western sides of this alignment intersect Joint Expeditionary Base Little Creek-Fort Story. Continuation of the line of protection across Fort Story grounds, around Cape Henry is not included at this time. Two alternatives were examined in consideration of the Naval Amphibious Base Little Creek. These alternatives offer solutions if the Navy does or does not desire to establish a surge barrier at Little Creek Inlet. Although some coordination has been undertaken by the City, no direction is available at his time. One option assumes that a surge barrier at Little Creek will not be possible, and the City will need to close the line of protection at Northampton Boulevard by elevating the roadway, where needed, and establishing a rolling gate across Lookout Road, coupled with an in-water gate across Lake Pleasure House.

Alternatively, a storm surge barrier would be constructed across Little Creek Inlet and tied into a combination seawall and fortified dune system continuing into Norfolk. Such a line of protection has already been examined for Norfolk, as part of its USACE Coastal Storm Risk Management Feasibility Study and was not found to be a preferred option. These interventions are estimated to cost $1.13 billion, with this number increasing to $2.31 billion if it is extended across Little Creek Inlet. This number excludes costs for continuing into Norfolk.



Lynnhaven Watershed alignment with seawalls and sliding gate.

COST

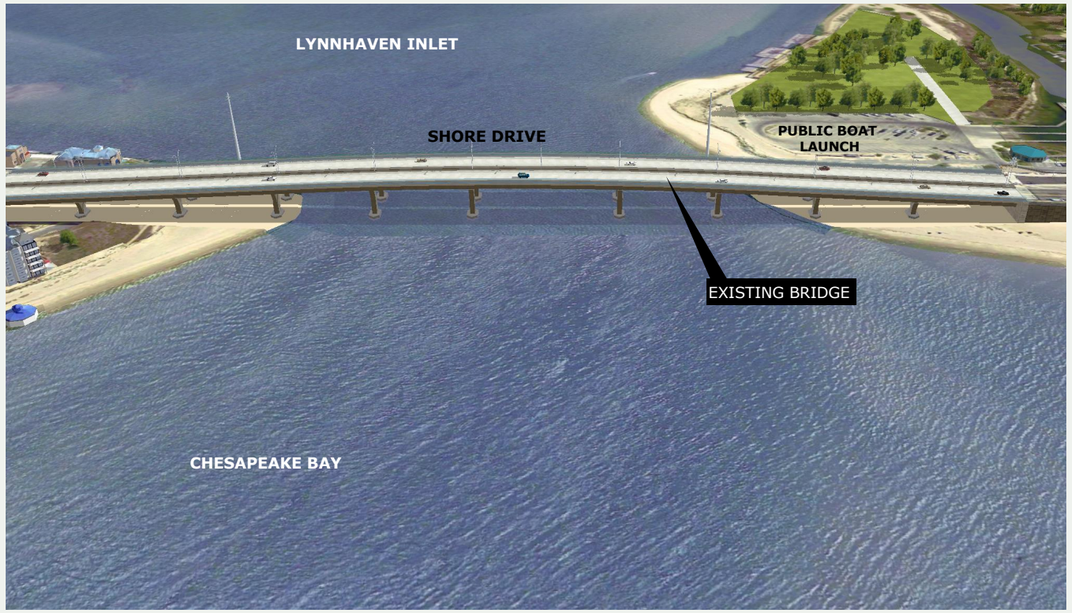
$$$$

TIMELINE

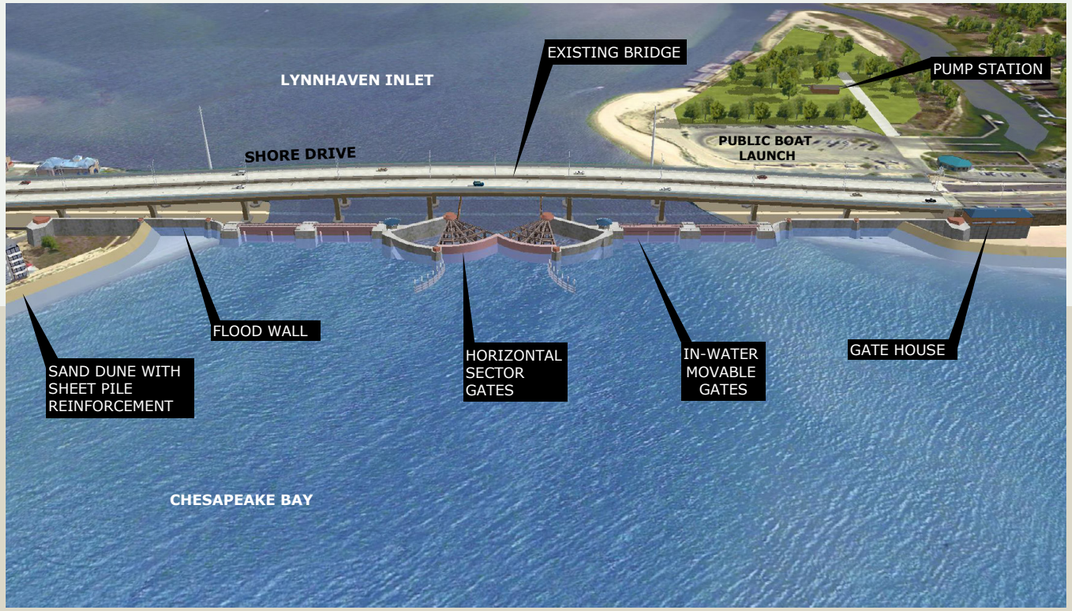
near-term mid-term long-term

BENEFITS

- Although a long-term strategy subject to significant cost and permitting hurdles, such a barrier would protect about 28,000 structures from coastal flood impacts for the assumed 3 feet sea level rise scenario.
- If designed for federal certification, protected property-owners would receive flood insurance rate discounts.
- This strategy also protects the maritime industry in the Lynnhaven Watershed, maintains the tax base, and has a cost-benefit ratio of 2.01.

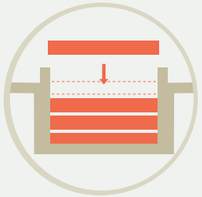


Lynnhaven Inlet existing conditions



Lynnhaven Inlet structural protection system under flood condition

Lynnhaven Inlet circular and movable gate system under flood condition (enlarged view)



Lynnhaven Watershed

West of Lesner Bridge Neighborhood Alignment

Flood protection could be provided to a lesser degree to address more common coastal storm surge events and short-term increases in sea level rise. Two alternatives to the Chesapeake Bay alignment were developed that would be considerably less expensive than the City-wide option and could be achievable on a shorter timescale. They could be considered together as a flood protection system that would provide protection to Shore Drive which is a critical hurricane evacuation route, in addition to providing flood risk reduction benefits for residents and business communities.

The area located west of the Lesner Bridge is a mixed neighborhood consisting of residential, commercial, recreational, and educational facilities along with Shore Drive, which serves as a major hurricane evacuation route within the City. This area is vulnerable to flooding from 1.5 feet sea level rise combined with more common coastal storm events. The structural flood protection system will be at approximately 8 feet (NAVD88 datum) elevation and protect residential and commercial areas between Lynnhaven Inlet and US 13.

The West of Lesner Bridge alignment would consist mostly of a floodwall and raised roadways. Due to the multiple boat ramps and roadways, a mix of coastal flood protection designs would be required to maintain the line of projection. These include deployable barriers such as gates or flood logs. Backflow prevention devices should also be considered for the local stormwater drainage system. Due to the presence of several boat docks along the alignment, there will be potential challenges to adapt permanent and deployable flood protection measures along the alignment. This alignment would cost $15.8 million.

In the evaluation process, concerns were raised about residual flood risk with the lower level of protection. The structures could be overtopped by severe, less common storm events, and offer a false sense of security to individuals and businesses in the protected area. This approach would also offer a shorter life-span and require continued investment in the future to raise the elevation. Therefore, these alternatives are only recommended as a stop-gap measure to buy some time for gradual relocation of protected properties, or as an alternative to the City-wide option, if found infeasible by future studies.

COST

$$$$

TIMELINE

BENEFITS

- The West of Lesner Bridge system would protect the area between Lynnhaven Inlet and Northampton Boulevard as well as the critical transportation routes such as Shore Drive from strong storms up to 1.5 feet sea level rise, with severe storms having the potential of overtopping the system and causing damage.

Location of West of Lesner Bridge structural protections with raised roadways, floodwalls, and deployable gates.

Lynnhaven Watershed

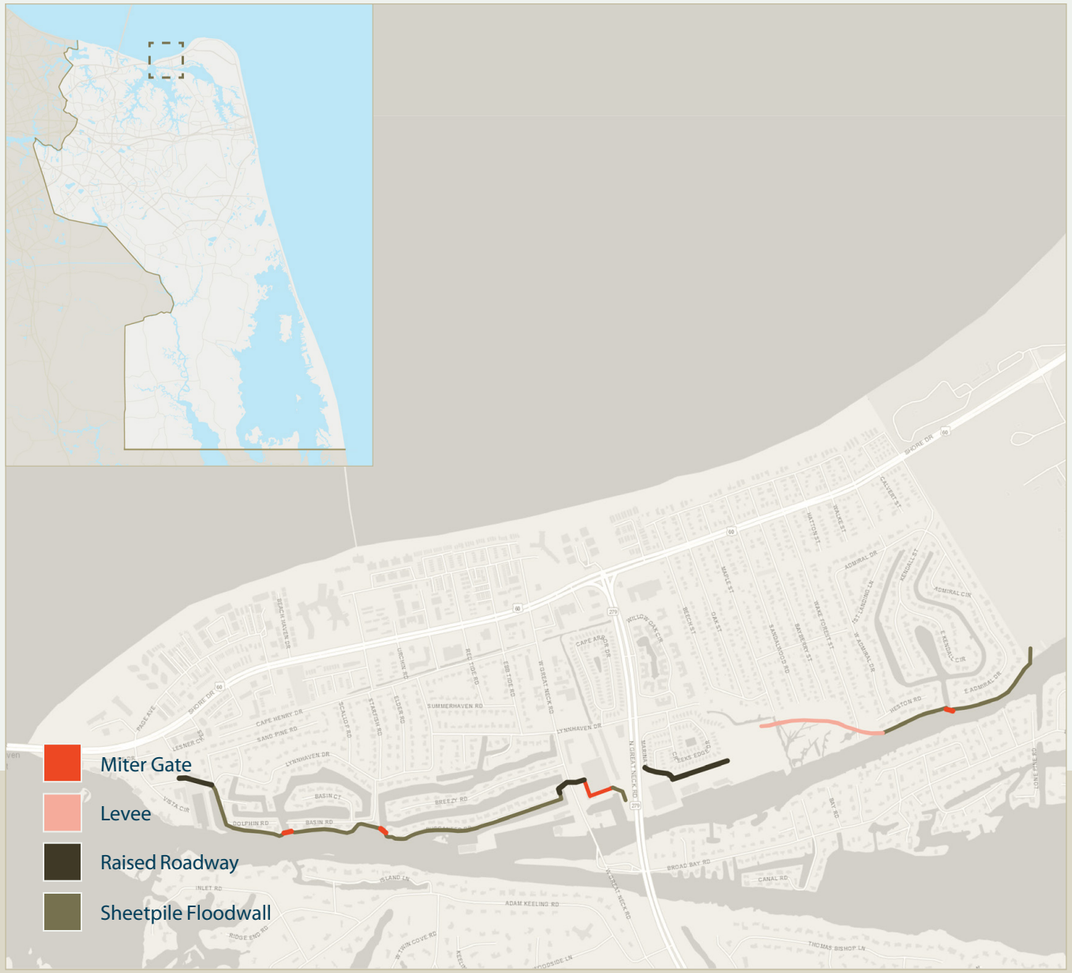
East of Lesner Bridge Neighborhood Alignment

Shore Drive is one of the critical vehicular routes within the City that also serves as an evacuation route. It also acts as one of the two vehicular access points for the Fort Story military base, thus making this roadway critically important for serving federal defense facilities. The area located east of the Lesner Bridge is a mixed neighborhood of commercial and residential properties while the neighborhood of Bay Island is predominantly a residential community. The majority of both areas are at a risk of flooding from sea level rise combined with more common coastal storm surge events.

The structural flood protection system in this neighborhood area is broken into two components – East of Lesner Bridge system is to protect residential and commercial areas between Long Creek and Atlantic Ocean from strong, less frequent storms and 1.5 feet of sea level rise with a design elevation of approximately 8 feet (NAVD88 datum). The second system will protect the residential community of Bay Island from frequent storm events and 1.5 feet of sea level rise with a design elevation of approximately 7 feet (NAVD88 datum).

The East of Lesner Bridge alignment could consist mostly of floodwalls, earthen levees, and raised roadways. These features would need to tie into local high ground and ensure that floodwaters would not bypass the line of protection. A mix of other coastal flood protection designs would be required to maintain current roadway and canal access. Deployable barriers such as gates or flood logs could be used at these entrances. The need for numerous deployable barriers along the Bay Island alignment, especially at entrances to boating docks, would result in a unreliable flood protection system. Due to this the Bay Island flood protection system was not considered feasible.

The East of Lesner Bridge alignment cost would be $35.5 million excluding costs for protecting Bay Island community.



Location of East of Lesner Bridge structural protections with raised roadways, floodwalls, miter gates, and levees.

COST

$$$$

TIMELINE

near-term mid-term long-term

BENEFITS

- The East of Lesner Bridge system would protect the area between Long Canal and Atlantic Ocean as well as the critical transportation routes such as Shore Drive from a strong coastal storm surge events and 1.5 feet of sea level rise.

Lynnhaven Watershed

Commercial Floodproofing

Following the study of Individual Building and Site-Level Flood Risk, a total of 261 commercial buildings in the Lynnhaven River watershed were found to be a cost-effective solution. Floodproofing these buildings ranged from moderately cost- effective to highly cost-effective and would serve to protect the commercial and economic interests of these structures from the impacts of flooding. For some of these structures, both wet and dry floodproofing were found to be a good solution, but the strategy with the higher return on investment is recommended. There are 146 buildings suitable for wet floodproofing that would amount in $ 13,283,301 in cumulative costs and 115 buildings suitable for dry floodproofing that would amount to $10,941,345 in cumulative costs.

COST

$$$$

TIMELINE

near-term mid-term long-term

BENEFITS

- Wet floodproofing would result in $ 24,179,236 cumulative benefits and a benefit-cost ratio of 1.8.
- Dry floodproofing would result in $ 25,325,095 in cumulative benefits and a benefit-cost ratio of 2.3.

Lynnhaven Watershed

Floodplain Regulation

In consideration of sea level rise, the City is exploring changes to the definition of the "regulatory floodplain" that would expand the area to which the regulations apply to either the 500-year floodplain or the "future 100-year floodplain."

These changes to floodplain regulations across the City would impact development in areas that fall within this new regulatory floodplain.

Under an expanded "future 100-year floodplain" with 3.0 feet of sea level rise, there would be an additional 12.1 square miles in the regulatory floodplain.

COST

$$$$

TIMELINE

near-term mid-term long-term

BENEFITS

- Reduced vulnerability to flood risks for new development and substantial redevelopment
- Safer long-term growth
- Preservation of life and property

Lynnhaven Watershed

Mitigation Reconstruction

Within the Lynnhaven Watershed, there are nearly 1,840 structures that may be a good fit for a demolition/rebuild scenario, which represents 2.6% of the watershed's residential structures.

Demolition and rebuilding of a residential structure allows for higher building codes and standards to be applied to that structure, which in turn reduces the risk of flooding. While this option is more expensive than the voluntary acquisition of property for land conservation purposes, it ensures that community members stay in their communities and helps to maintain a consistent tax base.

The total project costs if all 1,840 structures were demolished and rebuilt would be about $346.4 million, with an average cost per structure of $188,300. This is the middle average protection cost out of the three options (voluntary acquisition, home demolition and rebuild, and home elevations).

COST

$$$$

TIMELINE

near-term mid-term long-term

BENEFITS

- Total benefits of $822.6 million
- Benefit-cost ratio of 2.36
- Maintain community relationships
- Maintain tax base
- Avoid and reduce damages to property

Lynnhaven Watershed

Resilient Roadways

The vulnerability of Virginia Beach's road network and community assets should be recognized and addressed by the City's efforts to improve resilience to coastal flooding. The identified roads are essential and represent key conduits for the tourism, service, and defense industries, or accessibility to key community resources such as fire and emergency stations, hospitals, and police stations. In addition to accessibility concerns, some of these community facilities become increasingly vulnerable to damage during storm events. The City should seek to address these vulnerabilities through resilient design, relocating vulnerable facilities to higher ground, and road improvement projects.

In the Lynnhaven Watershed, primary roads such as Virginia Beach Boulevard, Shore Drive, and North Great Neck Road are essential for evacuation, commuting, and accessibility to key resources. Portions of all three of these roads become increasingly vulnerable to coastal flooding. For example, access to several heath care facilities on First Colonial Road becomes restricted during large storm events and some of these facilities are at risk to flooding.

Shore Drive is also a critical route that provides access to several vulnerable community assets including Joint Expeditionary Base – Little Creek Fort Story. The proposed Lynnhaven Inlet structural protection system would protect Shore Drive from coastal flooding during large storms. However, Shore Drive is vulnerable to recurrent flooding in today's condition - an issue that has also been identified by the Joint Land Use Study. Such vulnerability will only worsen in the future with increase sea levels. Given the anticipated long-term timeline for construction of the proposed Lynnhaven surge barrier, near-term strategies are likely needed. Additionally, the City must consider how much the surge barrier would be closed in a long-term future condition to protect against more frequent flood events. Neighborhood level projects, such as the West and East of Lesner Bridge neighborhood strategies would help address such issues. The City should explore how the integrated suite of solutions presented within this study would protect Shore Drive and other vulnerable routes that provide access to critical community assets.

COST

$$$$

TIMELINE

near-term mid-term long-term

BENEFITS

- Reduced risks of flooded critical infrastructure assets such as roads, bridges, and highways
- Increase accessibility to critical community assets
- Increased safety of people and property
- Increased safety of evacuation and emergency response routes

Lynnhaven Watershed

Responsible Development

The Lynnhaven's five SGAs underscore the importance of responsible development within this watershed, as the City focuses the majority of its growth in this region in the coming decades. All five SGAs are impacted by the City's Chesapeake Bay Preservation Act Ordinance, which regulates water quality in an effort to protect and improve the water quality of tributaries that flow into the Chesapeake Bay. Developing for recurrent flooding should take into consideration not only mitigating and adapting to changing rainfall patterns and storm intensity, but also the impact that the development will have on the natural systems within the watershed, and how that impacts the broader Chesapeake Bay ecosystem.

Responsible development within the Lynnhaven Watershed should center around ensuring that the SGAs, where both commercial and residential development will occur, highlight "high and dry" areas that are largely protected from flooding.

The City should also consider singling out higher-risk coastal zone areas as specific floodplain districts. These could include areas within the future floodplain, or those impacted by high energy waves during storm events.

COST

$$$$

TIMELINE

near-term mid-term long-term

BENEFITS

- Building smarter and stronger
- Reducing risks for new and current residents
- Potential for reduced flood insurance costs
- Decrease in flood losses to homes and businesses

Lynnhaven Watershed

Building Elevation

The Lynnhaven has the most individual residential properties, out of the entire City, that are worthy candidates for a home elevation to 3 feet of freeboard. This strategy is highly effective at reducing the risk to homeowners from flood events, but it can take years to find funding and grants to help homeowners pay to elevate a home.

There are nearly 2,300 residential structures that would be cost beneficial to elevate, helping to protect both lives and properties during storm events. These 2,300 structures make up 3.93% of the watershed's total residential properties. The total cost to the City to elevate these structures would be over $388 million, with an average cost of about $169,000 per structure. This is the lowest average protection cost out of the three options (voluntary acquisition, home demolition and rebuild, and home elevations).

COST

$$$$

TIMELINE

near-term mid-term long-term

BENEFITS

- Total benefits of $1 billion
- Benefit-cost ratio of 2.53
- Maintain community relationships
- Maintain tax base
- Avoid and reduce damages to property

Lynnhaven Watershed

Business Outreach and Education

The Lynnhaven has a prosperous business community that provides area residents with a wide range of services and products, while also providing the City with vital sales tax revenue. Outreach and education targeted towards the business community is vital in reducing economic losses brought about by flood events. The City should focus on educating and collaborating with the Lynnhaven business community to create continuity plans and emergency operations. The City can also educate businesses on the importance of flood insurance to cover the losses and help businesses regain their footing following a flood event. The City can also work with the Department of Economic Development to help foster conversations and bring additional awareness about flood risks to the business community.

Coordination efforts for advance these activities can be made through the various business organizations in the City. In fact, the City has already met and discussed the SLR and flooding issues with several such organizations, including the Bayfront Advisory Commission, Minority Business Council, the Realtor's Association, and others.

COST

$$$$

TIMELINE

near-term mid-term long-term

BENEFITS

- Reduce vulnerability of industrial and commercial businesses to flood risks

Lynnhaven Watershed

Flood Insurance Expansion

Flood insurance serves as a valuable backstop, helping families and businesses to recover faster from a flood event. The Lynnhaven, positioned at the mouth of the Chesapeake Bay with numerous waterways, has a lower insurance penetration rate than the Oceanfront Watershed. Lynnhaven boasts an 11% insurance policy penetration rate, which is the same as the overall City-wide penetration rate but significantly lower than the Oceanfront Watershed at 25% policy penetration.

In addition, the Lynnhaven has slightly over 50% penetration within Special Flood Hazard Areas (SFHAs), compared to Oceanfront's 85%. These statistics offer a solid case for increased expansion, education, and awareness around the importance and value of flood insurance, not only for homeowners, but also businesses and commercial enterprises. The City has a large opportunity to increase policy penetration in Lynnhaven's SFHAs through outreach, engagement, and advertising.

The City should focus on increasing flood insurance penetration within areas in the Lynnhaven Watershed that have the highest residual risk – which is the risk that remains after applying a flood insurance deductible. The most under-insured neighborhoods in the Lynnhaven Watershed today include:

- Ocean Park
- Princess Anne Plaza
- Lynnhaven Colony
- Windsor Woods
- Cape Story by the Sea

COST

$$$$

TIMELINE

near-term mid-term long-term

BENEFITS

- Provide Community Rating System benefits for the City
- Allow residents and businesses to recover faster following a flood event

FLOOD INSURANCE STATISTICS

- 53% coverage inside Special Flood Hazard Area
- 7% coverage outside Special Flood Hazard Area
- 3,993 total claims
- $ 239.4 million total losses reported from claims

Lynnhaven Watershed

Residential Community Education

The Lynnhaven River has long been a focus of local non-profits. These community and grassroots organizations have dedicated themselves to educating the public regarding the importance of the health of the Lynnhaven Watershed.

Through their efforts, numerous community education programs have been created. These programs not only raise concerns about habitat and water quality, but also educate residents on the impacts of sea level rise and changing conditions within the watershed.

The City is well positioned to continue to collaborate closely with these programs, providing support through both visibility and funding.

Many of these programs partner with Lynnhaven area schools and have been very successful in involving kids and young adults in restoring the health of the Lynnhaven Watershed, as well as educating people on the role that plants and nature based assets can play in flood reduction.

Due to the large number of residential waterfront homes in this area, Virginia Beach has a unique opportunity to continue outreach and education regarding the importance and benefits of living shorelines and encourage community members to think about converting hard infrastructure into nature based solutions.

COST

$$$$

TIMELINE

near-term mid-term long-term

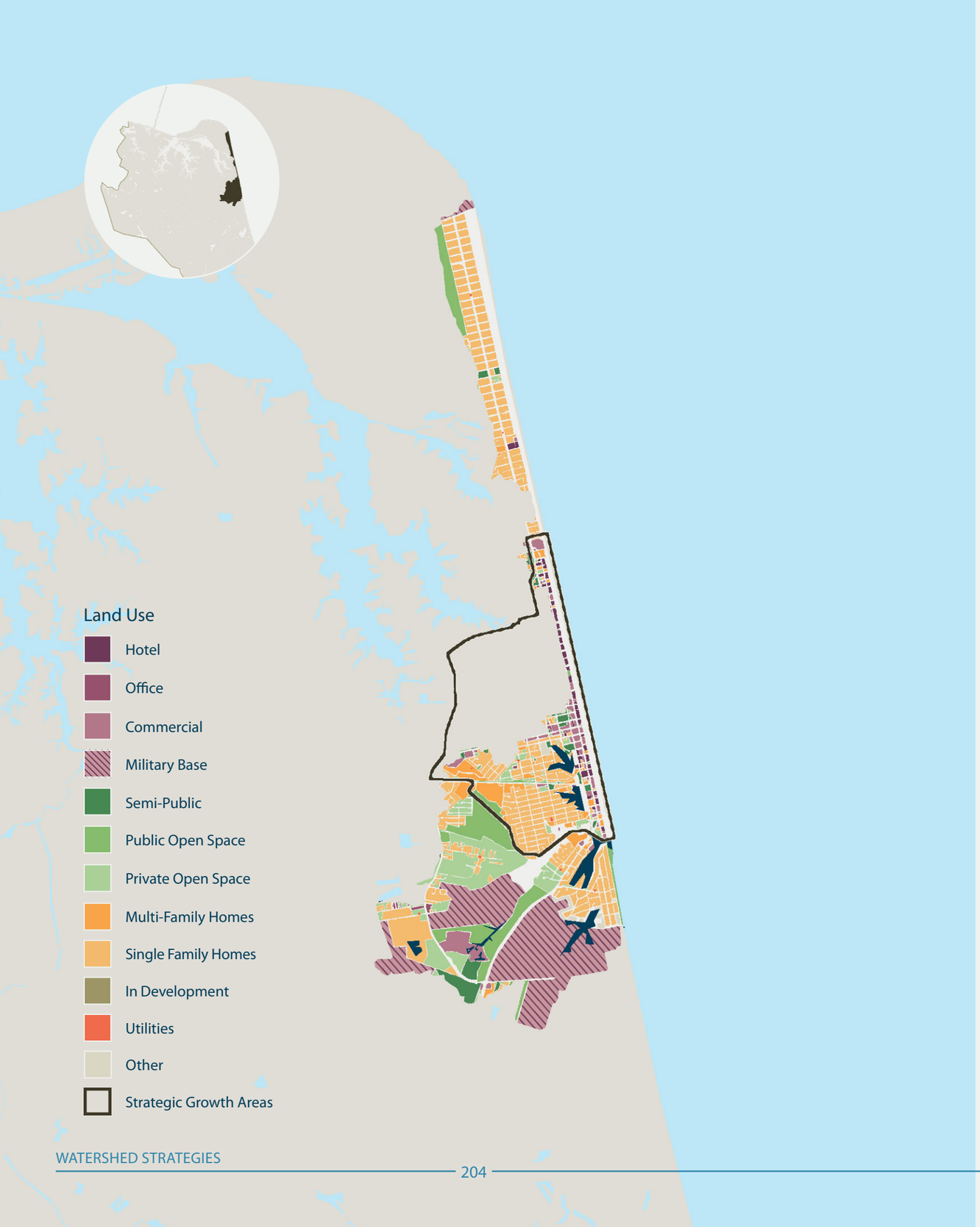
BENEFITS

- Enhance community awareness of flood issues
- Encourage a better understanding of the impact that green infrastructure plays in flood mitigation

OCEANFRONT

At 5.5 square miles, the Oceanfront is the smallest watershed in the City but provides invaluable economic growth from the tourism industry. The watershed is densely developed with both residential and commercial establishments. In 2017, this area underwent re-zoning and integrated a form-based code system to make both residential and commercial development easier.

The City has dedicated substantial resources to improving this area in order to build upon the tourism, retail, and convention-centered business. While this area is dedicated to economic growth, the residents of the Oceanfront Watershed are acutely aware of the risks of both sea level rise and storm events. 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.



Oceanfront Watershed

Community Context

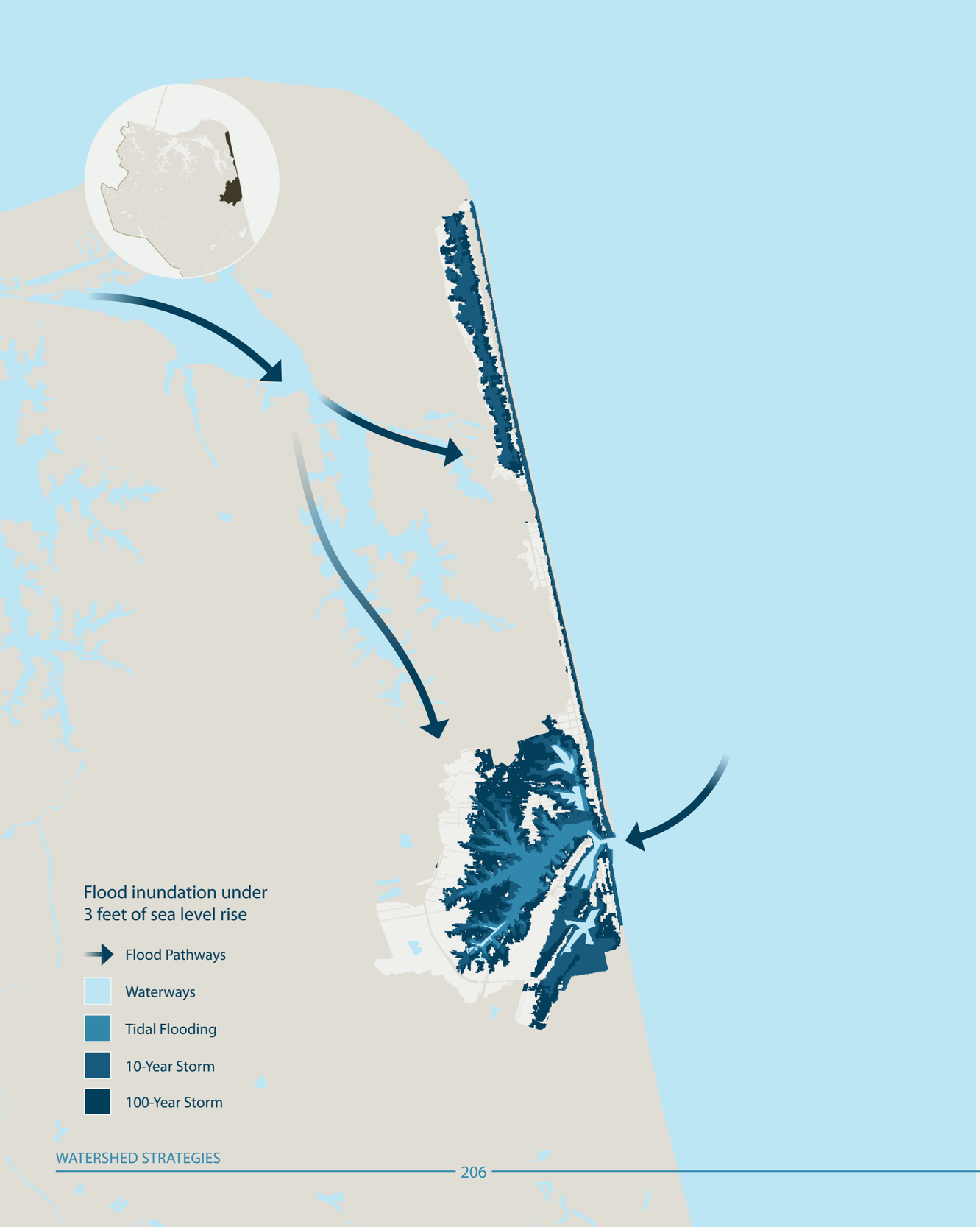
Waterways: The Oceanfront Watershed faces the Atlantic Ocean. Rudee Inlet creates a tidal estuary into Lake Rudee, Lake Wesley, and Owls Creek.

Natural Resources: The Oceanfront Watershed borders the Atlantic Ocean and is the core of the tourism industry in Virginia Beach. This area, though focused on tourism and commercial activity, still has important natural resources. The restoration and conservation of the beach and dune system is critical to attracting and maintaining beach-goers and providing a natural buffer from powerful wave action and storm surges. The beaches in this area are expanding, due mostly to nourishment activities. Along with wide beaches, the Oceanfront Watershed is also home to a tidal estuary because of Rudee Inlet. While a small tidal estuary, Lake Rudee, Owl's Creek, and Lake Wesley provide an amazing place for wildlife, surrounded by salt marshes and tidal flats. Given the influx of salinity from the Atlantic Ocean, this tidal estuary is also home to underwater oyster reefs and a variety of other habitats and species. Residents are able to access views of these natural resources by driving over General Booth Boulevard or walking along the pedestrian South Beach Trail. The Virginia Aquarium and Marine Science Center is located along Owl's Creek and provides educational opportunities to learn about the watershed's important natural resources.

Residential Population: Although the Oceanfront Watershed is heavily occupied by commercial businesses, there is a residential population of 15,650 with almost 9,500 housing units. Of these housing units, 40% are owned, 36% are rented, and 24% are used as vacation homes. The median household income is $70,244, which is the highest in the City[29], and boasts the highest per capita income of $48,701. Community members who reside in the Oceanfront Watershed are predominantly white, at 78%, with the black population at 12%, and the Hispanic population at 9%, and 1% other. Over 50% of residents have a college degree or higher. [30]

Economic Industries: The Oceanfront Watershed is home to Virginia Beach's tourism industry, and is a huge economic and tax revenue driver for the City. The services, construction, and finance/insurance industry are the main employers of residents. While the Oceanfront Resort Area commands a significant portion of the tourism industry, the North End is also a popular stop for visitors with numerous condos and vacation rentals for tourists and short-term renters. The military also has a strong presence in this watershed. Camp Pendleton is located entirely within the watershed, and Dam Neck Annex extend into the southern portion of the watershed.

Strategic Growth Areas: The Oceanfront Watershed is home to the Resort SGA. This SGA is vital to the community's economic prosperity and tax base, and is home to the travel and tourism industry. Over 6 million people stay overnight here annually.[31] This area is dominated by retail and corporate office space and is home to the Virginia Beach Convention Center. In 2015, the City designated the ViBe Creative District, which is a zoning boundary to promote the arts, culture, and technology in an area dedicated to creativity where artisans can both live and work. Additionally, the Virginia Beach Sports Center will be opening in 2020. This area, like the other seven SGAs in the City, will continue to be a center for growth and development for years to come.



Oceanfront Watershed

Flood Pathways and Extents

Pathways: The Oceanfront Watershed used to face flood risks directly from the Atlantic Ocean. With a narrower beach and lower seawall, storms were able to overtop these protections. Such was the case during the Ash Wednesday storm in March 1962. Since reconstruction of the Resort Area seawall and continued beach nourishment, the oceanfront is now protected from all but the most extreme flood conditions. Such is the case even with conditions for a 3 ft sea level rise scenario. Coastal flood risk is controlled by floodwaters entering into the City, and flanking the existing oceanfront protection. The Rudee and Lynnhaven Inlets are the key gateways to floodwaters for the Oceanfront Watershed. Waters entering Rudee Inlet propagate into Lake Rudee, Lake Wesley and surrounding areas. Coastal floodwaters may also enter into the Oceanfront Watershed from the Southern Watershed. This can occur during relatively extreme events, as floodwaters from the Back Bay travel north beyond Dam Neck Road and merge with flooding originating from Rudee Inlet.

Tidal Flooding: With 3 feet of sea level rise, less than a square mile of land is expected to be permanently inundated during high tide. Most of this land is undeveloped.

10-Year Storm: During a moderate storm event, flooding originating from Little Neck Creek from the Lynnhaven can begin to enter the Oceanfront Watershed. Less than a square mile of land is impacted today. With 1.5 feet of sea level rise, flooding can reach further into the watershed and bypass Laskin Road. A large storm event with 3 feet of sea level rise could result in even more extensive flooding, expanding into an additional 1 square mile of land and extending south to I-264. Further south, flooding also increases in the lowest lying areas directly adjacent to Lake Rudee, Lake Wesley, and Owls Creek.

100-Year Storm: 3 foot sea level rise scenario where 2.4 square miles of land become at risk of flooding. Coastal floodwaters entering at the Lynnhaven Inlet can travel through Long Creek and Linkhorn Bay to flood the backside of the Oceanfront through Crystal Lake and Little Neck Creek. Flooding is also expected to reach much further south of I-264 and converge with flooding originating from Rudee Inlet. Further south, coastal floodwaters from Back Bay travel north beyond Dam Neck Road and merge with flooding originating from the south side of Rudee Inlet through Lake Wesley, resulting in a convergence of all three flood pathways.

Oceanfront Watershed

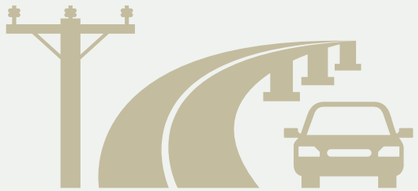
Notable Impacts

Impacts on Buildings

Today in the Oceanfront Watershed, nearly 500 buildings are exposed to flood risks. With 3 feet of expected sea level rise, that number jumps to over 3,500, with building, contents, and displacement costs equaling $8.8 million in annualized losses. While this number is lower than the other three watersheds, the relatively small size of the Oceanfront Watershed combined with its importance as a center for both tourism and retail would make these losses deeply felt within the City.

Flood Exposure of Buildings

	Now	1.5 ft SLR	3 ft SLR
# Buildings	478	1,422	3,512
# Residents	4,744	9,641	12,953
Expected Building, Content, and Displacement Costs	$272,800	$1.31M	$8.83M



Impacts on Infrastructure

Today, there is are no community facilities and less than a mile of critical evacuation routes that are exposed to coastal flood risks. With three feet of sea level rise, 4 facilities and more than 5 miles of evaluation routes become threatened by coastal flooding.

Vulnerable Critical Facilities

	Now	1.5 ft SLR	3 ft SLR
Police Stations	0	0	1
Fire Stations	0	0	1
Schools	0	1	2
Miles of Critical Roads	0.8	2.2	5.4

Impacts on Habitats

Some coastal habitats are able to keep pace with sea level rise or migrate into undeveloped areas whereas other habitats are at risk of being lost due to drowning or being blocked by development. Towards the end of the century, 3 feet of sea level rise will likely increase the footprint of open water in the Oceanfront Watershed by 18%. This expansion in open water will have significant impacts on coastal wetlands surrounding the river. The analysis of habitat vulnerability showed that 36% of grass marshland and 2% of woody wetland habitats could be lost. Tidal flats could increase by 82% due to conversion of these habitats.

Changes in Acres of Habitat

	Now	1.5 ft SLR	3 ft SLR
Woody Wetlands	265	260	260
Grass Marsh	53	53	34
Tidal Flat	8	5	14
Open Water	208	223	246

Impacts on People

Today nearly 5,000 residents live in homes vulnerable to flooding, but that number could triple as sea level rise leads to an expanded floodplain. By the end of the century, nearly 13,000 people in the Oceanfront Watershed could be exposed to coastal flood hazards. Out of those residents exposed to future flooding, over 50% many may experience increased vulnerability due to physical and socioeconomic factors. These populations may require greater assistance and support from the City regarding supporting mitigation and preparedness.

Vulnerable Populations Exposed to Flooding

	% Today	% at 1.5 ft SLR	% at 3 ft SLR
People of Color	7%	40%	62%
Children (<5)	15%	52%	67%
Elderly (>65)	45%	61%	78%
Institutionalized	0%	100%	100%
Limited English	32%	62%	80%
Limited Income	16%	50%	71%
Disabled	22%	53%	74%

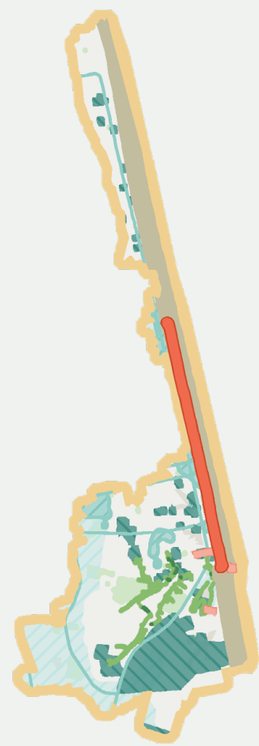
Oceanfront Watershed

Adaptation Vision

The Oceanfront Watershed is one of the most prepared watersheds in the City in regards to sea level rise and changing rainfall levels. Though it is the smallest watershed, it plays an integral role in the economic growth and development of the City. It is a tourist hot spot and is home to a significant number of commercial enterprises and business, including the Virginia Beach Convention Center.

Residents in this area, particularly within the FEMA floodplain, have a very high level of insurance coverage and even those outside of the FEMA floodplain still have a very high penetration rate. Despite the high level of preparedness in this community, sea level rise and Atlantic based storms will continue to impact this area.

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.



Natural Mitigations

- Beach and Dune Nourishment
- Ecological Revetments
- Land Conservation
- Marsh Restoration and Creation
- Shellfish Reefs and Oyster Restoration

Engineered Defenses

- Atlantic Oceanfront City-Wide Alignment
- Rudee Heights Neighborhood Alignment

Adapted Structures

- Commercial Floodproofing
- Floodplain Regulation
- Mitigation Reconstruction
- Resilient Roadways
- Responsible Development
- Structure Elevation

Prepared Communities

- Business Community Education
- Flood Insurance Expansion

Oceanfront Watershed

Beach and Dune Nourishment

The Oceanfront beach has undergone extensive beach nourishment over a number of years. This has consisted of sand being pumped onto the beach to increase the width and depth of the beach.

Nourishment of the Oceanfront Watershed beaches began in the 1950s, using sand that was dredged from other areas around Virginia Beach, and redone every 4-5 years. In 2001 the implementation of the beach restoration component of the Virginia Beach Erosion Control and Hurricane Protection project was enacted, which led to the beaches in this area to be replenished from offshore areas. The last beach nourishment in the Oceanfront area was in the summer of 2019. The $22 million dollar project was funded with a combination of funding from Virginia Beach and the federal government.

The City should continue to support these efforts, which though expensive, have seen a strong return on investment. USACE Nofolk has stated that the beach nourishment program has saved $450M in damages over a course of 10 years.[32]

COST

$$$$

TIMELINE

near-term mid-term long-term

BENEFITS

- Expanding the width of beaches and increasing recreation areas.
- Offering enhanced protection storm events.
- Accelerated dune growth and habitat enhancement.

Oceanfront Watershed

Ecological Revetments

Rudee Inlet leads into Lake Rudee and Lake Wesley. There are opportunities within the northern portion of the lake for the City to incorporate revetments (much like a retaining wall or barrier). These planted revetments could be a potential mitigation tactic throughout the broader watershed, especially in open water.

In addition, the City could explore renovating traditional revetments to incorporate different materials and add forms of vegetation that could grow on top of or over the structure. This mitigation tactic will incorporate aspects of a living shoreline into existing structures, and will mitigate the impacts of sea level rise and flooding, but also benefit water quality and provide fish and wildlife habitats.

COST

$$$$

TIMELINE

near-term mid-term long-term

BENEFITS

- Reduce the impacts of sea level rise and flooding
- Potential to reduce the intensity of waves
- Enhance fish and wildlife habitats
- Bolster water quality
- Aesthetically pleasing and reduces the visibility of hardened structures

MARSHVIEW PARK

Marshview Park in a hundred-acre park nestled between several neighborhoods along the banks of Owls Creek, which connects with Lake Rudee.

Oceanfront Watershed

Land Conservation

The Oceanfront Watershed has 2.2 square miles of conserved land, the majority of which is owned by the military. There are several city-owned park properties that serve to maintain open space and provide public access to the natural landscapes, especially surrounding the Rudee Inlet tidal estuary. There is an opportunity for private waterfront landowners to conserve additional open space through a conservation easement. A conservation easement would be a voluntary option for residents or even commercial property owners. By conserving open space, vital natural assets to the community will be preserved for future generations, while ultimately helping to absorb flood waters and precipitation.

This Oceanfront Watershed only has two properties that are cost effective for voluntary acquisition. This would be extremely expensive, due to the high cost of real estate in this area. The average protection cost per parcel would be $1,716,500, and is an expensive option at $3.43 million cumulative acquisition costs, but could provide important open space to accommodate coastal flooding.

COST

$$$$

TIMELINE

near-term mid-term long-term

BENEFITS

- Create additional open space land
- Enhance the green infrastructure network and bolster the naturalized landscape
- Provide additional recreational space for watershed residents
- Relocates owners from high-risk properties

Oceanfront Watershed

Marsh Restoration and Creation

Almost the entirety of Lake Rudee, which opens to the Atlantic Ocean through Rudee Inlet, is a candidate for marsh restoration. The area around the lake is a thriving ecosystem that plays host to numerous species and their habitats. The ecosystem boasts an impressive array of bird species such as loons, osprey, and eagles.[33] Reptiles, fish, oysters, and even the occasional manatee inhabit or visit the area.

Marsh restoration throughout these shorelines will increase the habitat areas, bolster the green infrastructure network within the Oceanfront Watershed, and provide additional flood protection.

COST

$$$$

TIMELINE

BENEFITS

- Enhancing habitats and fostering diverse species
- Improving water quality
- Reducing flood risks
- Bolstering the shellfish and oyster industry / commercial and recreational fishing

Oceanfront Watershed

Shellfish Reefs and Oyster Restoration

Lake Rudee is home to ongoing oyster restoration programs, many of which have been funded by non-profits such as the Rudee Inlet Foundation. The Foundation has partnered with the Virginia Aquarium to fund the first installation of a sanctuary oyster reef in 2015. The Owls Creek Oyster Reef is one of many planned restoration projects that will increase the quality of water and promote habitats in the Oceanfront Watershed. The City could further support these efforts with additional funding and support.

COST

$$$$

TIMELINE

BENEFITS

- Restoring habitats and species
- Improving water quality
- Bolstering the shellfish and oyster industry / commercial and recreational fishing

Oceanfront Watershed

Atlantic Oceanfront City-Wide Alignment

The Atlantic Oceanfront alignment consists of three main elements - a storm surge barrier at Rudee Inlet, extension of the boardwalk seawall, as well as increasing the elevation of and fortifying dune systems with an engineered core.

Rudee Inlet is a direct source of floodwaters into the flood-vulnerable areas surrounding Lake Rudee and Lake Wesley. To prevent flooding from this source, two of the three structural defense alternatives for the City envision a sector gate at the inlet. The conceptual gate would be hinged to the south side of the inlet and tied into the boardwalk seawall to the north, and a fortified dune system to the south. Use of a sector gate would accommodate the needs of the federal navigation channel. The gate would have a design elevation of approximately 18 feet (NAVD88 datum). This elevation may increase when considering the effects of wave runup and overtopping.

As mentioned, tie-in structures would be established to integrate the gate with the boardwalk seawall to the north. This is conceptualized as a short curb wall in lieu of the current fence. Sliding or swinging gates would allow beach access and the walkways.

This configuration is similar to the seawall at Ocean City, Maryland. The original USACE design incorporated a similar curb wall element, which was removed during the design process. South of Rudee Inlet, the surge barrier would tie into a seawall complex around the gate itself, which would then transition to natural dunes to the south. The design requires elevating the dunes to approximately 14 feet (NAVD 88 datum), including fortification of the dune cores with sheet pile or rubble mound to meet federal certification requirements and decrease flood insurance rates.

The estimated project costs for this system are $282 million.

COST

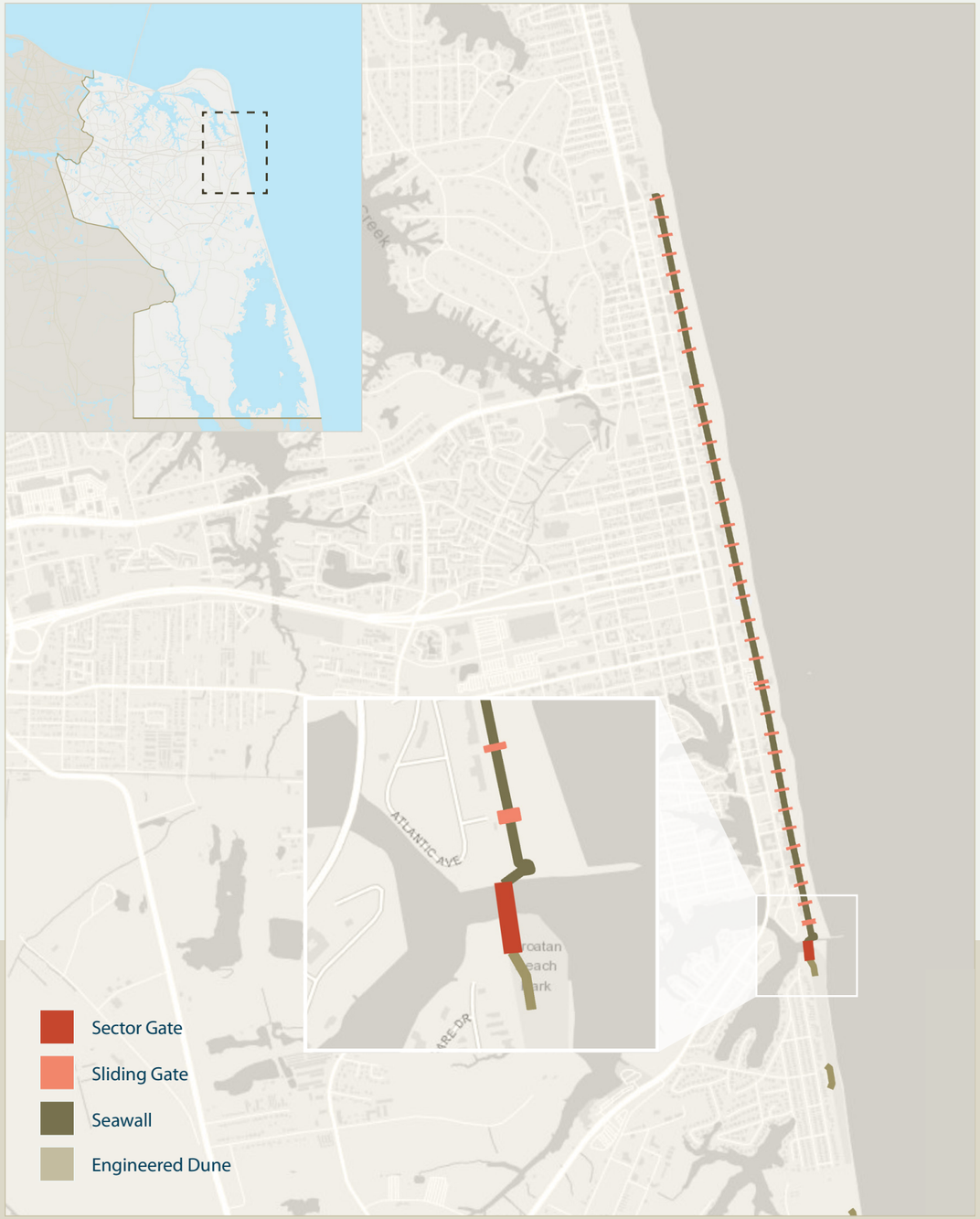
$$$$

TIMELINE

near-term mid-term long-term

BENEFITS

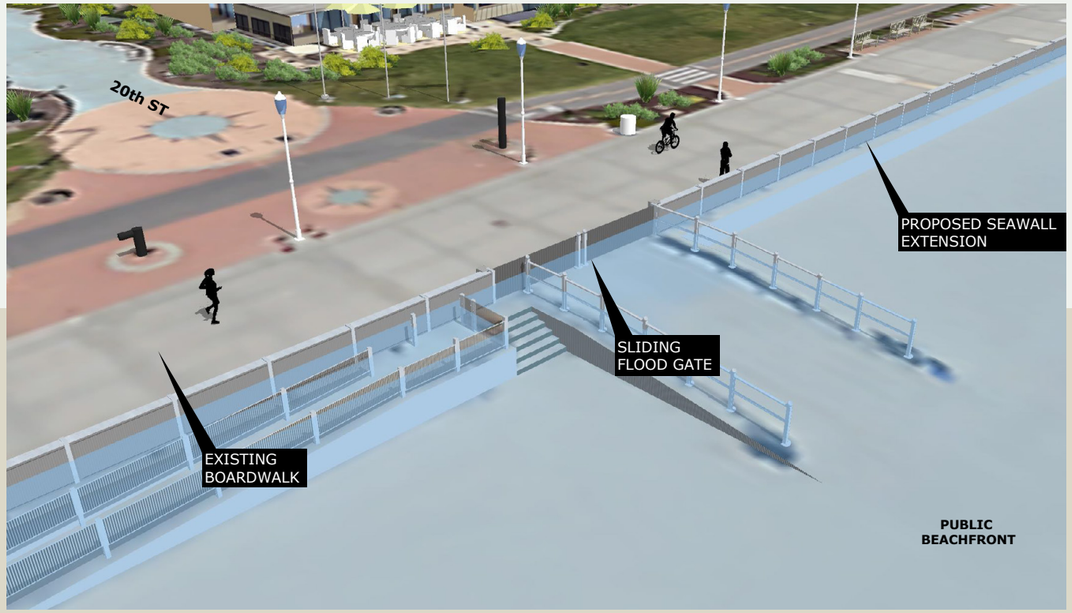
- Leverages existing protection in boardwalk area
- Leverages natural features south of inlet
- Flood insurance policy rate decreases in protected area
- Protects resort area from flood impacts, especially important economic development areas
- Maintains tax base
- Avoids and reduces damages to property



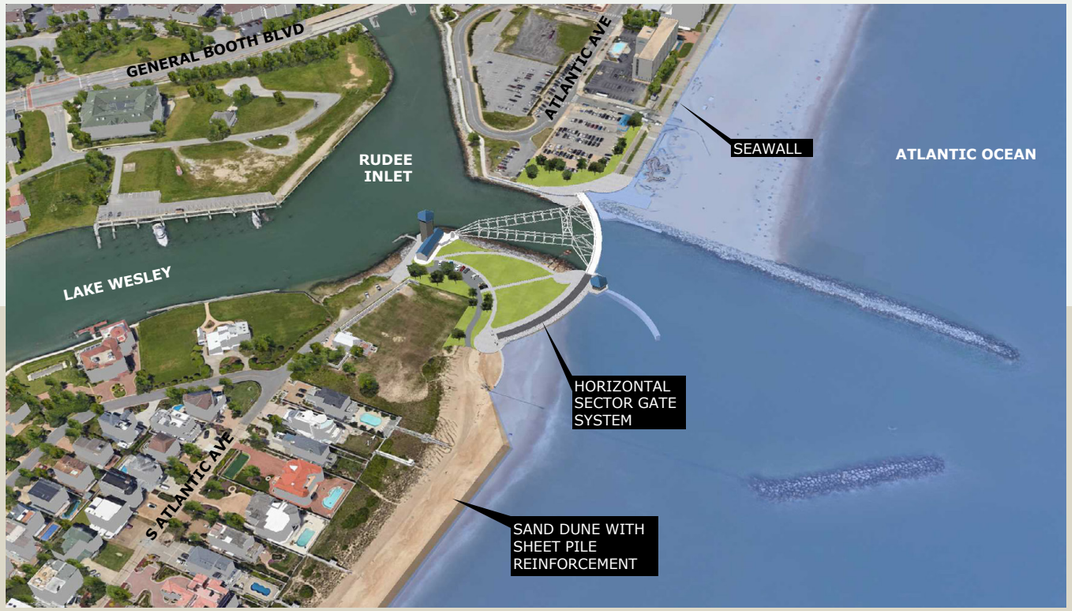
Atlantic Oceanfront alignment with seawalls, sliding gates, sector gate, and dunes.

Atlantic Oceanfront existing conditions

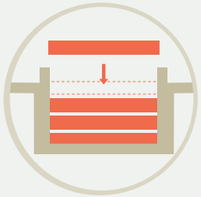
Rudee Inlet existing conditions



Atlantic oceanfront structural protection system under flood condition



Rudee Inlet structural protection system under flood condition



Oceanfront Watershed

Rudee Heights Neighborhood Alignment

Flood protection could be provided to a lesser degree, at a lower design level, to address higher frequency coastal storm surge and short-term increases in sea level rise. Rudee Inlet and Little Neck Creek are two locations that can serve as flood pathways for sea level rise and more common coastal storm surge events that inundate major commercial corridors and residential communities that surround these locations.

The majority of the residential communities and commercial properties located in the northern section of Rudee Inlet (especially along Lake Rudee and Lake Holly) are vulnerable to flooding from a 3 feet sea level rise combined with very common coastal storms. The communities located in neighborhoods south of Rude Inlet (especially south of Lake Wesley) are vulnerable to flooding from a 3 feet sea level rise combined with stronger, less frequent storms. Floodwaters from these less frequent storms can lead to flooding from Little Neck Creek into the areas located north of the Rudee Inlet. An on-going project at Laskin Road could include roadway improvements such as raising the roadway that could act as a barrier to prevent the intrusion of sea level rise and surge from Little Neck Creek.

The structural flood protection system in the Rudee Heights neighborhood area is broken into two components, one for Lake Rudee, and a second for Lake Wesley. The Lake Rudee system was conceptualized to protect residential and commercial areas between Virginia Beach Boulevard and Lake Rudee from common storm events and 3 feet of sea level rise using a design flood elevation of approximately 8.5 feet (NAVD88 datum). The second component is to protect residential and commercial properties located south of Lake Wesley from less common, stronger storm events and 3 feet of sea level rise using a design elevation of approximately 10 feet (NAVD88 datum).

The Lake Rudee alignment could include a mix of flood protection designs including floodwalls, flood logs at entrances to buildings or roadway crossing, and roadways that can be raised until they intersect with higher ground to ensure flood waters do not bypass the protection system. The Lake Wesley alignment would include raising Croaton Road for approximately 800 feet that will prevent surge and sea level rise intrusion into the Dam Neck area as well. This system is reliant upon another protection measure being construction to prevent floodwaters from the Southern Watershed encroaching north. The flood protection system is estimated to cost $10.8M, out of which $9.7 million is to protect the Lake Rudee neighborhoods and $1.1 million is to protect the Lake Wesley neighborhood. These options would not protect from significant storm events and would not reduce flood insurance policy rates.

COST

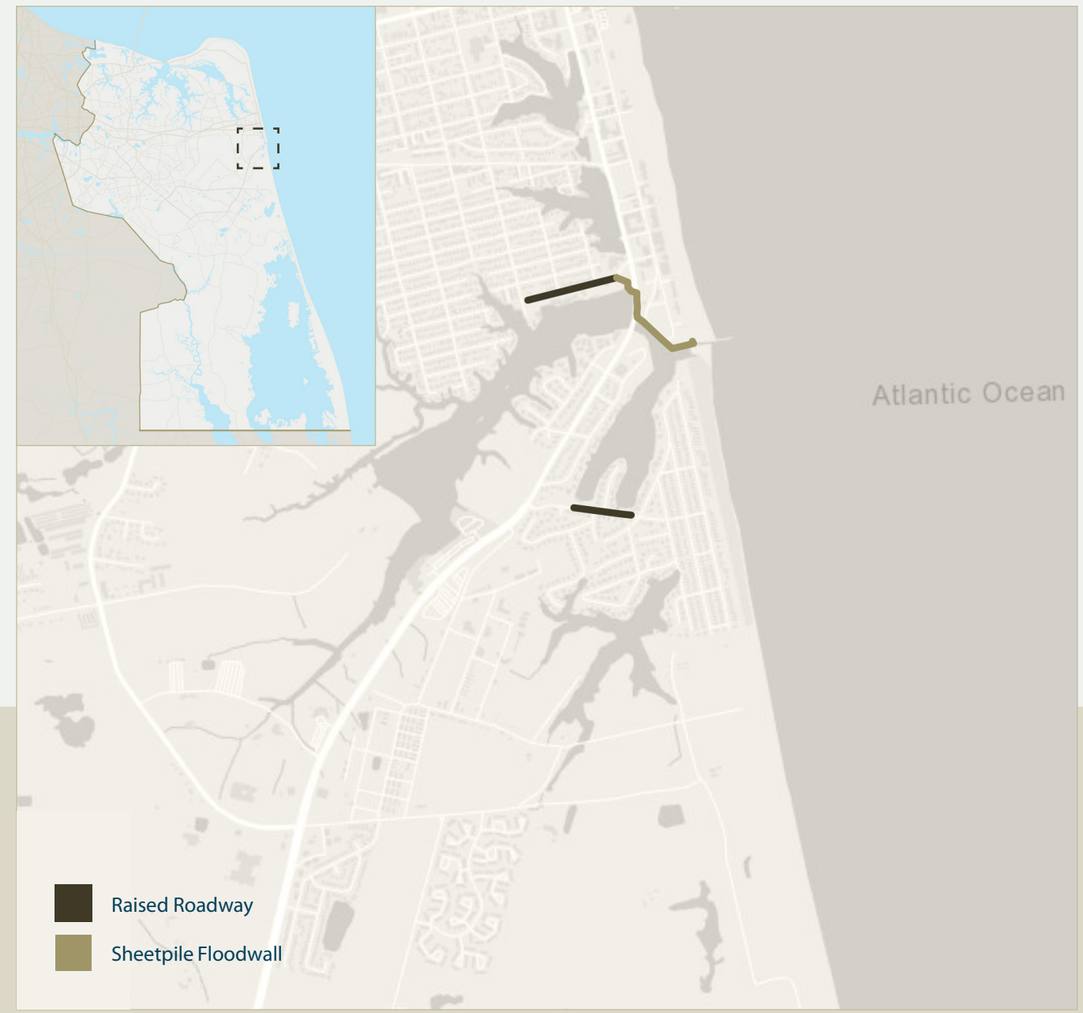
$$$$

TIMELINE

near-term mid-term long-term

BENEFITS

- Leverages natural features to south of inlet
- Protects resort area from common flood impacts, especially important economic development areas
- Maintains tax base
- Avoids and reduces damages to property



Rudee Heights alternative structural protection with raised roadway and floodwall

Oceanfront Watershed

Commercial Floodproofing

Floodproofing was found to be a cost-effective solution for a total of 39 commercial buildings in the Oceanfront Watershed. Floodproofing these buildings ranged from moderately cost-effective to highly cost-effective and would serve to protect the commercial and economic interests of these structures from the impacts of flooding. For some of these structures, both wet and dry floodproofing were found to be a good solution, but the strategy with the higher return on investment is recommended. There are 9 buildings suitable for wet floodproofing that would amount in $332,598 in cumulative costs and 30 buildings suitable for dry floodproofing that would amount to $2,194,801 in cumulative costs.

COST

$$$$

TIMELINE

near-term mid-term long-term

BENEFITS

- Wet floodproofing would result in $613,998 cumulative benefits and a Benefit-cost ratio of 1.8.
- Dry floodproofing would result in $3,713,352 in cumulative benefit and a Benefit-cost ratio of 1.7.

Oceanfront Watershed

Floodplain Regulation

In consideration of sea level rise, the City is exploring changes to the definition of the "regulatory floodplain" which would expand the area regulations apply to, to either the 500-year floodplain or the "future 100-year floodplain". These changes to floodplain regulations across the City would impact development in areas that fall within this new regulatory floodplain.

Under an expanded "future 100-year floodplain" with 3.0 feet of sea level rise, there would be an additional 2.0 square miles in the regulatory floodplain.

COST

$$$$

TIMELINE

near-term mid-term long-term

BENEFITS

- Reduced vulnerability to flood risks for new development and substantial redevelopment
- Safer long-term growth
- Preservation of life and property

Oceanfront Watershed

Mitigation Reconstruction

Similar to eligible structure elevations, the Oceanfront Watershed has a handful of residential structures that may be eligible for demolition and rebuild. There are 39 residential properties where mitigation-reconstruction would be both beneficial and cost effective, which is the second lowest out of the four watersheds. Once demolished, these homes could be rebuilt using either 2 or 3 feet of freeboard depending on changes to the zoning ordinance.

The total project costs if all 39 structures were demolished and rebuilt using 2 feet of freeboard would be over $7 million, with an average cost of about $180,000 per structure. This is the middle average protection cost out of the three options (voluntary acquisition, mitigation reconstruction, and home elevations).

While mitigation reconstruction can be more expensive than the voluntary acquisition of property for land conservation purposes, it ensures that community members stay in their communities, and helps to maintain a consistent tax base.

It is important to note that alternative strategies such as voluntary acquisition and home elevation could also be considered in these areas. Moving forward, the City should work with individual homeowners to determine which strategy is the overall best fit.

COST

$$$$

TIMELINE

near-term mid-term long-term

BENEFITS

- Total benefits of $15.5 million
- Benefit-cost ratio of 2.19
- Maintains community relationships
- Maintains tax base
- Avoided and reduced damages to property

Oceanfront Watershed

Resilient Roadways

The vulnerability of Virginia Beach's road network and community assets to flooding should be recognized and addressed by the City's efforts to improve resilience to coastal flooding. The identified roads are essential and represent key conduits for the tourism, service, and defense industries, or accessibility to key community resources such as fire and emergency stations, hospitals, and police stations. In addition to accessibility concerns, some of these community facilities become increasingly vulnerable to damage during storm events. The City should seek to address these vulnerabilities through existing or new road improvement projects.

Routes into the oceanfront resort area—such as Laskin Road, 21st and 22nd Streets—are essential for evacuation, commuting, and the tourism industry. Sections of these roads become increasingly vulnerable to coastal flooding and it will become more difficult to access community facilities. In particular, flooding during storm events with higher sea levels makes it difficult to drive to several schools located between 14th Street and Laskin Road.

Additionally, Pacific Avenue is a critical route that is used for local evacuations during storms and provides access to Joint Expeditionary Base–Fort Story. Virginia Beach Boulevard is also an important local evacuation route. General Booth Boulevard is both an evacuation route and provides access to military installations such as Dam Neck Annex, Naval Air Station Oceana, and Camp Pendleton.

The proposed Atlantic Oceanfront structural protection system would protect these critical routes and access to community assets from coastal flooding. An on-going project at Laskin Road could include roadway improvements such as raising of roadway. The City should explore how the integrated suite of solutions presented within this study, or additional roadway improvements could reduce the vulnerability of these critical routes.

COST

$$$$

TIMELINE

near-term mid-term long-term

BENEFITS

- Reduced risks of flooded critical infrastructure assets such as roads, bridges, and highways
- Increase accessibility to critical community assets
- Increased safety of people and property
- Increased safety of evacuation and emergency response routes

Oceanfront Watershed

Responsible Development

The Oceanfront Watershed is heavily developed with a combination of both commercial and residential properties.

Mitigation options for residential structures in this area is limited and extremely expensive. There are opportunities to make sure that development within the Resort SGA is undertaken with sea level rise and increasing storm surge into account, particularly in regards to infrastructure, stormwater, and commercial properties.

The City should consider putting increased standards on redevelopment, whether that is substantial or not, so that additions and updates to structures will account for sea level rise. The City should also consider singling out higher-risk coastal zone areas as specific floodplain districts. These could include areas within the future floodplain, or those impacted by high energy waves during storm events.

COST

$$$$

TIMELINE

near-term mid-term long-term

BENEFITS

- Building smarter and stronger
- Reducing risks for new and current residents
- Potential for reduced flood insurance costs
- Decrease in flood losses to homes and businesses

Oceanfront Watershed

Structure Elevation

There are 66 residential properties where home elevations would be both beneficial and cost effective. Of all the watersheds, Oceanfront has the second lowest number after the Elizabeth river. These homes could be elevated using either 2 or 3 feet of freeboard depending on changes to the zoning ordinance.

The total project costs if all 66 structures were elevated using 2 feet of freeboard would be over $12 million, with an average cost of about $183,000 per structure. This is the lowest average protection cost out of the three options (voluntary acquisition, mitigation reconstruction, and home elevations). This strategy is highly effective at reducing the risk to homeowners from flood events, but it can take years to find funding and grants to help homeowners pay to elevate a home.

While these structural elevation opportunities are not as plentiful as other watersheds, such as Lynnhaven and Southern Rivers, they are clustered in areas that would reduce risk to oceanfront residents. Moving forward, the City should work with individual homeowners to determine which strategy is the overall best fit.

COST

$$$$

TIMELINE

near-term mid-term long-term

BENEFITS

- Total benefits of $26 million
- Benefit-cost ratio of 1.99
- Maintains community relationships
- Maintains tax base
- Avoided and reduced damages to property

Oceanfront Watershed

Business Outreach and Education

The resort industry that dominates the Oceanfront Watershed is a unique opportunity for the City to engage the business community in terms of sea level rise awareness, preparedness, and mitigation.

While historically, the City has focused on residential outreach and education, the City understands the value to recovery and economic resilience that comes from businesses, industries, and private utilities who are prepared for and mitigate against flood events. There is ample opportunity to reach out to commercial businesses, especially those outside the SFHA who believe their risk of flooding is low, to educate them on their risk and vulnerability to flood events and sea level rise.

Coordination efforts for advance these activities can be made through the various business organizations in the City. In fact, the City has already met and discussed the SLR and flooding issues with several such organizations, including the Resort Advisory Commission, Minority Business Council, the Realtor's Association, and others.

COST

$$$$

TIMELINE

near-term mid-term long-term

BENEFITS

- Enhanced community awareness of flood issues
- Better understanding of the impact that green infrastructure places in flood mitigation

Oceanfront Watershed

Flood Insurance Expansion

Flood insurance serves as a valuable backstop, helping families and businesses to recover faster from a flood event. The Oceanfront Watershed faces the Atlantic Ocean. Residents and businesses here are well aware of the threat posed by storm events, storm surges, high tides, and sea level rise.

This area boasts the highest penetration of flood insurance of any of the four watersheds. That being said, there is still opportunity to increase penetration, especially in the Resort Area and the North End.

An increased focus on insurance penetration in the business community, while encouraging mitigation and continuity planning will be beneficial for this area.

COST

$$$$

TIMELINE

near-term mid-term long-term

BENEFITS

- Provides CRS benefits for the City
- Allows residents and businesses to recover faster following a flood event

FLOOD INSURANCE STATISTICS

- 85% Coverage inside Special Flood Hazard Area
- 22% Coverage outside Special Flood Hazard Area
- 283 Total claims
- $ 2.6 million total losses reported from claims

Oceanfront Watershed

Residential Community Education

The Oceanfront Watershed is home to a wide range of residents that bring both demographic and cultural diversity to the community.

Education regarding flood risks and how to mitigate flooding at home is vital to reducing the risk of the watershed as a whole, but especially the risk of vulnerable community members.

The Oceanfront Watershed has numerous community gathering places such as public schools, community and recreational centers, and city parks. These community assets are well positioned to provide flood risk education throughout the watershed. The City should continue to partner with non-profits such as the Virginia Beach Aquarium and Marine Science Center Foundation to do educational outreach to kids and young adults regarding marsh restoration, living shorelines, and the importance of natural assets – not only for beautification purposes but also for flood risk reduction benefits.

Flood education can be conducted from the perspective of helping individual homeowners and renters in Oceanfront understand the risk to their structures, properties, and contents (such as what flood zone is your home located in?). Alternatively education can take the form of mitigation actions to help reduce the flood risk overall, or even go so far as to educate the public on what to do in the case of a flood.

All of these components can be highlighted through various outreach and engagement channels, which provide benefits to the entirety of the City.

The City should ensure that outreach is accessible to vulnerable populations, whether that takes the form of printing materials and providing information in languages other than English or crafting materials that provide benefits to community members with specific disabilities such as hearing or eyesight impairment.

COST

$$$$

TIMELINE

near-term mid-term long-term

BENEFITS

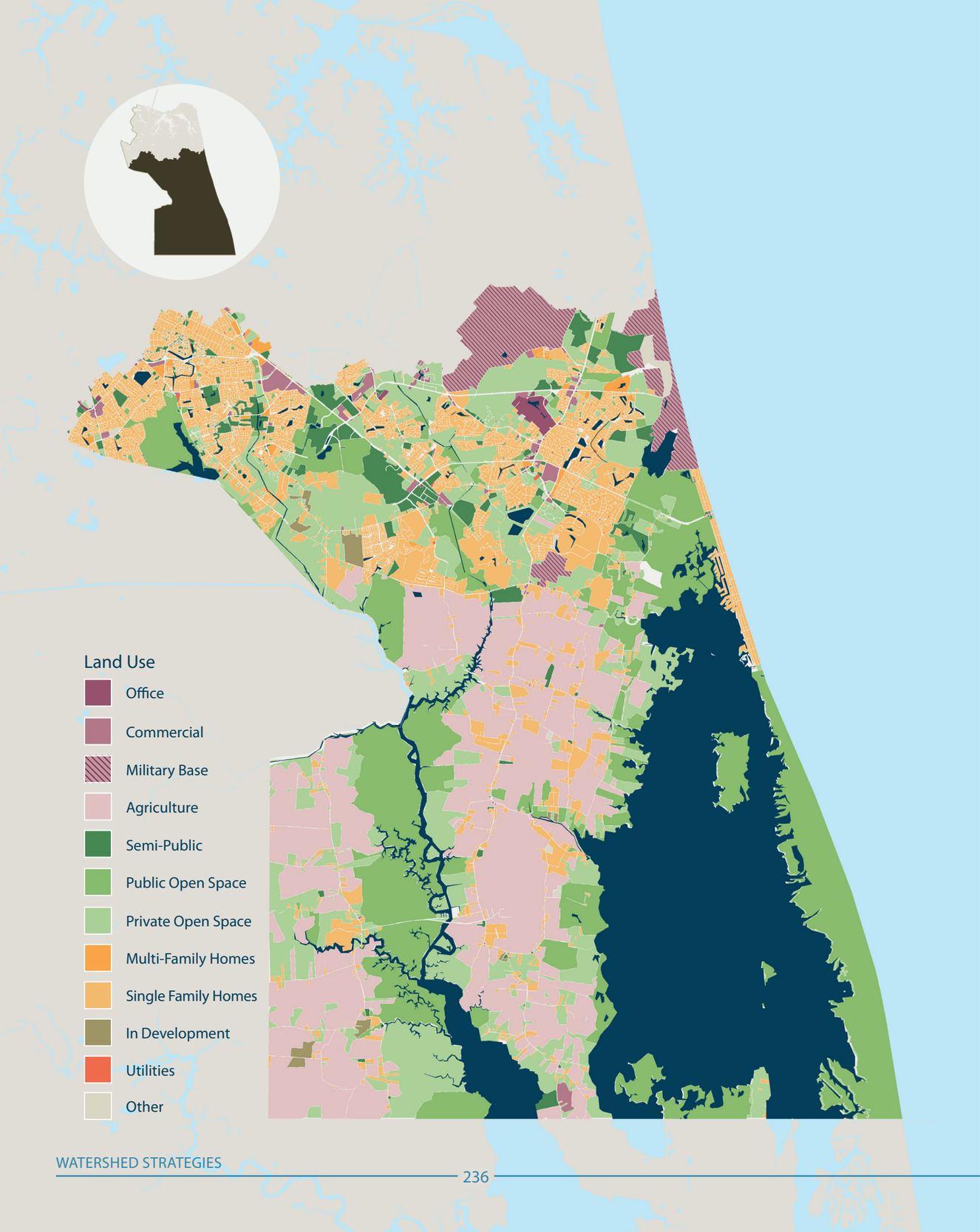
- Enhance community awareness of flood issues
- Encourage a better understanding of the impact that green infrastructure plays in flood mitigation

SOUTHERN RIVERS

The Southern Rivers Watershed is the largest watershed in Virginia Beach, encompassing more than 205 square miles, which represents more than 67 percent of area within the City limits. The Southern Rivers Watershed shares its borders with the City of Chesapeake to the west and the state of North Carolina to the south. The Southern Rivers Watershed has significant environmental, ecological, and economic value because it is home to distinctive rural community, the City's agricultural industry, important rivers and canals for navigation, and large expanses of parks and protected land that extend south to North Carolina. Tucked away along the barrier island, the Southern Rivers Watershed is also home to the Sandbridge resort area which attracts visiting tourists and permanent residents that enjoy a unique beach-front community.

The Southern Rivers Watershed has the largest amount of low-lying land in the City, representing more than 90% of land area in the City under an elevation of 3 feet, which make it particularly susceptible to repetitive coastal flooding during times when winds blow from the south for several days. This type of flooding, referred to as "wind tide flooding", can block roads and access to community facilities, and degrade resident's quality of life. Investments have been made in water level gauges and sophisticated computer models to better understand wind-driven flooding.

Residents and businesses in the Southern Rivers Watershed have a long history of living with water and combating coastal flooding. The earliest observations of flooding date back to the early 1900's, where farmers claimed that flooding resulted in annual damages of thousands of dollars.[34] The frequency and intensity of these events will increase with sea level rise. With five large-scale wind-driven flood events occurring in the last two years, both residents and stakeholders have a right to be concerned. Analysis completed by the City identified that loss of marsh and aquatic vegetation is partially responsible for increased flooding. 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.



Southern Rivers Watershed

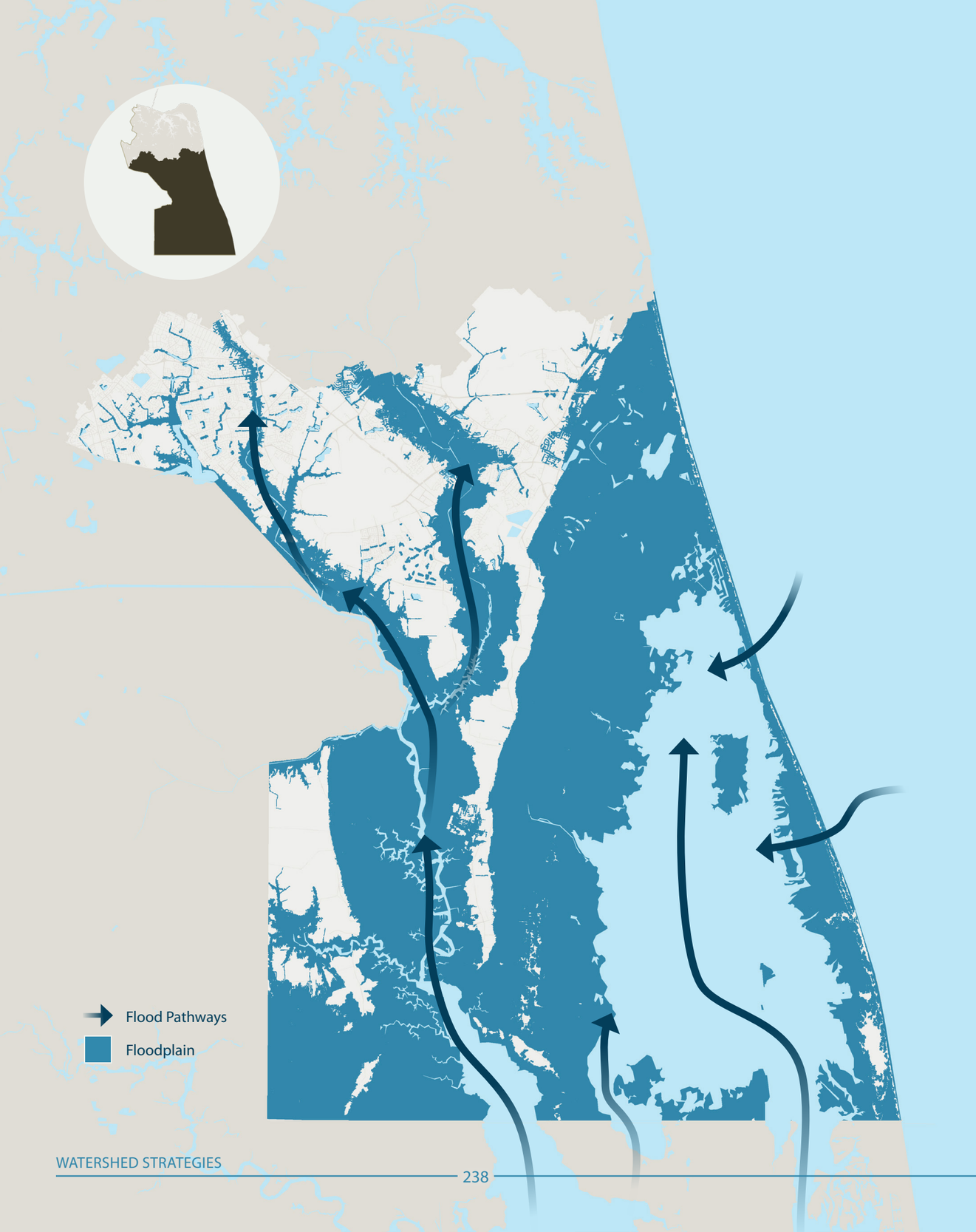
Community Context

Waterways: The Southern Rivers Watershed is narrowly separated from the Atlantic Ocean to the east by a barrier island and marshlands. To the west, it is bounded by the Albemarle and Chesapeake Canal that connects the upper North Landing River to the Southern Branch of the Elizabeth River in Chesapeake. The watershed is also connected to North Carolina's Currituck Sound by Back Bay and North Landing River. West Neck Creek connects North Landing River to the London Bridge Creek, a tributary of the Eastern Branch of the Lynnhaven River.

Natural Resources: The Southern Rivers Watershed is home to large areas of undeveloped land and natural resources including beaches, dunes, barrier islands, forests, wetland and marshes, and submerged aquatic vegetation beds. The land surrounding Back Bay and North Landing River is owned and protected by various public, private, and nonprofit conservation organizations. The large expanses of protected habitat provide flood attenuation benefits by slowing down the movement of water and stabilizing sediments. This is especially important in Back Bay, during wind tide events, as it reduces the amount of open water over which wind can blow. The natural landscapes in the Southern Rivers Watershed also provide benefits related to recreation and tourism, clean water, and habitat for ecologically diverse plants and wildlife.

Residential Population: The Southern Rivers Watershed is home to a diverse set of residential communities. These range from distinct rural neighborhoods along Back Bay and the North Landing River to the more densely developed resort neighborhoods in Sandbridge along the Atlantic oceanfront. The majority of residential development is concentrated in the northern portion of the Watershed, above the 'Green Line,' an active attempt to control urban sprawl. The watershed's population is 147,744 with 48,550 households. In 2019, the median income was $89,813 with a per capita income of $35,972. Residents are 65% white, 17% black, and 8% Hispanic, with the remaining 10% including all other residential population sections. Regarding ownership, 74% of residents own their home, 20% are renters, and 6% are vacation homes.[35]

Economic Industries: Virginia Beach's agricultural industry, which brings in more than $136 million annually, is concentrated in the Southern Rivers Watershed.[36] Farmland and pastures comprise more than 40 square miles of land area and support over 200 farms and farm-related businesses that contribute to the environment, quality of life, and economy of the City and the region.[37] Tourism is also a significant driver of the local economy as the numerous local, state, and federal parks attract locals and tourists to engage in recreational activities such as boating, hunting, and fishing. In northern areas there are several commercial centers focused on retail and recreation services, including City park facilities, golf courses, and public trails in roadside buffers.



Southern Rivers Watershed

Flood Pathways

The two key flood entry points into the Southern Rivers Watershed are Back Bay and the North Landing River. Southerly winds move water up from Currituck Sound in North Carolina into Back Bay and the North Landing River. Sustained southerly winds over multiple days can cause flooding, or flooding can occur as tropical storms or hurricanes track across the area. The amount of flooding depends on the wind direction, speed, and duration, soil saturation conditions, and whether it rains at the same time. Sustained wind conditions over multiple "sunny" days can cause as much flooding as the wind associated with a hurricane.

Coastal floodwaters can also enter the Southern Rivers Watershed from the Oceanfront – for example, during a large event, such as a hurricane, waters from Rudee Inlet can overtop land and propagate south into the upper Back Bay area. Similarly, severe flood conditions in the Back Bay can push floodwaters into the Oceanfront Watershed.

Although the Albemarle Chesapeake Canal provides a connection between the upper North Landing River and the Southern Branch of the Elizabeth River in Chesapeake, it is not a significant flood pathway into southern Virginia Beach. The Great Bridge Lock is located about 20 miles northwest from the south side of Knott's Island. East of the Great Bridge Lock, the canal and the North Landing River have plenty of storage capacity to hold water before it can effect water elevations in Back Bay. A spatial analysis of high-accuracy topographic data for the City shows that there are close to 25 square miles of available flood storage area along the North Landing River for water elevations up to 2.5 feet above normal high tide. The City also completed an exploratory analysis using a sophisticated computer model to evaluate how the lock, open or closed, would affect water elevations. The water levels between the two simulations were compared to identify the effects of the lock on flooding. The model showed that when the lock is closed, the average elevation difference in the canal is less than a tenth of a foot. The simulations indicate that Great Bridge Lock has negligible effects on water elevations in the North Landing River, and no effect on water surface elevations in Back Bay.

Sustained Southerly Winds

What causes wind tide flooding?

Wind tide events in the Southern Rivers are driven by sustained winds that blow from the south, called southerly winds. During times of sustained southerly winds, water moves in a northerly direction from the Currituck Sound, located in North Carolina, up through the Back Bay and North Landing River. This process causes water levels to increase by multiple feet, and results in the flooding of low-lying areas. In the last two years, several flood events have occurred as a result of southerly winds. For example, a recent wind event caused water elevations to rise in Back Bay to about 2.5 feet in early May 2017.

Is wind tide flooding a new type of flooding?

Flooding in the Southern Rivers Watershed as a result of wind tides is not a recent phenomenon. Increased flooding for lands adjacent to Back Bay and the North Landing River has been noted as early as the 1930s.[38] Relative sea level increases have increased base water levels, and in turn have increased the frequency and depth of flooding from wind tide events. Such conditions are expected to worsen in the future as sea level continues to rise.

How often does wind tide flooding happen?

Wind tide flooding can occur several times a year. Between 2017 and 2019, five such events occurred resulting in extensive flooding and mounting concern from residents.

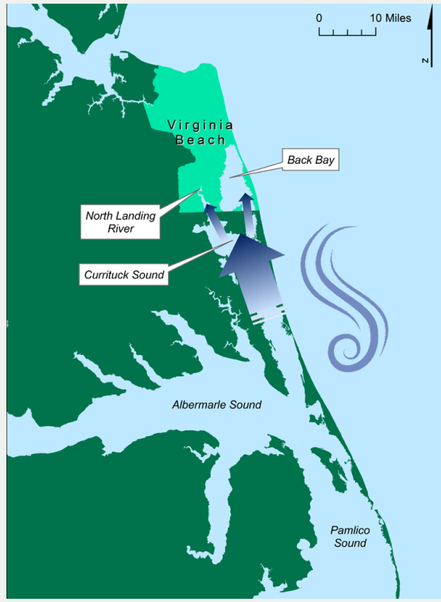
The City had experts in meteorological statistics evaluate how often wind conditions driving wind tides are happening in Virginia Beach. Historical wind records at Oceana Naval Air Station, as well as Duck and Manteo, North Carolina, were analyzed. Despite the number of occurrences in recent years, the study found that the events were outside of normal pattern. No trends were found to suggest that sustained southerly winds are occurring any more frequently than they used to. Other factors may be partially responsible for the relatively high number of wind tide flood events in the 2017 to 2019 period. Increasing water levels and loss of marsh both contribute to allowing water to move faster into the Southern Rivers Watershed during period of sustained winds. Increased rainfall in recent years may also be a factor – as there is some relationship between rainfall and water levels in the Currituck Sound.

Why is wind tide flooding getting worse?

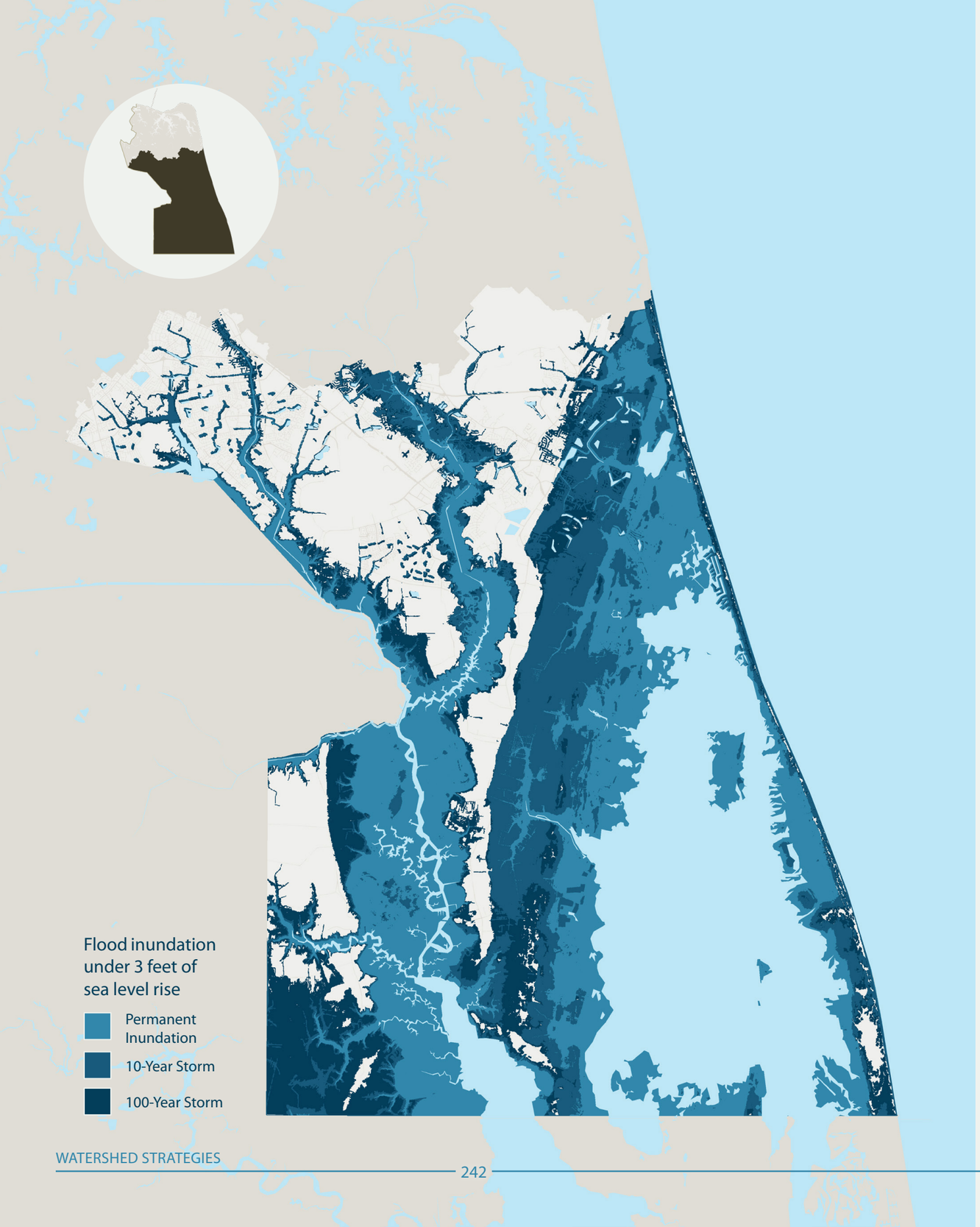
Wind tide flood events are generally poorly understood due to a lack of long-term water level records in the area. The City installed water-level gauges in Back Bay and North Landing River in 2016, and has invested in sophisticated computer models to supplement limited observational data and improve the understanding of these events.

The City evaluated wind tide flooding using a state-of-the art coastal hydraulics computer model—a technology used and approved by both FEMA and USACE. The model included the entire Intracoastal Waterway between the Elizabeth River and North Landing River, the Back Bay, Currituck, and Albemarle-Pamlico Sound down to Cape Hatteras. The model's accuracy was validated against measured water elevations at Beggars Bridge for wind tide events in May 2017 and September 2018.

The model was used to simulate wind tide conditions for a range of wind speeds and directions for sustained southerly winds. The study found that sustained winds from due south resulted in the highest wind tides, and that maximum water levels were reached between three to five days depending on wind speed and location.



The model was also used to understand how wind tides may change in the future. Wind tides were simulated with 1.5 and 3 feet of sea level rise. The model showed that a higher starting water level due to sea level rise will cause wind tide flooding faster. For example, the 1.5 foot sea level rise scenario would have peak wind tide approximately two days earlier than existing conditions, whereas the peak wind tide under the 3 foot sea level rise scenario could occur three days earlier.



Southern Rivers Watershed

Flood Extents

Permanent Inundation: The coastal waterbodies in the Southern Rivers Watershed do not experience fluctuations in water levels due to astronomical tides like the other watersheds in Virginia Beach, but they will still rise along with sea levels. The Southern Rivers Watershed has the largest expansion of land area at risk to permanent inundation with a higher sea level. With 1.5 feet of sea level rise, 25 square miles of land is anticipated to be permanently inundated. An additional 21 square miles of land becomes vulnerable to permanent inundation with 3 feet of sea level rise. Most of this permanent inundation occurs in the low-lying fringing marsh areas directly adjacent to Back Bay, North Landing River, and West Neck Creek.

10-Year Storm: A moderate storm event today impacts approximately 39 square miles of land, impacting mostly undeveloped fringing marsh area. With 1.5 feet of sea level rise, an additional 15 square miles of land is impacted, with flooding reaching further inland and extending into some agricultural lands and low-lying roads. With 3 feet of sea level rise, flooding becomes more expansive, impacting an additional 23 square miles of land square miles of land, including several developed areas such as Sandbridge and the neighborhoods surrounding the Dam Neck Annex. Note that recent wind tide events have exceeded the FEMA 10-Year storm elevation. Peak elevations for those events were equivalent to a 50-year event per the FEMA flood study.

100-Year Storm: During a large storm event today, the amount of flooded land substantially increases, flooding about 55 square miles of land. The flooding driven from Back Bay begins to connect with flood waters entering into Rudee Inlet. This merging of flood pathways generates more extensive flooding, especially near Dam Neck and on the east side of the Pungo Ridge. With 1.5 feet of sea level rise, 12 additional square miles of land are flooded. With 3 feet of sea level rise, there is potential for an additional 30 square miles of land to be at risk of flooding.

Southern Rivers Watershed

Notable Impacts

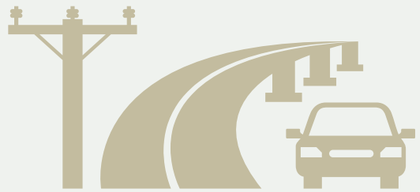
Impacts on Buildings

Due to their low-lying elevations, many buildings in the Southern Rivers Watershed are susceptible to repetitive coastal flooding. Approximately 45% of the entire risk exposure in the City is concentrated in this area.

The Southern Rivers Watershed has nearly 15,000 buildings exposed to coastal flooding under long-term sea level rise projections. If not addressed, average annual flood losses to buildings, contents, and associated displacement of occupants is approximately $2 million under today's condition, but jumps to nearly $123 million with 3 feet of sea level rise.

Flood Exposure of Buildings

	Now	1.5 ft SLR	3 ft SLR
# Buildings	1,914	6,033	14,981
# Residents	22,036	40,768	69,952
Expected Building, Content, and Displacement Costs	$1.95M	$11.89M	$122.8M



Impacts on Infrastructure

Today, there are only 2 community facilities and approximately 4 miles of critical evacuation route that exposed to coastal flood risks. With three feet of sea level rise, 15 facilities and nearly 13 miles of critical evacuation route become threatened by coastal flooding.

Vulnerable Critical Facilities

	Now	1.5 ft SLR	3 ft SLR
Police Stations	0	1	2
Fire Stations	2	2	5
Schools	0	3	8
Miles of Critical Roads	4.4	6.9	12.9

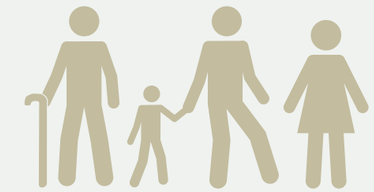
Impacts on Habitats

Despite being somewhat protected from developmental pressures, Back Bay has experienced substantial deterioration of its habitat. Over the past century, over 2,000 acres of vegetated marsh have transformed into open water as a result of wave action, erosion, and sea level rise. With more open water, flooding can occur even more quickly as there is less resistance against the wind, allowing water to flow. Fragmented ecosystems also decrease habitat connectivity, leading to loss of other systems that depend on the protection such as aquatic vegetation and fish.

Looking forward, rising water levels will likely result in even more habitat loss. With 3 feet of sea level rise, the Southern Rivers Watershed could see a 55% increase in the amount of open water. This expansion in open water will have significant impacts on coastal wetlands surrounding Back Bay and North Landing River. The analysis of habitat vulnerability showed that 46% of grass marshland and 37% of woody wetland habitats could be lost.

Changes in Acres of Habitat

	Now	1.5 ft SLR	3 ft SLR
Woody Wetlands	28,200	25,000	17,800
Grass Marsh	9,600	9,600	5,200
Tidal Flat	2,500	2,800	5,100
Open Water	33,900	39,100	52,500



Impacts on People

Today approximately 22,000 residents live in homes vulnerable to flooding, but that number could more than triple as sea level rise leads to an expanded floodplain. By the end of the century, nearly 70,000 people in the Southern Rivers Watershed could be exposed to coastal flood hazards. Out of those residents exposed to future flooding, over 50% many may experience increased vulnerability due to physical and socioeconomic factors. These populations may require greater assistance and support from the City regarding supporting mitigation and preparedness.

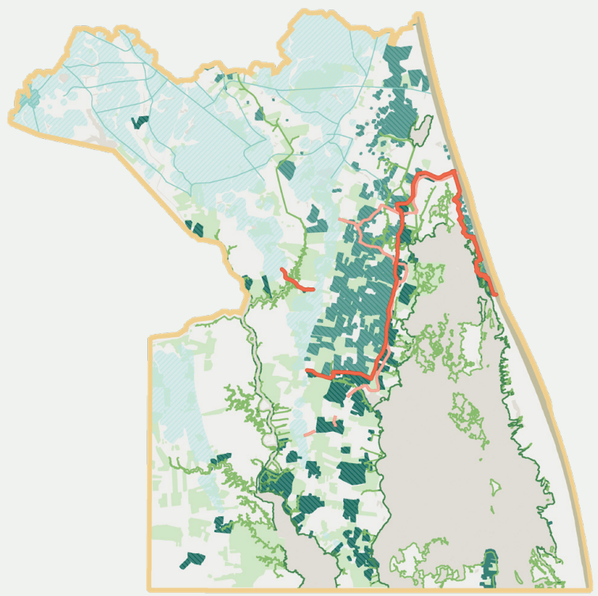
Vulnerable Populations Exposed to Flooding

	% Today	% at 1.5 ft SLR	% at 3 ft SLR
People of Color	9%	20%	39%
Children (<5)	15%	28%	49%
Elderly (>65)	16%	33%	58%
Institutionalized	0%	3%	4%
Limited English	9%	20%	38%
Limited Income	14%	27%	46%
Disabled	15%	29%	52%

Southern Rivers Watershed

Adaptation Vision

The layered flood protection system for the Southern Rivers Watershed could provide long-term protection from rising sea levels and coastal flooding, and create social, environmental, and economic benefits. The 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.



Natural Mitigations

- Beach and Dune Nourishment
- Land Conservation
- Living Shorelines
- Marsh Restoration and Creation
- Seagrass Restoration

Engineered Defenses

- West Neck Creek City-Wide Alignment
- Muddy Creek Road City-Wide Alignment
- Sandbridge City-Wide Alignment
- Alternatives to Sandbridge and Muddy Creek Road City-Wide Alignments

Adapted Structures

- Building Elevation
- Commercial Floodproofing
- Floodplain Regulation
- Mitigation Reconstruction
- Responsible Development
- Resilient Roadways

Prepared Communities

- Residential Community Education
- Flood Insurance Expansion
- Business Outreach and Education

Southern Rivers Watershed

Beach and Dune Nourishment

There are approximately 19 miles of beachfront in the Southern Rivers Watershed. The beach and dune system varies with respect to land ownership, beach usage, and condition. This strategy recommends continued investment in nourishment and maintenance of recreational beaches to protect property from storm surge and provide beaches for tourism. It also recommends sustained conservation of the naturalized beaches.

The majority of beachfront is protected by state and federal agencies. Back Bay National Wildlife Refuge and False Cape State Park are located on the natural barrier islands between Back Bay and the Atlantic Ocean. The barrier island beach and dune systems are naturally wide. Besides incorporation of sand fences in the dune system back in the 1930s to prevent overwash and erosion during storm events, these beaches remain naturalized to protect the many plants and animals that use this area as habitat. Threatened loggerhead sea turtles come ashore to nest every summer. Sandpipers, sanderlings, and willets feed in the intertidal moist sand. Ospreys, gannets, gulls and terns can be seen fishing offshore.

North of these two parks is a section of beach that provides more accessible beach access. To protect property and provide beaches for tourism, the City began nourishing Sandbridge beach and Little island Park, on the south end of Sandbridge. This section of Virginia Beach's ocean coast erodes at about 2 feet per year and is a divergent area of sediment transport. This means that north of Little Island Park, sand moves north. South of Little Island, sand move south. Nourishment of these beaches began in 1998 and the latest nourishment was completed in 2013 where 2.18 million cubic yards of sand was added along Sandbridge beaches. The total cost of the project was $15.9 million. Since completion of the 2013 nourishment, beach profile monitoring of the project site has occurred in the spring and fall of each year to determine how much sand is remaining within the system and to gauge the remaining project life. Results of the Fall 2016

Beach Profile Monitoring Report indicate that the average remaining design life for the project is just under 4 years. The fifth beach renourishment project to place 1.56 million cubic yards of sand between Back Bay National Wildlife Refuge and Dam Neck Naval Facility is scheduled to start in February 2020. This project is expected to cost $21.5 Million, funded by established Sandbridge Special Service District funds and $3 million dollars in Federal funding.[39]

The beaches along Naval Air Station Oceana Dam Neck Annex have also been nourished regularly to maintain a wide, protective beach. In addition, a large dune was built to protect upland infrastructure from storm surge. The large dune has a rock core to add additional stability in case the dune erodes during a large storm event.

COST

$$$$

TIMELINE

near-term mid-term long-term

BENEFITS

- Restoring storm sure barrier function of dunes
- Reduces shoreline erosion (temporarily)
- Creation of beach habitat for nesting sea turtles and shorebirds
- Adding new sand encourages existing beach plants to spread, anchoring the dunes and building additional dunes

Southern Rivers Watershed

Land Conservation

More than 56 square miles of land are already protected as federal, state, or local parks, and over 15 miles of shoreline are protected acres under conservation easements. These protected pieces of undeveloped shoreline will enable migration of natural landscapes in response to rising sea levels.

There is an opportunity for other landowners and residents of properties that border Back Bay and North Landing River to conserve the natural assets of the waterway through a conservation easement or by selling their property to the City—both voluntary options. In the Southern Rivers Watershed, there are over 1,300 parcels of land that were found to be highly cost beneficial for voluntary acquisition. The majority of these parcels are located along the northern banks of Back Bay.

This strategy was shown to be worthwhile with respect to costs versus benefits because of the significant environmental benefits that result from converting a property into open space. The cumulative cost of all potentially cost-beneficial voluntary acquisition projects in the Southern Rivers Watershed is approximately $527 million. This tactic may also lead to potential loss in property tax revenue for the City.

COST

$$$$

TIMELINE

near-term mid-term long-term

BENEFITS

- Tax benefits for the landowner conserving the land
- Conservation of habitats
- Water sink during flood and storm events
- Beautifies the waterfront area and offers additional natural assets
- Relocated citizens from potential flooding

Southern Rivers Watershed

Living Shorelines

Although proposed structural interventions such as the elevation of Muddy Creek and Sandbridge Roads will be much more effective at mitigating large storm surges, there is still opportunity within the Southern Rivers Watershed to construct living shorelines. Living shorelines along the banks of Back Bay and the North Landing River would provide a first line of defense during flood events, slowing the water's advance so that neither the structures nor the land feel as much of an impact. The majority of the shorelines along Back Bay and North Landing River are already naturalized, providing an ideal opportunity for construction of living shorelines. Offshore breakwaters could be constructed to break up wave energy and reclaim historically lost fringing marsh.

Unlike the City's other three watersheds, the majority of the shoreline in the Southern Rivers Watershed is protected under conservation land or easements. Of the 69 miles of shoreline suitable for construction of living shorelines, approximately 53% border conserved lands. These lands provide ample opportunity for the City to partner with these land owners to identify sites and design large-scale living shoreline protection systems.

Living shorelines can also be constructed on private lands. Homeowners can contact a Restoration Project Coordinator at Lynnhaven River NOW to get a free consultation to help determine what options exist for living shorelines on private properties. Although their office is not located in the Southern Rivers Watershed, they are willing and able to provide support to residents in the Southern Rivers Watershed. The Living River Restoration Trust and the Elizabeth River Project provide assistance to homeowners to help in the design, financing, and construction of living shorelines.

The construction costs for living shoreline projects vary widely depending on the shoreline length, level of protection needed, and the costs for materials and labor. Construction of all living shoreline projects identified in the Southern Rivers Watershed could range from $54 to $183 million.

COST

$$$$

TIMELINE

near-term mid-term long-term

BENEFITS

- Offers ecosystem services
- Provides erosion control
- Reduces flooding during smaller storms
- Improves water quality
- Beautifies the waterfront area
- Enhances habitats for wildlife and aquatic species

Southern Rivers Watershed

Marsh Restoration and Creation

Despite the conservation of much of Back Bay in federal and state park systems, it has experienced substantial deterioration of marsh island and fringing marsh habitat. Over the past century, over 2,000 acres of vegetated marsh have transformed into open water as a result of wave action and rising water levels. As noted earlier, a future with higher sea levels could result in almost complete loss of marsh islands in Back Bay, widening existing flood pathways and opening up new ones. The marsh islands in the middle of the bay, the fringing marshes extending into the Knotts Island channel and within Mackay Island National Wildlife Refuge in North Carolina are especially important given that they provide an obstruction to primary flood pathways into Virginia Beach. Restoration of these islands was conceptually evaluated using a state-of-the-art numerical model and found to slow down flood waters.

Frequent wind tides pose a significant challenge to marsh restoration. Addressing this challenge will require a truly novel approach. The City has partnered with Back Bay National Wildlife Refuge and the Virginia Department of Game and Inland Fisheries to develop conceptual designs for construction of marsh terraces, a technique used extensively along the Gulf coast to convert shallow subtidal bottom to marsh. These ridges of new marsh create a calmer environment where the marsh and seagrass are able to establish and grow. The City is committed to implementing this demonstration project and has budgeted funds to initiate this study in 2020. This planned project is expected to be evaluated with computer modeling, as well as post-construction monitoring to assess benefits, and evaluate how to pursue larger-scale marsh restoration projects in Back Bay for dual flood reduction and ecosystem restoration purposes.

The site selection and conceptual design of marsh terraces in Back Bay is anticipated to cost between $400,000-$450,000.

COST

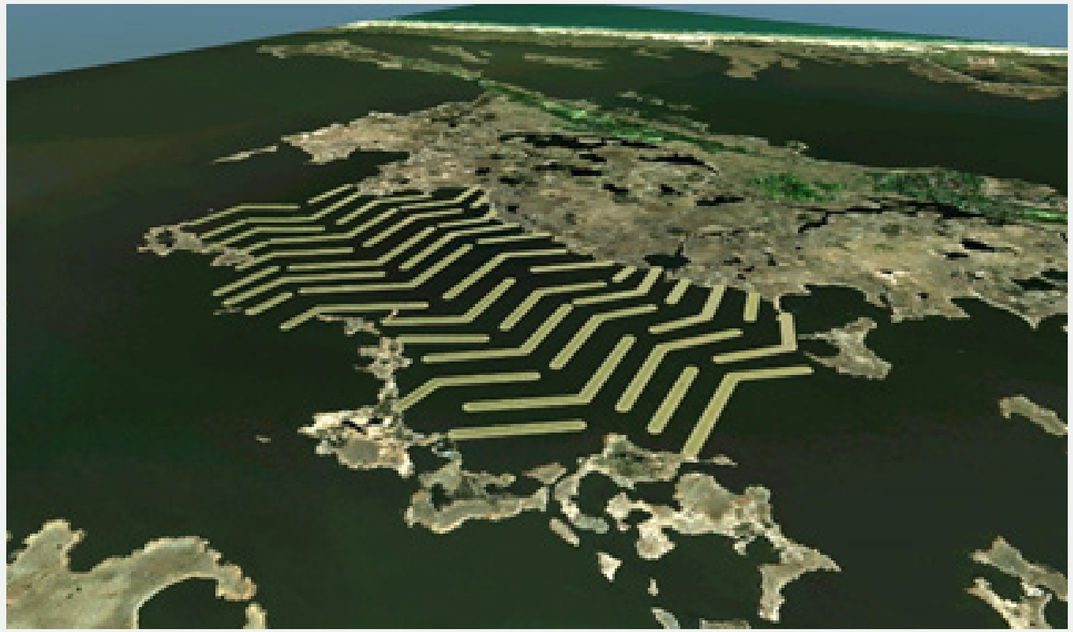
$$$$

TIMELINE

near-term mid-term long-term

BENEFITS

- Lessons-learned from this pilot project will support larger-scale restoration projects in Back Bay and other locations in Virginia Beach



Oblique aerial view of Back Bay showing conceptual application of marsh terraces

Conceptual view of marsh terraces from water level

Southern Rivers Watershed

Seagrass Restoration

Thick and healthy seagrass historically covered large regions of Back Bay. These habitats began to decline in the 1920s and remain patchy and sparse today. Restoration of these habitats is challenging because of poor water clarity driven by frequent wind tides. This is because of the open and shallow nature of Back Bay – even the smallest wind action is enough to churn the water from the surface to the bottom. Like all plants, seagrass needs sunlight to grow, which makes improving water clarity an important step in seagrass restoration. Several promising strategies have been explored including using construction of marsh terraces that are designed to break up wave energy and create a calm environment where grass can establish and grow. These techniques should allow for natural reestablishment of seagrass, but dispersal of seeds or transplanting adult seagrass plants can be used to speed along the process. The City is actively partnering with Back Bay National Wildlife Refuge and the Department of Game and Inland Fisheries to identify priority locations for seagrass restoration.

The cost of seagrass restoration will vary based on size of the project site.

COST

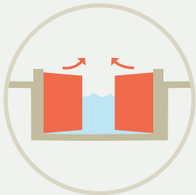
$$$$

TIMELINE

near-term mid-term long-term

BENEFITS

- Slows down flood waters
- Improve water quality and clarity
- Trap sediment
- Reduce erosion



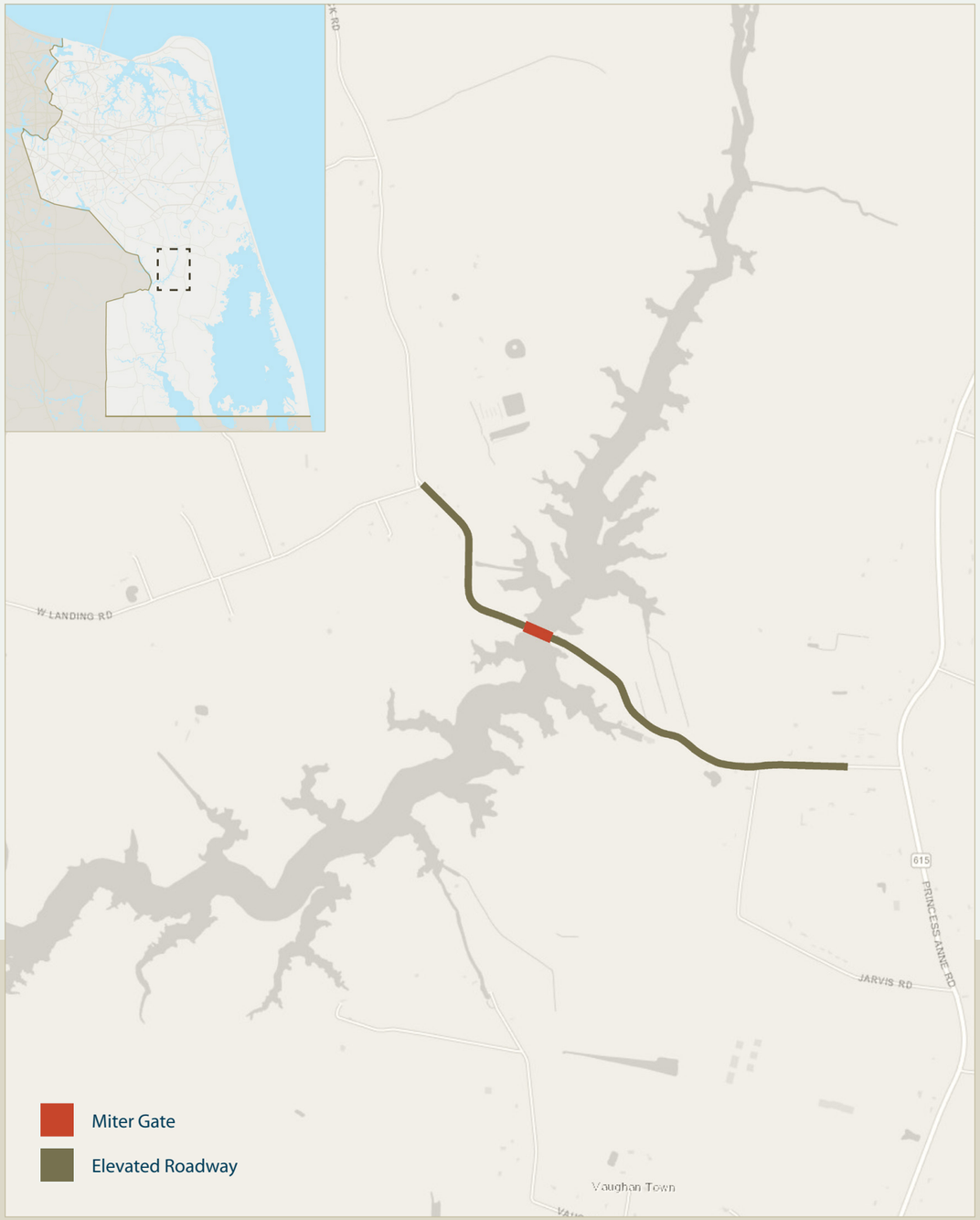
Southern Rivers Watershed

West Neck Creek City-Wide Alignment

West Neck Creek allows a significant volume of flood waters to inundate residential properties north of the bridge at West Neck Road.

A conceptual design calls for a series of in-water miter gates spaced similarly to the existing bridge piers. This gate would be tied into West Neck Road with earthen levees. To ensure flood waters do not flank the gated system, the bridge and sections of West Neck Road on either side of the bridge would be raised. The gate will remain open outside of storm events, and is expected to have a minimal impact to the everyday creek flow and habitat.

The system would cost approximately $69 million to design and construct.



West Neck Creek miter gate and elevated roadway.

COST

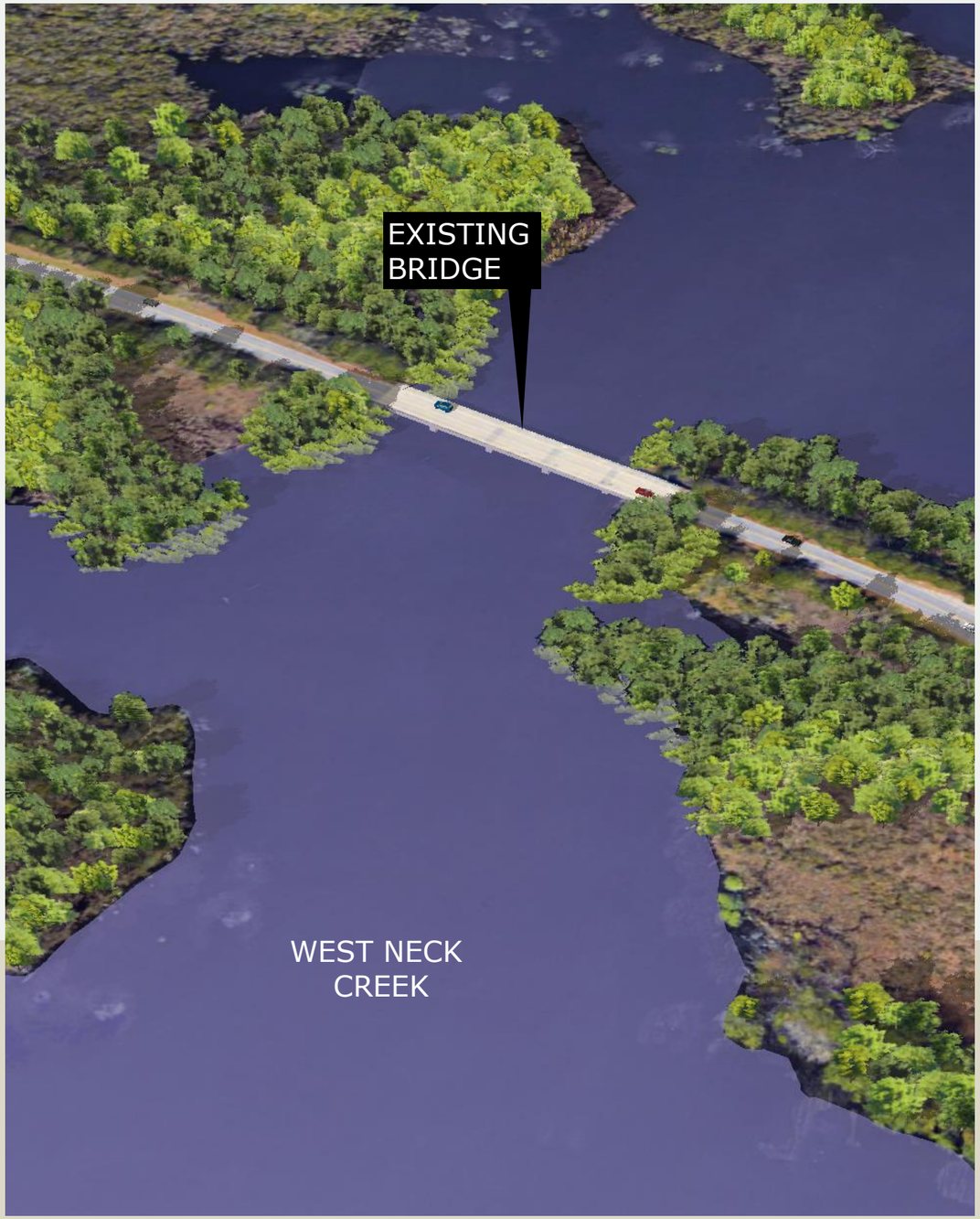
$$$$

TIMELINE

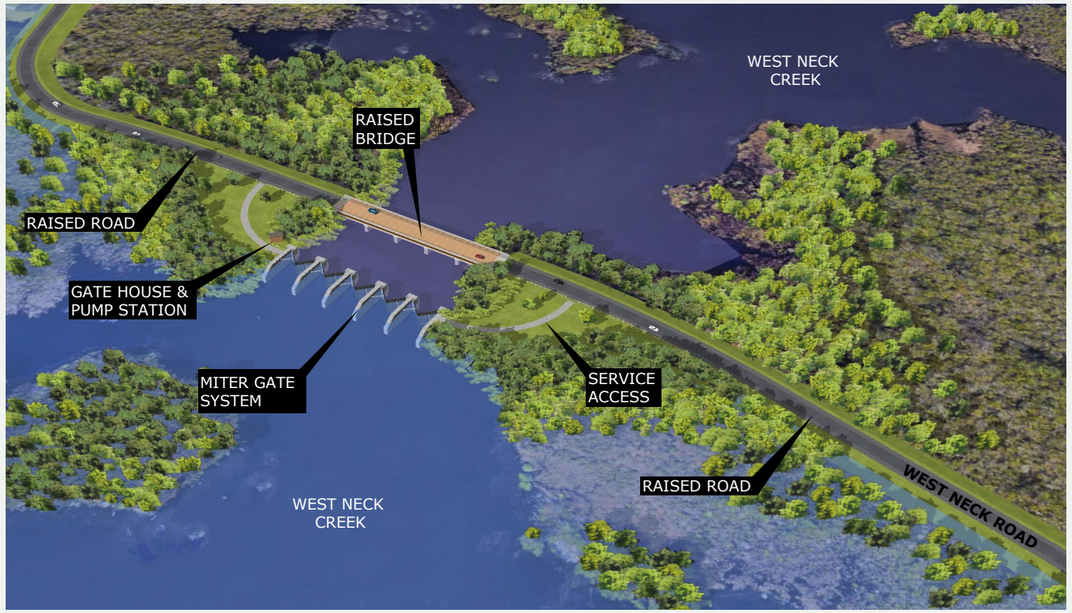
near-term mid-term long-term

BENEFITS

- The West Neck Creek structural protection system would effectively block the flood pathway originating from the North Landing River and West Neck Creek, thereby providing protection to residential properties north of West Neck Road.



West Neck Creek existing conditions



West Neck Creek structural protection system under flood condition

West Neck Creek structural protection system under flood condition (enlarged view)

Southern Rivers Watershed

Muddy Creek Road City-Wide Alignment

Muddy Creek Road provides access to important rural and agricultural communities as well as to Back Bay and the Wildlife Refuge. As one of the lowest-lying roadways in all of Virginia Beach that frequently floods, Muddy Creek Road was identified as a critical location to provide flood protection through the City-Wide Structural Alternative Flood Protection analysis.

The proposed system, known as the Muddy Creek Road Alignment, would involve transforming much of Muddy Creek Road into a levee, with the road on the crown of the levee.

Most of this structure would be designed to an elevation of 8 feet (NAVD88 datum). Sections of adjacent roadways would also need to be raised until they intersect with higher ground to ensure flood waters do not bypass the protection system. As Muddy Creek Road crosses several waterways, miter or circular flood gates would need to be installed at Muddy Creek, Beggars Bridge Creek, and Nanneys Creek.

The estimated cost of this project is $283 million.

Muddy Creek Road levee, elevated roadway, circular gate, and miter gate.

COST

$$$$

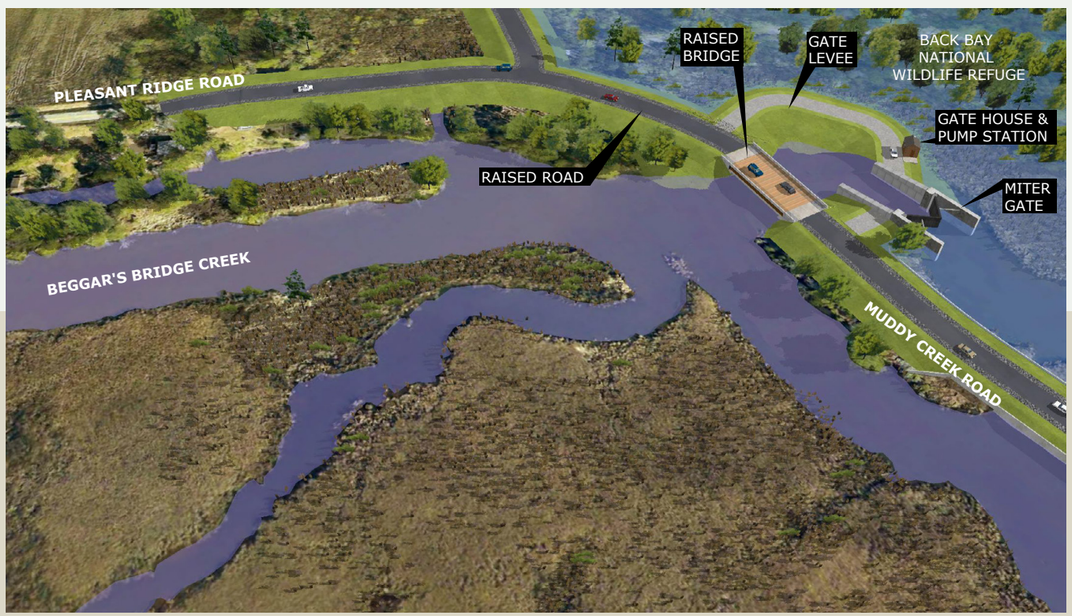
TIMELINE

near-term mid-term long-term

BENEFITS

- Together with the Sandbridge protection system, the Muddy Creek Road Alignment would protect a substantial amount of area north of Nanneys Creek Road and west of Muddy Creek Road.
- Although this protection would only protect ~2% of buildings vulnerable to future flooding, it protects agricultural lands that are vital to the economic vitality of the Southern Rivers Watershed.

Muddy Creek Road existing conditions



Muddy Creek Road structural protection system under flood condition

Muddy Creek Road structural protection system under flood condition (enlarged view)

Southern Rivers Watershed

Sandbridge City-Wide Alignment

The Sandbridge resort community and neighborhoods to the north are especially vulnerable to flooding due to low-lying elevations and location at the north of Back Bay where water can pile up during sustained southerly winds and storm conditions.

Protection of these areas from coastal flooding during a large storm event with sea level rise would require a complex and expensive structural protection system because of the manufactured land configuration on the backside of Sandbridge.

The proposed protection system includes elevating Sandbridge Road to an elevation of 8 to 10 feet (NAVD88 datum), and construction of a network of seawalls, levees, and gates along the Back Bay shoreline of Sandbridge. The system would cost approximately $862 million to design and construct.

Engineering and accessibility design challenges that would maintain the spirit of the community and the private access to the waterfront for residents exists along this alignment. Depending on the choice of flood protection system, the proposed design may require construction either on the private property or the Natural Wildlife Preserve of Back Bay.

One choice of flood protection system can include a combination of floodwall with numerous deployable closure structures at waterfront access points to restrict the limits of the required construction space; however, this flood protection system would decrease the reliability of the system due to the need for human intervention to properly operate and maintain deployable closure structures.

To minimize this human intervention risk, another choice could be a wider flood protection system (for example, levee) that can accommodate waterfront and floating dock access without the need for deployable closure structures. This flood protection system would encroach the Natural Wildlife Preserve of Back Bay resulting in significant environmental mitigation and would also need to comply to any applicable state and federal codes such as ADA requirements. The choice of any of these flood protection system types would impact the current community spirit and use.

Due to the significant challenges between community and choice of structural flood protection system, it is recommended to review planning alternatives (raising of structures, buyouts, etc.) for this segment of the alignment.

COST

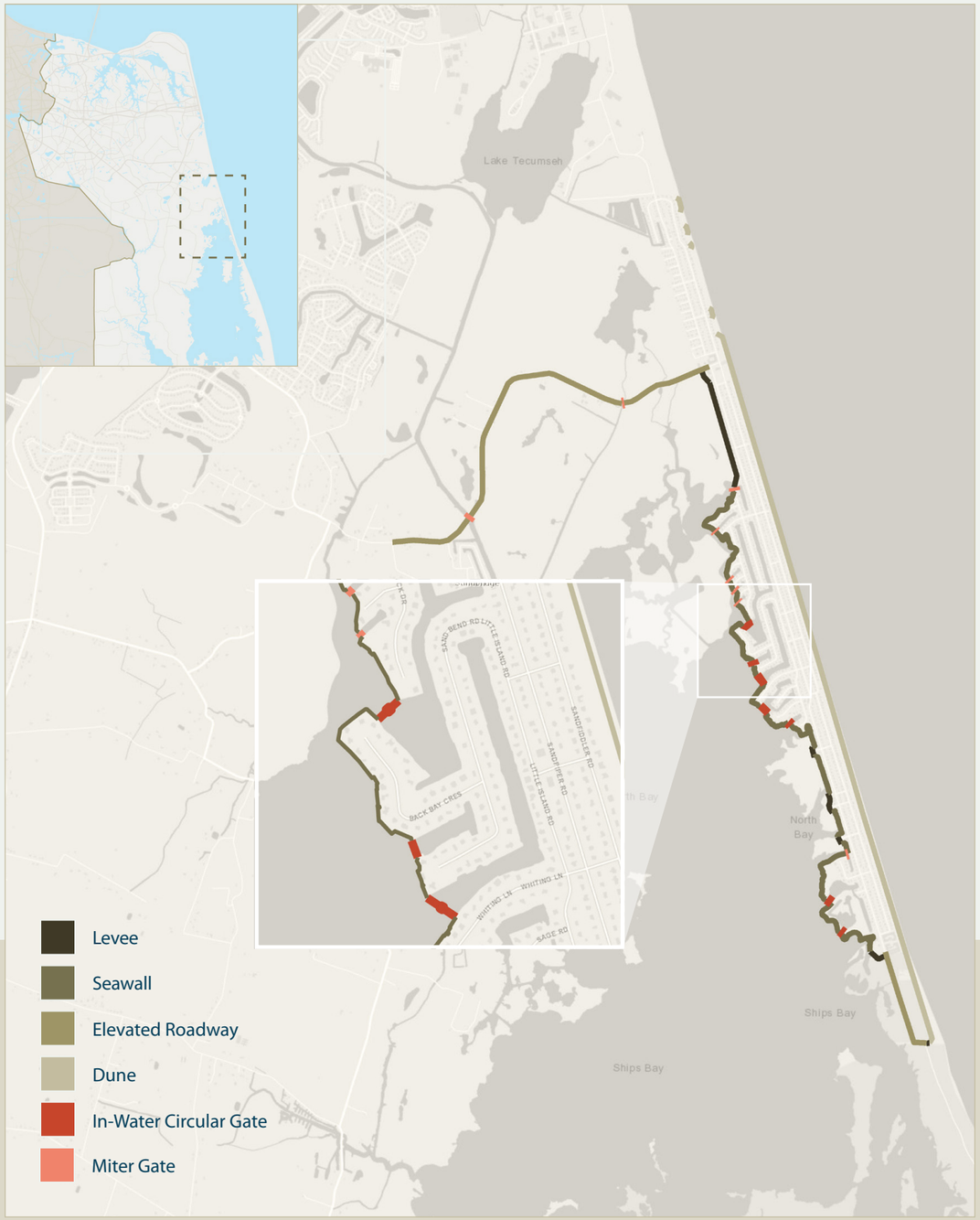
$$$$

TIMELINE

near-term mid-term long-term

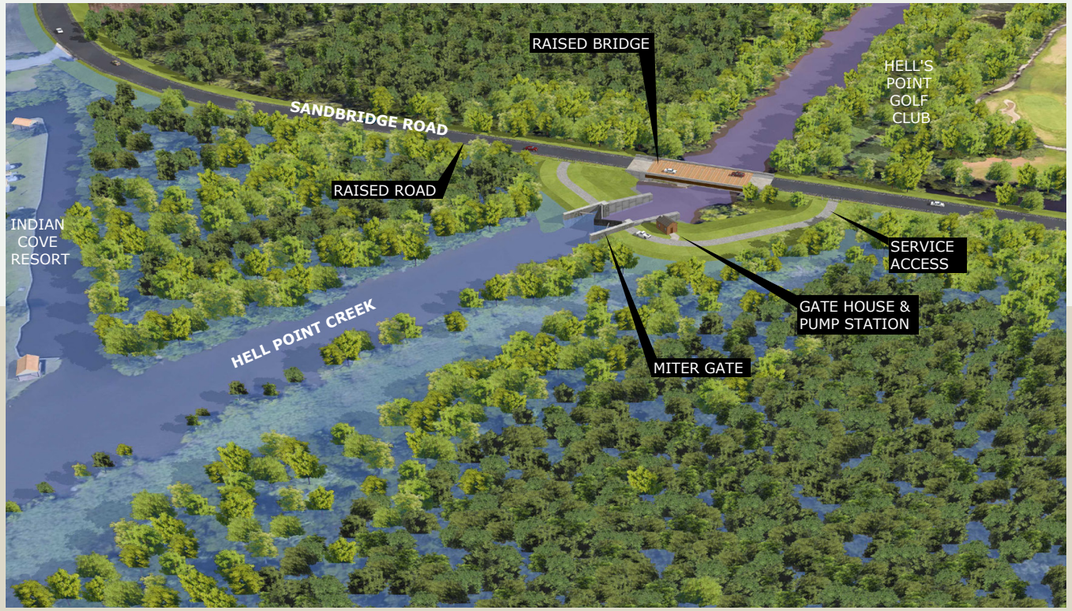
BENEFITS

- This protection system would block flood pathways originating from Back Bay, providing protection to the Sandbridge community and neighborhoods north of Sandbridge Road.
- Together with the Atlantic Oceanfront structural protection system (see Oceanfront chapter) and continued beach nourishment, this system would also provide protection to Naval Air Station Oceana Dam Neck Annex.



Sandbridge Road and neighborhood protections.

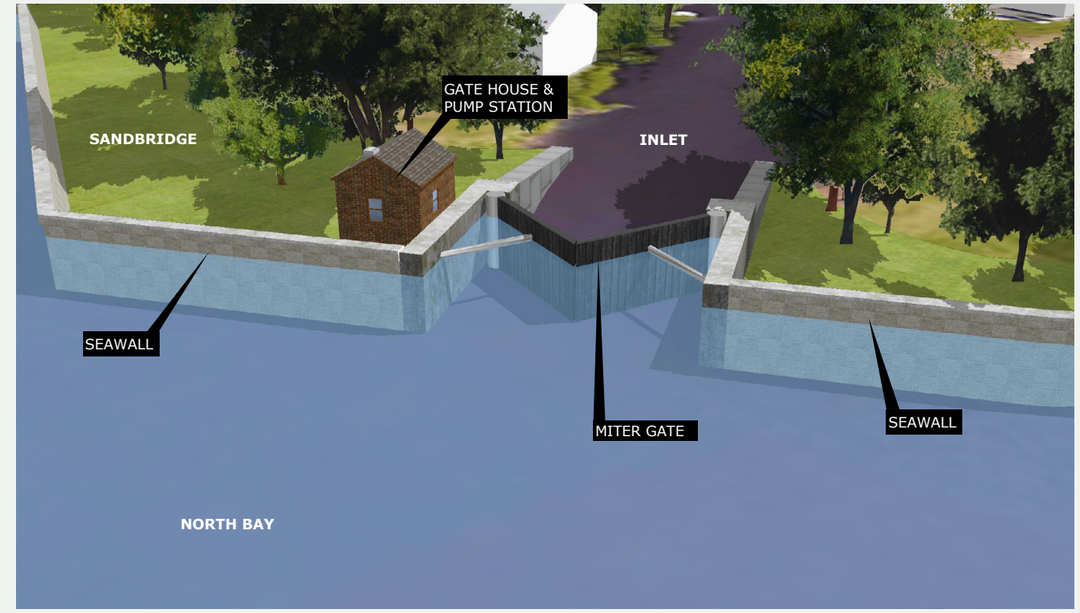
Sandbridge Road existing conditions



Sandbridge Road structural protection system under flood condition

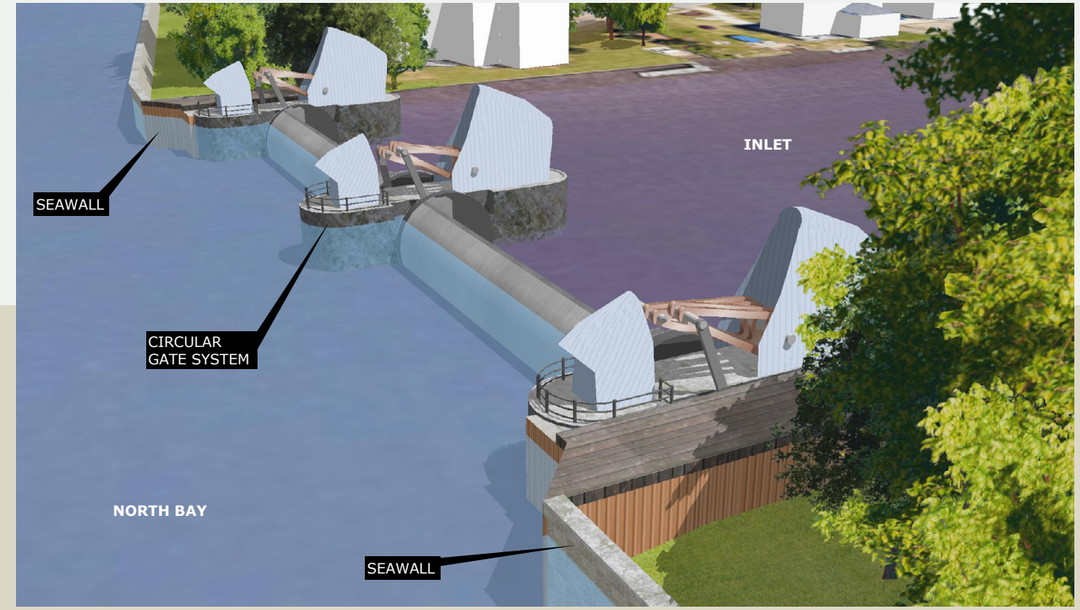
Sandbridge Road structural protection system under flood condition

Sandbridge Neighborhood existing conditions



Sandbridge structural protection seawall and miter gate

Sandbridge Neighborhood structural protection system under flood condition



Sandbridge structural protection circular gates

Southern Rivers Watershed

Alternatives to Sandbridge and Muddy Creek Road City-Wide Alignments

Flood protection could be provided at a lower design level to address more frequent coastal storm surge events and short-term increases in sea level rise. Two alternatives to the Southern Rivers Watershed alignments were developed that would be considerably less expensive than the City-wide options, and could be achievable on a shorter timescale. Instead of the Sandbridge and Muddy Creek Road large scale structural solutions, a coastal flood protection system following an alignment that is parallel to Sandbridge Road and New Bridge Road (built to approximately elevation 8.5 [NAVD88 datum]) could be constructed to protect Sandbridge and areas north of Sandbridge Road. The other alternative is a coastal flood protection system following an alignment parallel to Muddy Creek Road (built to approximately elevation 7 [NAVD88 datum]) where the Sandbridge City-wide Structural solution would still be built.

The flood protection alternatives would be designed for a moderate coastal storm events (50-yr storm) and 3 feet sea level rise and could include a mix of coastal flood protection designs consisting of earthen levees, miter flood gates, gates at roadway crossings (or raised roadways), and backflow prevention devices at culverts. Sections of roadways can be raised until they intersect with higher ground to ensure flood waters do not bypass the protection system. These areas will remain vulnerable to flooding from the Oceanfront Watershed unless one of the alternatives in that section is constructed.

In the evaluation process, concerns were raised about residual flood risk with the lower level of protection. The structures could be overtopped by severe storm events, and offer a false sense of security to individuals and businesses in the protected area. This approach would also offer a shorter life-span, and require continued investment in the future to raise the elevation. Therefore, these designs are only recommended as a stop-gap measure to buy some time for gradual relocation of protected properties, or as an alternative to the City-wide option(s), if found infeasible by the future studies. The total cost would be $133 million for both alignments, of which $61 million is for the Sandbridge alternative and $72 million is for the Muddy Creek alternative.

COST

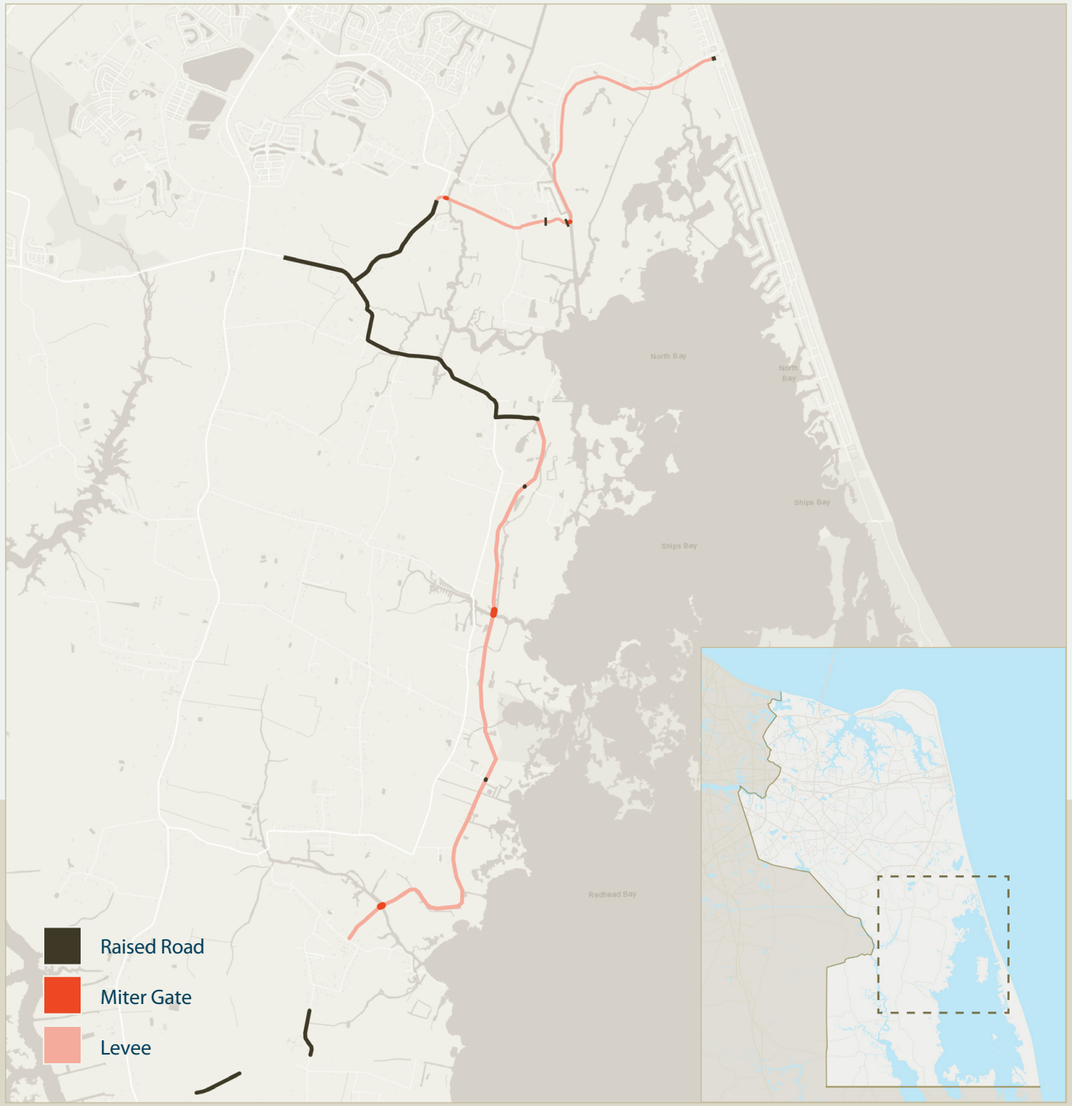
$$$$

TIMELINE

near-term mid-term long-term

BENEFITS

- This flood protection system would protect the Sandbridge and neighborhoods to the west and north of Muddy Creek Road from strong storm events and 3 feet of sea level rise. It is assumed that this system will work in conjunction with another design from the Oceanfront Watershed.



Sandbridge and Muddy Creek Road alternative alignment with raised roads, miter gates, and levees.

Southern Rivers Watershed

Building Elevations

The Southern Rivers Watershed is home to 1,635 residential properties where home elevations would be both beneficial and cost effective. These homes could be elevated using either 2 or 3 feet of freeboard depending on changes to the zoning ordinance.

The total project costs if all1,635 structures were elevated using 2 feet of freeboard would be nearly $393 million, with an average cost of about $240,350 per structure. This is the lowest average protection cost out of the three options (voluntary acquisition, mitigation reconstruction, and home elevations). This strategy is highly effective at reducing the risk to homeowners from flood events, but it can take years to find funding and grants to help homeowners pay to elevate a home.

It is important to note that alternative strategies such as voluntary acquisition and mitigation-reconstruction may also be a cost-effective option in these areas. Moving forward, the City should work with individual homeowners to determine which strategy is the overall best fit.

COST

$$$$

TIMELINE

BENEFITS

- $898 million in cumulative benefits
- Benefit-cost ratio: 2.55

Southern Rivers Watershed

Commercial Floodproofing

A study of Individual Building and Site-Level Flood Risk Strategies found that floodproofing was a cost-beneficial solution for a total of 122 commercial buildings in the Southern Rivers Watershed. Floodproofing these buildings ranged from moderately cost- effective to highly cost-effective and would serve to protect the commercial and economic interests of these structures from the impacts of flooding. For some of these structures, both wet and dry floodproofing were found to be a good solution, but the strategy with the higher return on investment is recommended. There are 50 buildings suitable for wet floodproofing that would amount in $2,341,175 in cumulative costs and 62 buildings suitable for dry floodproofing that would amount to $2,929,523 in cumulative costs.

COST

$$$$

TIMELINE

BENEFITS

- Wet floodproofing would result in $4,491,346 cumulative benefits and a Benefit-cost ratio of 1.9.
- Dry floodproofing would result in $12,497,810 in cumulative benefits and a Benefit-cost ratio of 1.4.

Southern Rivers Watershed

Floodplain Regulation

The existing Flood Insurance Study for Virginia Beach (effective 2015) was found to underestimate coastal flood elevations in the Southern Rivers Watershed. Review of the FEMA storm surge elevations against data from both the USACE and North Carolina Floodplain Mapping Program support raising the regulatory floodplain by approximate 1.5 ft for most areas in the watershed. The City is examining approaches for revising the floodplain in coordination with FEMA or as a revision to the Floodplain Ordinance. Within the Floodplain Ordinance, it could be incorporated into the Floodplain Subject to Special Restrictions, which is a local flood protection area with additional standards.

In consideration of SLR, the City is exploring changes to the definition of the "regulatory floodplain," which would expand the area regulations to apply to either the 500-year floodplain or the "future 100-year floodplain". These changes to floodplain regulations across the City would impact development in areas that fall within this new regulatory floodplain. Under an expanded "future 100-year floodplain" with 3.0 feet of sea level rise, there would be an additional 42.2 square miles in the regulatory floodplain.

COST

$$$$

TIMELINE

near-term mid-term long-term

BENEFITS

- Reduced vulnerability to flood risks for new development and substantial redevelopment
- Safer long-term growth
- Preservation of life and property

Southern Rivers Watershed

Mitigation Reconstruction

The Southern Rivers Watershed is home to 1,422 residential properties where mitigation-reconstruction would be both beneficial and cost effective. Once demolished, the new structure could be raised to either a 2 feet or 3 feet freeboard depending on changes to the zoning ordinance.

The total project costs if all structures were demolished and rebuild using 2 feet of freeboard would be over $406 million, with an average cost of about $285,800 per structure. This is the middle average protection cost out of the three options (voluntary acquisition, mitigation reconstruction, and home elevations).

While mitigation reconstruction can be more expensive than the voluntary acquisition of property for land conservation purposes, it ensures that community members stay in their communities, and helps to maintain a consistent tax base.

It is important to note that alternative strategies such as voluntary acquisition and home elevation could also be considered in these areas. Moving forward, the City should work with individual homeowners to determine which strategy is the overall best fit.

COST

$$$$

TIMELINE

near-term mid-term long-term

BENEFITS

- $728 million in cumulative benefits
- Benefit-cost ratio: 1.79

Southern Rivers Watershed

Responsible Development

The Green Line was established in 1979 and serves as an urban growth boundary, protecting rural assets in the Southern Rivers Watershed from increasing urban sprawl. Concentrating new development north of the Green Line and in Strategic Growth Areas located outside of the Southern Rivers Watershed helps reduce the geographic spread of urban areas exposed to flood risks while also protecting undeveloped land, open space, and natural areas.

Given that 43% of land area within the Southern Rivers Watershed is below three feet, "high and dry" areas should be identified and designated as locations for responsible development, be that residential or commercial. Strong consideration should be given to future flood areas, and any new development should be cited out of harm's way.

Responsible development in the Southern Rivers Watershed should include the preservation of existing tree canopy, encourage re-introduction of tree canopy into existing development, where feasible, and set minimum canopy requirements for new development recognizing the role that forests can play in flood mitigation and reducing stormwater runoff.

Any new developments, critical facilities or community assets, such as fire stations, schools, and hospitals, in the Southern Rivers Watershed should be built outside of the future 100-year floodplain for the 3 foot scenario, when feasible, and if not, should be built with flood resilience and future flood scenarios in mind.

COST

$$$$

TIMELINE

near-term mid-term long-term

BENEFITS

- Reduced risks of flooded critical assets
- Reduced vulnerability to flood risks for new development and substantial redevelopment
- Safer long-term growth
- Preservation of green infrastructure

Southern Rivers Watershed

Resilient Roadways

The vulnerability of critical pathways in Virginia Beach's road network should be recognized and addressed by the City's efforts to improve resilience to coastal flooding. The identified roads are essential and represent key conduits for the tourism, service, and defense industries, or accessibility to key community resources such as fire and emergency stations, hospitals, and police stations. In addition to accessibility concerns, some of these community facilities themselves becomes increasingly vulnerable to damage during storm events. The City should seek to address these vulnerabilities through existing or new road improvement projects.

In the Southern Rivers Watershed, primary roads such as General Booth Boulevard, Dam Neck Road, Princess Anne Road, and Nimmo Parkway are essential for evacuation, commuting, and accessibility to key resources. Each of these roads have vulnerability to future flooding. Flooding of these roadways can restrict access to several important community facilities, including several schools, military installations, police and fire stations.

The City has an ongoing project to improve and raise Sandbridge Road which will address existing flood issues. The proposed Sandbridge flood protection system would provide for increasing the elevation of the road and turning it into a levee, with flood gates to protect areas to the north, including Dam Neck Road. Dam Neck and Sandbridge Roads could be protected by the neighborhood strategy that considers a small levee parallel to segments of Sandbridge and New Bridge Roads. The City should continue to explore how the integrated suite of solutions presented within this study, or additional roadway improvements could reduce the vulnerability of these critical routes.

COST

$$$$

TIMELINE

near-term mid-term long-term

BENEFITS

- Reduced risks of flooded critical infrastructure assets such as roads, bridges, and highways
- Increase accessibility to critical community assets
- Increased safety of people and property
- Increased safety of evacuation and emergency response routes

Southern Rivers Watershed

Residential Community Education

The Southern Rivers Watershed is home to a wide range of residents who bring both demographic and cultural diversity to the community. Education regarding flood risks and how to mitigate flooding at home is vital to reducing the risk of the watershed as a whole, but especially the risk of vulnerable community members.

A large percentage of residents who live within the Southern Rivers Watershed are increasingly vulnerable to flood risk due to factors such as age, income, physical and mental disabilities, and race.

The Southern Rivers Watershed is home to numerous community gathering places such as public schools, community and recreational centers, and nearly 100 city parks. These community assets are well positioned to provide flood risk education throughout the watershed. The City should continue to partner with non-profits and conservation organizations such as the Back Bay Restoration Foundation and Friends of Back Bay to do educational outreach to kids and young adults regarding marsh restoration, living shorelines, and the importance of natural assets – not only for beautification purposes but also for flood risk reduction benefits.

Flood education can be conducted from the perspective of helping individual homeowners and renters in the Southern Rivers Watershed understand the risk to their structures, properties, and contents (such as what flood zone is your home located in?). Alternatively education can take the form of mitigation actions to help reduce the flood risk overall, or even go so far as to educate the public on what to do in the case of a flood. All of these components can be highlighted through various outreach and engagement channels, and cater to a broad demographic of residents. The City should ensure that outreach is accessible to vulnerable populations, whether that takes the form of printing materials and providing information in languages other than English or crafting materials that cater to community members with specific disabilities such as hearing or eyesight impairment.

COST

$$$$

TIMELINE

near-term mid-term long-term

BENEFITS

- Residents have a better understanding of their individual flood risks and more general understanding of what to do in a flood scenario

Southern Rivers Watershed

Business Outreach and Education

The Southern Rivers Watershed has a strong business community that provides area residents with a wide range of services and products, while also providing the City with vital sales tax revenue. Outreach and education targeted towards the business community is vital in reducing economic losses brought about by flood events. The City should focus on educating and collaborating with the Southern business community to create continuity plans and emergency operations. The City can also educate businesses on the importance of flood insurance to cover the losses and help businesses regain their footing following a flood event. The City can also work with the Department of Economic Development to help foster conversations and bring additional awareness about flood risks to the business community.

Coordination efforts for advance these activities can be made through the various business organizations in the City. In fact, the City has already met and discussed the SLR and flooding issues with several such organizations, including the Minority Business Council, the Realtor's Association, and others.

COST

$$$$

TIMELINE

near-term mid-term long-term

BENEFITS

- Reduced vulnerability of industrial and commercial businesses to flood risks

Southern Rivers Watershed

Flood Insurance Expansion

Flood insurance is vitally important to recovering from a flood event. A major component of preparing the community for increased sea level rise and recurrent flooding, is ensuring that residents and businesses have the means to recover from a flood event.

The overall flood insurance policy penetration in the Southern Rivers Watershed is 9%. This is 2% lower than the overall flood insurance penetration rate across the City, which is approximately 11%. The majority of the population that holds flood insurance policies are located along the Atlantic Oceanfront in the Sandbridge community. However, the flood risk assessment revealed that many other locations in the watershed are vulnerable to flooding but do not have sufficient coverage to recover from flood events.

The City should focus on increasing flood insurance penetration within areas in the Southern Rivers Watershed that have the highest residual risk – which is the risk that remains after applying a flood insurance deductible. The most under-insured neighborhoods in the Southern Rivers Watershed today include:

- Pungo
- Blackwater
- Back Bay Meadows
- Knotts Island
- Lake Placid

This can be accomplished through targeted outreach via numerous channels (radio, newspaper, digital ads, etc.) while providing educational background on the importance of flood insurance and who exactly should buy it. Partnership with FEMA can also provide pre-made marketing materials and data to reach high potential insurance buyers.

COST

$$$$

TIMELINE

near-term mid-term long-term

BENEFITS

- Provides CRS benefits for the City
- Allows residents and businesses to recover faster following a flood event

FLOOD INSURANCE STATISTICS

- 59% Coverage inside Special Flood Hazard Area
- 8% Coverage outside Special Flood Hazard Area
- 1,343 Total claims
- $ 21.4 million total losses reported from claims

PART V

THE PATH FORWARD

Planning and Coordination

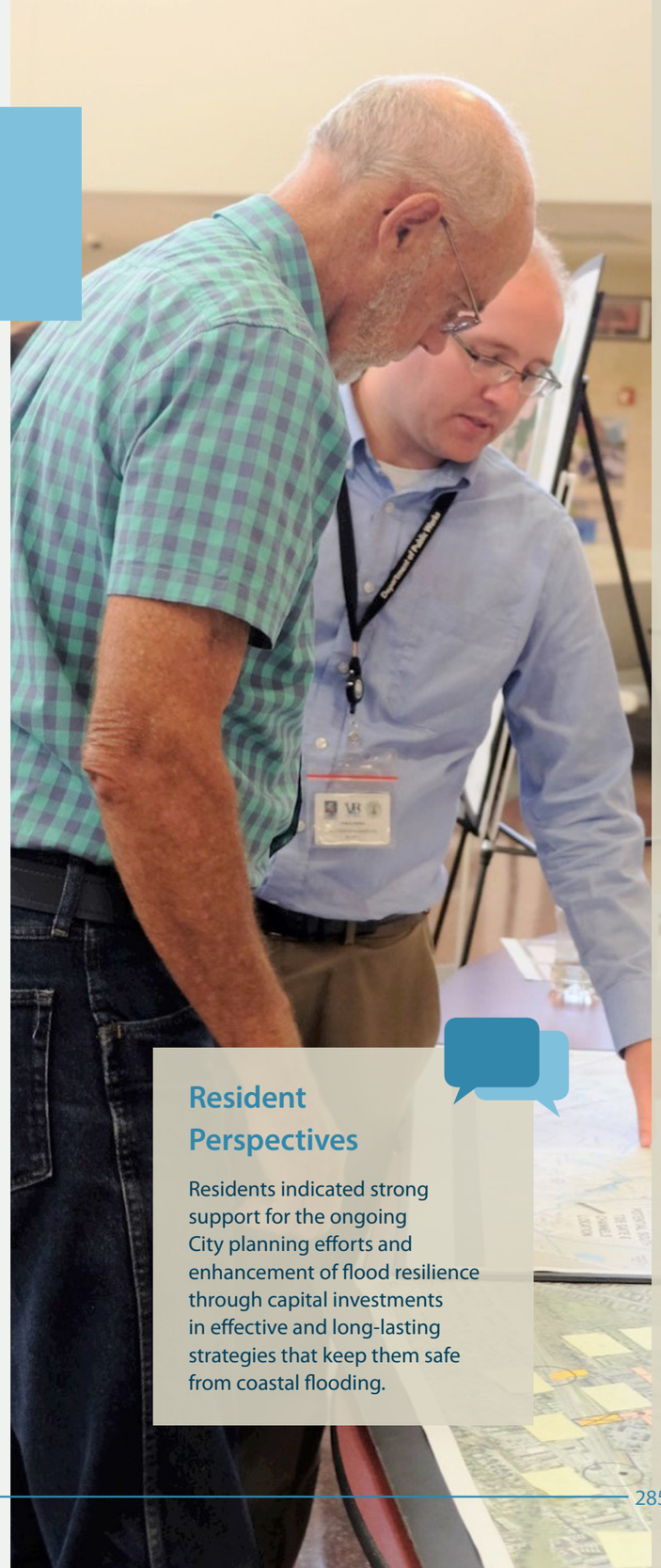
Reducing flood risks and planning for a vibrant future is an ongoing, iterative process, requiring sustained actions from the City and its partners.

As the City continues to plan for a future with increasing flood hazards, adaptation planning will be an ongoing process. Especially as conditions and risks evolve over time, plans, programs and projects will require continued development and iteration.

Through the continuation of the Sea Level Wise effort, the City should further sea level rise and recurrent flooding-related research, advocacy, planning and strategy implementation. The City has been a vocal proponent of planning for and mitigating against sea level rise and changing rainfall, and, in 2017, Virginia Beach Mayor Bobby Dyer joined the Global Covenant of Mayors for Climate and Energy, further underscoring the importance of planning for a changing climate. The 2019 adopted City budget established a 15 year capital improvement program to provide $1.3 billion to fund operations, maintenance, and construction to facilitate flood risk reduction.[40] This work, as well as the monies invested to date, demonstrates the City's commitment and provides a strong foundation that will ensure continued action.

Beyond Sea Level Wise, there are numerous City efforts that look to the future and overlap with Sea Level Wise themes and challenges. And as initial sea level rise and flooding research efforts continue to gain traction, many agencies and institutions outside of the City are continuing to produce new research and make plans for coastal adaptation. As Virginia Beach continues to grow the Sea Level Wise program, the City should continue to support cross-departmental coordination and maintain collaborative relationships with regional partners, leveraging all available resources to find, fund, and implement the most effective risk-mitigating solutions.

Continued planning should also take into account additional documents that could help the City plan for and mitigate flood risk. Currently, Virginia Beach does not have a comprehensive floodplain management plan. This planning document has the potential to serve as a key input into the comprehensive planning process and ensure that flood mitigation practices focus on structures that continually flood and enhance natural floodplain functions. There is also an opportunity to create specific asset management plans that would provide a long-term plan to protect large City assets and provide yet another opportunity to incorporate SLR and recurrent flooding data.



Resident Perspectives

Residents indicated strong support for the ongoing City planning efforts and enhancement of flood resilience through capital investments in effective and long-lasting strategies that keep them safe from coastal flooding.

Continued City Response Efforts

The Sea Level Wise program should continue to advance flood adaptation efforts within the City and region through:

- Coordination and information exchange with the Master Drainage Study.
- Continued internal interdepartmental coordination, and monitoring of implementation of recommended strategies through the Sea Level Rise Working Group.
- Coordination with private utilities, local businesses, civic organizations, and other affected stakeholders in the region.
- Continued participation in resilience activities through the Hampton Roads Planning District Commission, Old Dominion University, other regional planning organizations, and regional initiatives.
- Pursuit of authorization for a U.S. Army Corps of Engineers Coastal Storm Risk Reduction feasibility study to forward defense concepts to a preferred solution, initial design, and authorization for federal cost-sharing.
- Additional localized research, risk assessment, and feasibility studies as needed to advance conceptual strategies to fruition.
- Updates to this primary adaptation plan on a regular basis, accounting for progression in research, implementation and available scientific insights.

Planning Processes and Frameworks

Virginia Beach has numerous planning documents that help to guide the City's resources—governing everything from transportation, economic development to emergency management efforts. Key to implementation of this adaptation strategy will be close coordination across the City and with regional agencies to ensure that all relevant plans align with Sea Level Wise initiatives and decision making-processes incorporate future flood projections.

Integrated flood adaptation planning will involve propagating the findings from this report and the reports that come after it, throughout all City planning processes and decision frameworks. This integration and incorporation will be different for every department, process, and document. Sea level rise and recurrent flooding is a challenge that impacts nearly every area of the City in some capacity, underscoring the importance of incorporating the most up-to-date research and data into current and future planning.

The Commonwealth of Virginia also has dozens of programs and documents that help plan for the future. Sea Level Wise research has already been incorporated into Virginia's coastal planning efforts. As the Commonwealth continues to develop strategic plans that incorporate sea level rise, coastal flooding, and inland flooding, Virginia Beach should seek to insert its voice, research and data findings into these documents.

Comprehensive Planning

The Virginia Beach Comprehensive Plan is the official land use planning policy framework and comprises the roadmap for the City's future policies, development, and growth. The Planning Department works closely with various departments within the City to include the findings and recommendations of the numerous Sea Level Wise reports into the Comprehensive Plan. The Planning Department is examining how to implement policies, zoning, and ordinances into the Comprehensive Plan in order to begin the process of passing these recommendations into policy. The Planning Department will continue to integrate the most recent research and sea level rise data into the Comprehensive Plan, as this new research becomes available.

Hazard Mitigation Planning

Hazard Mitigation planning in the Virginia Beach region is conducted regionally, and is updated every five years. The current Hampton Roads Hazard Mitigation Plan (HMP) is made up of 22 participating communities throughout southeastern Virginia. The last update of the plan was completed in 2017, and when the next update occurs in 2022, the HMP should include the numerous identified infrastructure and built environment solutions that are highlighted in this document as well as the City-wide structural alternatives within the HMP's mitigation strategies. This is vitally important in order to ensure these projects are ready for a number of federal funding sources and grants should the state receive a major disaster declaration. In addition, nature-based solutions should also be incorporated into the mitigation strategies of the HMP. The City will continue to participate in this planning process and ensure that chosen future mitigation actions are highlighted.

Military Collaboration and Planning

The Norfolk and Virginia Beach Joint Land Use Study, sponsored by the Hampton Roads Planning District Commission, is a joint effort between Norfolk, Virginia Beach, and the Navy installations that call both cities home. The Joint Land Use Study sets forth 22 actions and related coordination strategies that Norfolk, Virginia Beach, and the Navy can implement in response to threats from flooding and sea level rise. These actions aim to strengthen and enhance the Navy's ability to carry out its mission, improve the quality of life for sailors and their families, and allow the Navy to remain a major and robust part of the region's economy. Several strategies developed under the Sea Level Wise study are in alignment with related coordination strategies outlined in the Joint Land Use Study. The City is already engaging with the Navy on some of these actions, and will continue to collaborate and coordinate to refine conceptual strategies and seek opportunities for implementation.

Transportation Planning

The Virginia Beach's Master Transportation Plan is a multi-modal transportation plan that is contained within the City's Comprehensive Plan. Transportation goals and needs have also been integrated into numerous other plans throughout the City. Roads, bridges, and multi-modal infrastructure are affected by the increasing sea level rise and recurrent flooding throughout the City. As the City focuses on improving urban and rural mobility, ensuring that critical transportation routes are not vulnerable to increasing flooding risk is vitally important for the safety of the community as well as the economic prosperity of the region.

The findings of the Sea Level Wise study should be incorporated into the Master Transportation Plan, with a specific focus on the impacts of sea level rise and recurrent flooding on the primary roadway network and the regional transportation plan highway network. In addition, policies relating to transportation in the Policy Response document should be incorporated into the "Recommended Policies: Roadways" in the Master Plan.

Emergency Operations Planning

The Virginia Beach Emergency Operations Plan recognizes all hazards and details how the City should respond to an emergency situation. This plan should include important components of the Sea Level Wise study, particularly in regard to important facilities, evacuation routes, and critical transportation corridors that have been identified as at risk to sea level rise and recurrent flooding.

Capital Improvement Programing

Virginia Beach's Capital Improvement Program plans for the acquisition, construction, expansion, maintenance, rehabilitation, and upgrading of public infrastructure throughout the City. This plan will house the flood defense infrastructure that the City chooses to move forward with. Any updates to transportation and stormwater infrastructure plans to increase resilience and reduce the risk of loss due to sea level rise and recurrent flooding will have to be considered and included. Additional tools to mitigate the impacts of flooding, such as back-up generators for critical facilities, should also be incorporated into the Capital Improvement Program.

Operations Budgeting

Virginia Beach's Operating Budget allocates yearly funding for projects throughout the City, and the Capital Improvement Program feeds into this budget. As the City begins prioritizing mitigation strategies and projects, these should be incorporated into the operating budget. Although larger infrastructure interventions will be housed in the Capital Improvement Program, other aspects of the Sea Level Wise recommendations such as community outreach, engagement, and education should be factored into the Operating Budget. These include projects such as internal data collection and accessibility, but also external focusing portals that serve to provide information to the community in a single, easily accessible location.

The City continuously updates numerous plans, and the burden of keeping these up to date with new data and science regarding sea level rise and precipitation should be budgeted for. In addition, the City may need to fund the creation of additional plans such as the Floodplain Management Plan and the Asset Management Plan in order to better manage the impacts and results of flooding.

Strategic Planning

The City of Virginia Beach's Strategic Plan must continue to address the increasing sea level rise and recurrent flooding which are concerning to so many members of the community. The City should integrate the solutions presented in this document and the findings and research in the broader Sea Level Wise study in an effort to communicate the work that is being done around the topic of sea level rise and the actions that the City is taking to address the problem. The City's Strategic Plan highlights the importance of economic vitality and notes the importance of infrastructure investment to foster growth and prosperity. This section should include ways in which to foster economic resilience in the face of changing climate patterns so that businesses are encouraged to continue to do business in Virginia Beach.

Strategic Growth Area Master Planning

Throughout this document, the Strategic Growth Areas and their importance to the continued growth and success of the City have been discussed in detail. The Sea Level Wise findings and research should be incorporated into the Strategic Growth Area Master Plans, particularly for the Pembroke and Resort Areas, which are particularly susceptible to flooding.

State Coastal Planning

Currently Virginia is in the process of developing a state-wide Coastal Resilience Master Plan. This effort is being done with collaboration from a number of federal and state agencies, as well as local communities. Virginia is incorporating research, analysis, and solution-sets that the City of Virginia Beach has developed over the course of the Sea Level Wise program over the last five years. Many of the strategy elements Virginia Beach has developed can be leveraged in other coastal communities, and even help to address nuisance flooding due to changing precipitation patterns down the entire coast of Virginia. Goal 7 of the Policy Response Report specifically addresses changes to state and federal policy that may incentivize, support and fund local resilience implementation and could be incorporated and bolstered within Virginia's Coastal Resilience Master Plan.

Project Implementation

Realizing the vision of a sea level rise-adapted Virginia Beach will require prioritizing and funding concrete adaptation projects and programs across multiple scales.

The implementation of projects presented in this Strategy will require significant time and resources dedicated to continued planning, stakeholder engagement, construction, and management. Specifics related to project costs, benefits, design and feasibility will likely need to be assessed in further detail to facilitate further prioritization and direct resources in the near-, medium-, and long-term.

While investing in adaptation will save the City and residents money in the long term, the implementation of large-scale adaptation projects will require significant financial capital. The City is evaluating all options to help fund and finance mitigation measures within Virginia Beach. Cities across the United States, both on the coast and inland, have been using innovative funding mechanisms to pay for flooding mitigation. Virginia Beach is carefully considering all of these options and plans to put together a tailored funding plan to pay for the numerous interventions that have been highlighted in this document.

Some elements of the adaptation strategy can be implemented immediately, while others may take decades to fund or fully build out. As implementation progresses over time, overlap and redundancy strengthen the resilience of the system overall, supporting existing protection and providing back-ups in the case of more extreme events.

Ongoing Research

The City plans on reviewing strategies as the science continues to mature and new projections are released. An important piece of tackling sea level rise and recurrent flooding is incorporating new research and findings into planning documents through an iterative process. As science improves, or as new threats arise, the City recognizes that it must be flexible and adaptable when it comes to planning for these evolving challenges.

The science behind sea level rise, precipitation, and recurrent flooding projections is not set in stone. Projections for these are expected to change in the future. The specific localized projections related to sea level rise and flooding will continue to mature, and trajectories may change for better or worse over time. Although proactive adaptation action is crucial, as conditions in Virginia Beach evolve over the next century, specific projects and approaches will need to be flexible and capable to evolve within ever-changing contexts.

Federal Funding Sources

The City is constantly evaluating how we may be able to utilize federal funding to support local flood mitigation infrastructure and address overall flood resilience in the City. Recent disaster declarations such as Hurricane Michael provide funding opportunities to the City through FEMA. In order to receive much of this funding, the infrastructure and planning projects need to be incorporated into the Hampton Roads Hazard Mitigation Plan. Furthermore, while there is significant opportunity to apply for federal funds to support flood mitigation, these programs are very competitive and require City staff time and resources in order to apply, putting further pressure on already limited City resources.

U.S. Army Corps of Engineers Funding

Getting authorization for a Federal flood control project is a top priority for the City. The U.S. Army Corps of Engineers (USACE) oversees national water resources development civil works programs, including flood risk management, navigation, infrastructure, environmental stewardship, recreation, and emergency response. The Water Resources Reform and Development Act (WRRDA) authorizes a wide variety of policies and projects administered by USACE, including flood control. Flood control projects authorized on the WRRDA are eligible for a federal cost share of 65 percent of project costs. Such a cost share agreement is essential for the City to move forward with the coastal flood defense strategies conceptually developed under Sea Level Wise.

FEMA Hazard Mitigation Grants

The FEMA Hazard Mitigation Grant Program provides grant funding to states and local governments following a disaster declaration. The City of Virginia Beach has received $175,000 in funding over the last 10 years. This funding is vital and supports rebuilding efforts post-disaster, helps to build more resilient infrastructure, and could pay for strategies such as home elevations.

FEMA Flood Mitigation Assistance Grants

FEMA Flood Mitigation Assistance Grants provide funding for flood mitigation planning and flood risk reduction projects that will reduce National Flood Insurance Program claims. Congress appropriates money annually for this grant. Potential structural elevation, acquisition, and other site-level mitigation projects recommended in this Strategy are compatible to the Grant requirements.

FEMA Pre-Disaster Mitigation Grants

FEMA Pre-Disaster Mitigation grants are used to reduce and eliminate claims under the National Flood Insurance Program and provide funding to communities to support projects and planning that reduce or eliminate long-term flood damage. Every year Congress appropriates money to fund these grants. The Pre-Disaster Mitigation program is currently in transition following the Disaster Recovery and Reform Act which was passed in October of 2018. This new law will impact large infrastructure funding and will provide ample opportunities for Virginia Beach to apply for funding to support flood infrastructure projects.

Coastal Storm Risk Management Feasibility Study

The authorization and completion of a Coastal Storm Risk Management Feasibility Study is a critical step to move towards USACE project authorization under the WRRDA. The City has been pursuing a feasibility study through direct request to the Norfolk District, as well as applying through USACE Section 7001 authority. After authorization, the feasibility study will take approximately three years to complete, and could potentially cost the City an additional $1.5 million in cost share. The completion of this study would advance the design and evaluation of the flood defense strategies, include an Environmental Impact Statement, and result in a preferred plan that would ultimately be submitted for WRRDA authorization.

FEMA Section 404 Grants

Section 404 grants are used to provide updates and protection to facilities that were not damaged following a disaster declaration. These grants are unique because the entire state can apply, not just those municipalities that received a Presidential disaster declaration following a large disaster.

FEMA Section 406 Grants

Section 406 grants are different than 404 grants because they are funded by FEMA's Public Assistance Program and provide funding for repairs to structures that were damaged during a disaster.

National Coastal Resilience Fund

The National Coastal Resilience Fund is administered by the National Fish and Wildlife Foundation (NWFW) and provides grant funding in order to enhance, strengthen, and restore nature and natural-based assets and infrastructure in coastal communities, while also creating habitats for wildlife.

Housing and Urban Development Grants

Housing and Urban Development (HUD) offers numerous grant programs, with Community Development Block Grants being one of the more well-known programs in terms of resilience funding. This program provides annual grants that promote affordable equitable housing and economic opportunities for vulnerable and disadvantaged communities, which can foster economic resilience and reduce the risk of vulnerable populations to flooding.

Military Funding

The Department of Defense (DoD) Community Infrastructure Pilot Program allows the DoD to make grants and supplement funds available under different agencies to community infrastructure that supports military installations.

The City should explore co-funding and financing opportunities with the Navy for mutually beneficial infrastructure projects.

State Funding Sources

Over the past few years, federal agencies have expected states and municipalities to increasingly take on the burden of funding and financing mitigation. The Commonwealth of Virginia has a number of grant programs that could potentially help pay for many of the projects and approaches identified in the adaptation strategy, without the national competition and significant dependence on post-disaster funding opportunities that federal funding often requires.

Virginia Department of Transportation Funding

There is an opportunity to partner with the Virginia Department of Transportation, potentially utilizing some of its funding, to help finance transportation upgrades and protect roads and bridges from sea level rise and recurrent flooding.

Virginia Department of Conservation and Recreation Fund

The Virginia Department of Conservation and Recreation Fund provides grants for dam safety and floodplain management grants focused on flood prevention and protection. Virginia Beach could potentially utilize this fund to support additional floodplain management planning, paying for additional studies, and implementing additional floodplain ordinances.

Virginia Clean Water Revolving Loan Fund

The Virginia Clean Water Revolving Loan Fund issues loans for the creation of living shorelines. This funding could be utilized to finance a number of the proposed nature-based solutions highlighted in the Sea Level Wise report.

Virginia Shoreline Resiliency Fund

The Virginia Shoreline Resiliency Fund is a low-interest loan fund, appropriated by the Virginia General Assembly, to aid residents in mitigating recurring flooding. Currently the fund has no dedicated funding and is not operational. This could change in the future if the General Assembly allocated capital out of the state budget.

Other Funding Sources

Beyond state and federal sources, the City has a number of options to raise funds through municipal revenue (taxes), bonds, and independent grant sources. The City is also looking at ways to co-fund projects with public utilities and service providers, as federal and state budgets are limited. Any type of bond issued for sea levle rise/ flooding projects impacts the total indebtedness of the City. The City's policy is to issue the most cost-effective bond instrument to minimize interest costs.

General Obligation Bonds

A general obligation bond is a municipal or city bond that is usually paid down through taxation and or revenue from the project which the bond paid for or funded. General Obligation bonds are backed by the full faith and credit of the City government, including its power to tax its citizens. General obligation bonds are among the safest bonds issued by governments and are generally associated with low interest costs.

Revenue Bonds

Revenue bonds are backed by a specific stream of revenue. For example, the City may issue revenue bonds to build water lines and sewage treatment facilities, with the debt to be repaid from usage fees and assessment fees. The dedicated repayment source for revenue bonds provides for lower interest costs.

Catastrophe Bonds

Similar to insurance policies, catastrophe bonds reduce the financial risks that come with a high-risk natural disaster, such as a direct hit by a hurricane. Catastrophe bonds can be purchased by a municipality, which will be set to pay out to the City if a specific event (such as a hurricane) hits the City with specific parameters (such as a 10-foot storm surge).

Social Impact Bonds

A social impact bond is a financial mechanism that works a bit like a contract, usually between a government agency or entity and the private sector. The private sector is paid a higher return on the mitigation investment if it performs better than expected. If the intervention performs worse than expected, the amount the public entity or agency has to pay to the investor is reduced. At present, this is not a suitable approach due to higher interest costs.

Resilience Bonds

Resilience bonds are a complex financial mechanism that uses savings from a planned flood mitigation investment to reduce the insurance premiums that a City has to pay for a catastrophe bond, using this cost savings to fund a new mitigation investment that will reduce risk.

Though resilience bonds are a new mechanism for paying for significant mitigation infrastructure projects, over the next decade, this new mechanism has the potential to become more common as cities seek new ways to fund mitigation. At this time, resilience bonds are not a suitable approach as they are extremely complex and have an excessively high transaction costs.

Mitigation Banks

A mitigation bank acts like much like checking account, in which a series of debits out of one area can be credited to a different area. For example, if development of a subdivision causes the destruction of a wetland, this can be offset by the creation of a new wetland somewhere else. This, in theory, results in a no net loss to the environment.

Municipal Revenue

The City can utilize a variety of municipal revenue streams to help fund flood mitigation strategies. Increasing fees and taxes or reallocating fees and taxes that are already in place are a few options that should be explored. Given the significant financial needs that are highlighted in this document, simply reallocating funds and increasing municipal revenue will not be sufficient to meet the flood mitigation needs of the City. Regardless, the City should continue to look for ways to allocate funds to efficiently and effectively address flood concerns.

Foundation Grants

Many non-profit organizations are dedicated to funding community resilience, risk management, and environmental conservation projects. The National Fish and Wildlife Foundation, for example, is a non-profit organization that has grown to become the nation's largest private provider of conservation grants. Its National Coastal Resilience Fund makes investments to restore and strengthen natural systems to protect communities from the impacts of floods and other natural hazards, while also enhancing habitats for important fish and wildlife populations. This grant is well suited for funding large-scale design, construction, and monitoring of natural and nature-based projects.

Continued Commitment

With this ambitious Adaptation Strategy, the City is committed to increasing flood resilience and ensuring a vibrant future for the City of Virginia Beach.

This strategy document presents a wide variety of potential adaptation initiatives, each with its own costs, benefits, and implementation challenges. 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. Some of the projects will require more detailed cost-benefit and feasibility studies to propel them towards implementation.

Development of this strategy has led to the important acknowledgement that sea level rise adaptation is a complex endeavor with many uncertainties and challenges. As our understanding of flood risks continues to evolve and modeled projections continue to become increasingly sophisticated, this strategy can be further refined. Furthermore, as a leader in adaptation planning and coastal resilience, the City will remain open to integrating additional adaptation options as new ideas and solutions arise.

Reducing flood risks and planning for a vibrant future is an ongoing, iterative process, requiring sustained actions from the City, its partners and local residents. The City of Virginia Beach and project team sincerely thanks the elected officials, municipal staff, and local residents for their partnership and patience in developing this strategy. We also thank you, the Virginia Beach community, in advance for your continued commitment and participation in shaping the future of our city.

Endnotes

1 U.S. Army Corps of Engineers Sea-Level Change Curve Calculator: http://corpsmapu.usace.army.mil/rccinfo/slc/slcc_calc.html

2 Nicholls et al. 2007. Ranking of the World' Cities Most Exposed to Coastal Flooding Today and in the Future. Executive Summary Extract from Organisation for Economic Co-operation and Deveopment, Environment Working Paper No. 1: https://forms2.rms.com/rs/729-DJX-565/images/fl_cities_coastal_flooding.pdf

3 Based on data from the National Oceanic and Atmospheric Administration (NOAA) Center for Operational Oceanic Products and Services

4 Eggleston, Jack, and Pope, Jason, 2013, Land subsidence and relative sea-level rise in the southern Chesapeake Bay region: U.S. Geological Survey Circular 1392, https://pubs.usgs.gov/circ/1392/

5 Date from NOAA Center for Operational Oceanic Products and Services

6 Sweet et. al. 2017. Global and Regional Sea Level Rise Scenarios for the United States. NOAA Technical Report NOS CO-OPS 083.

7 NOAA Center for Operational Oceanographic Products and Services, https://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?id=8638610

8 U.S. Army Corps of Engineers Sea-Level Curve Calculator, http://corpsmapu.usace.army.mil/rccinfo/slc/slcc_calc.html

9 Virginia Institute of Marine Science, Sea Level Rise Report Cards (retrieved November 2020), https://www.vims.edu/research/products/slrc/localities/nova/index.php

10 Sweet et. al. 2014. Sea Level Rise and Nuisance Flood Frequency Changes around the United States. NOAA Technical Report NOS CO-OPS 073.

11 Figure adapted from Union of Concerned Scientists. 2013. Causes of Sea Level Rise Fact Sheet.

12 Federal Emergency Management Agency. 2009. Flood Insurance Study, City of Virginia Beach, Virginia.

13 Values estimated using the Federal Transit Administration's Hazard Mitigation Cost Effectiveness Tool, Coastal Flood Recurrence Interval Estimator.

14 Heath, R. 2004. Basic ground-water hydrology: U.S. Geological Survey Water-Supply Paper 2220. https://pubs.er.usgs.gov/djvu/WSP/wsp_2220.pdf

15 Figure adapted from Rotzoll, K. and C. Fletcher. 2012. Assessment of groundwater inundation as a consequence of sea-level rise. Nature Climate Change. http://www.soest.hawaii.edu/coasts/publications/Rotzoll%20Fletcher%20NCC%202012.pdf

16 Moss, A., and M. Marani. 2016. Coastal Water Table Mapping: Incorporating Groundwater Data into Flood Inundation Forecasts. M.S. Thesis, Duke University. https://pdfs.semanticscholar.org/8c13/456ee54b5a4b1bf1360eb7e0da852b89b283.pdf

17 https://www.cnic.navy.mil/regions/cnrma/installations/nas_oceana.html

18 https://www.usmilitaryonthemove.com/militarybase/joint-expeditionary-base-little-creek-fort-story

19 https://www.vbgov.com/government/departments/agriculture/Pages/default.aspx

20 NOAA—http://www.oyster-restoration.org/wp-content/uploads/2012/06/tnc_noaa.pdf

21 Action-Oriented Stakeholder Engagement for a Reslilient Tomorrow Map—https://odu-gis.maps.arcgis.com/apps/MapSeries/index.html?appid=b671f417edf146aba58210092aa06718

22 ESRI Community Analyst

23 ESRI Community Analyst

24 https://www.nao.usace.army.mil/LynnhavenEco/

25 https://www.govinfo.gov/content/pkg/CDOC-113hdoc176/pdf/CDOC-113hdoc176.pdf

26 https://www.govinfo.gov/content/pkg/CDOC-113hdoc176/pdf/CDOC-113hdoc176.pdf

27 https://www.nao.usace.army.mil/LynnhavenEco/

28 ESRI Community Analyst

29 ESRI Community Analyst

30 ESRI Community Analyst

31 https://www.yesvirginiabeach.com/business-districts/Pages/oceanfront-resort.aspx

32 https://www.nao.usace.army.mil/about/projects/vbhurricaneprotection/

33 https://rudeeinletfoundation.org/virginia-beach-wildlife/

34 ESRI Community Analyst

35 ESRI Community Analyst

36 https://www.vbgov.com/government/departments/agriculture/Pages/default.aspx

37 Rephan, T.J. 2012. Agricuture in Virgnia Beach: Impact on the City Economy. University of Virginia Wheldon Cooper Center for Public Service. https://ceps.coopercenter.org/sites/ceps/files/VB_agriculture_0.pdf

38 Waterfield, H.H. 1951. Aquatic Vegetation Continues to be Retarded in Back Bay and Currituck Sounds after Thirty-Three Years of Investigations and Controversies

39 https://www.vbgov.com/government/departments/public-works/coastal/Pages/sb-bch-replenish-5-5-17.aspx

40 https://www.vbgov.com/government/departments/budget-office-management-services/budget-archives/Documents/fy20-adopted-budget/FY%202019-20%20Adopted%20ExecSummary%20WEB.pdf