CONTRIBUTORS

Technical Lead:
Alaurah Moss

Technical Contributions:
Alec Brazeau
Johanna Greenspan-Johnston
Tyler Miesse
Xiaohai Liu, Ph.D. P.E.

Project Manager, Technical Editor:
Brian Batten, Ph.D.

Copy Editors:
Michelle Bailey

REVISION HISTORY
March 16, 2019 – Draft Report
April 12, 2019 – Updated Report Including Chapter 6 on Numerical Modeling
April 25, 2019 – Draft Report Addressing City Comments
May 16, 2019 – Final Report Addressing City Comments
EXECUTIVE SUMMARY

To address the severe threats from sea level rise and associated recurrent flooding, the Comprehensive Sea Level Rise and Recurrent Flooding (CSLRRF) Study is evaluating a wide array of protection measures: structural, nonstructural, natural and nature-based interventions, illustrated in Figure 1. Natural and Nature-Based Features (NNBF) are features in the coastal landscape that reduce inland flood risks, while also providing economic, environmental, and social benefits to the surrounding area. NNBF are considered a complimentary flood risk management strategy, providing redundancy in flood protection, increasing resiliency, and enhancing the performance and durability of structural measures. This report focuses on identifying and evaluating opportunities for integrating natural and nature-based strategies to decrease short- and long-term flood risk in Virginia Beach. The proposed strategies will need to be evaluated along with policy measures, and neighborhood and city-wide structural solutions to help identify the most effective and practical solution set.

The CSLRRF study will result in strategic response plans to address the unique flooding issues within each of the City of Virginia Beach’s four major watersheds. In alignment with this approach, the suitability of different types of NNBF strategies were evaluated within each of the watersheds: the Lynnhaven, Elizabeth River, Oceanfront and Southern Rivers (hereafter referred to as the ‘Southern’ watershed). This assessment resulted in a high-level conceptualization of potential NNBF strategies across the City of Virginia Beach, shown in Figure 2 on the following page.
Figure 2: Potential natural and nature-based flood mitigation strategies for the City of Virginia Beach.
Numerical modeling can be used to assess the flood risk reduction potential of different NNBF design interventions. To accomplish this, the regional MIKE21 coastal hydrodynamic model developed for the CLSRRF study was leveraged to evaluate potential flood reduction benefits of a conceptual marsh island restoration in Back Bay and Northern North Carolina. The MIKE21 simulations were used to evaluate the benefits of restoring marsh island systems on flooding during a wind tide event for existing conditions (today) and also for a future condition scenario with 3 ft of SLR. The future condition simulation considered the projected degradation of the islands, as assessed by previous work evaluating marsh response to SLR under the CSLRRF study. Model simulations showed that marsh island restoration both reduced flood elevations and also delayed the propagation of flooding into the Back Bay. For example, flood depths were reduced by up to 2 ft on Knotts Island and 1.5 ft along the shorelines of Back Bay, and it took up to 4 days longer for flooding to occur. Overall, the exercise demonstrated that marsh island restoration could help reduce flooding impacts during wind tide events in the Southern watershed.

Additional work is required to understand how the other proposed natural and nature-based strategies compliment the identified policy measures, city-wide and neighborhood structural solutions. Specifically, to fully evaluate the potential of nature-based measures, cost-benefit assessments should be extended to quantify their full risk reduction benefits. This assessment could be taken further by accounting for infrastructure, social, and environmental losses avoided. This would enable a more holistic comparison to traditional engineering approaches.

Furthermore, the evaluation framework and suitability parameters presented in this report need to be systematically applied and evaluated with additional considerations such as design costs, environmental and regulatory requirements. Table 1 outlines a process for incorporating natural and nature-based flood protection measures into adaptation plans, based on a framework from the World Bank. The research presented in this report accomplishes the objectives of Step 3 of this process by developing an initial list of measures and a strategy map of potentially suitable intervention locations. This document also lays foundation work for the following steps through identification of best practices for evaluating, designing, constructing and monitoring NNBF projects. Moving forward, future work will focus on better understanding costs, benefits, and effectiveness of NNBF in Virginia Beach to determine which design interventions are selected for implementation.
Table 1: Process for incorporating nature-based flood protection measures into adaptation plans; graphic adapted from the World Bank

<table>
<thead>
<tr>
<th>STEP 1</th>
<th>STEP 2</th>
<th>STEP 3</th>
<th>STEP 4</th>
<th>STEP 5</th>
<th>STEP 6</th>
<th>STEP 7</th>
<th>STEP 8</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Scope</strong></td>
<td><strong>Ecosystem Aspects</strong></td>
<td><strong>Outputs</strong></td>
<td><strong>Process for incorporating nature-based flood protection measures into adaptation plans</strong></td>
<td><strong>Graphic adapted from the World Bank</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scale of natural system suitable for problem solving</td>
<td>Ecosystem presence, health, and functioning</td>
<td>Ecosystem potential, option identification</td>
<td>Effectiveness of ecosystem measure</td>
<td>Green and hybrid option design</td>
<td>Local investment in interventions, green financing</td>
<td>Conservation, restoration, and/or establishment of ecosystem elements</td>
<td>Monitoring ecosystem performance, resilience and stability</td>
</tr>
<tr>
<td>• Stakeholder needs</td>
<td>• Hazard and risk maps</td>
<td>• List of measures</td>
<td>• Cost-benefit analysis</td>
<td>• Design of measures</td>
<td>• Budget estimate</td>
<td>• Intervention lifetime</td>
<td>• Monitoring reports</td>
</tr>
<tr>
<td>• Maps of area of interest</td>
<td>• Ecosystem and land-use maps</td>
<td>• Strategy map</td>
<td>• Impact assessment</td>
<td>• Monitoring plan</td>
<td>• Overview of resources</td>
<td>• Regulatory frameworks</td>
<td>• Actions if needed</td>
</tr>
<tr>
<td>• Project objectives</td>
<td>• Flood zone maps</td>
<td>• Risk assessment with interventions</td>
<td>• Risk assessment with interventions</td>
<td>• Maintenance plan</td>
<td>• Implemented measures</td>
<td>• Share lessons learned</td>
<td></td>
</tr>
</tbody>
</table>
TABLE OF CONTENTS

CONTRIBUTORS ........................................................................................................................... ii
REVISION HISTORY .................................................................................................................... ii
EXECUTIVE SUMMARY .............................................................................................................. iii
TABLE OF CONTENTS ................................................................................................................ vii
LIST OF FIGURES .......................................................................................................................... x
LIST OF TABLES ......................................................................................................................... xiv
ACRONYMS .................................................................................................................................. xv

1. INTRODUCTION ....................................................................................................................... 1
   1.1. Background ................................................................................................................. 1
   1.2. Purpose ....................................................................................................................... 3
   1.3. Context ........................................................................................................................ 3
       1.3.1. Marsh Response to Sea Level Rise ............................................................ 3
       1.3.2. Water Resources in the Southern Watershed ............................................. 4
       1.3.3. Policy Adaptation ....................................................................................... 5
       1.3.4. Regional Green Infrastructure Planning .................................................... 6
   1.4. Objectives and Approach .......................................................................................... 11

2. IDENTIFICATION OF POTENTIAL STRATEGIES ................................................................ 11
   2.1. Non-Structural Strategies ....................................................................................... 12
       2.1.1. Beach Nourishment/Dune Enhancement: ........................................................ 12
       2.1.2. Wetland Restoration, Enhancement, or Creation ........................................ 13
       2.1.3. Forest Restoration, Enhancement, or Creation ............................................. 14
       2.1.4. Submerged Aquatic Vegetation Restoration ............................................ 15
       2.1.5. Shellfish Reefs/Oyster Restoration .............................................................. 16
   2.2. Hybrid Strategies ...................................................................................................... 17
       2.2.1. Living Breakwaters ...................................................................................... 17
       2.2.2. Ecologically-Enhanced Revetments ............................................................ 17
       2.2.3. Marsh Sills .................................................................................................... 18

3. SUITABILITY OF STRATEGIES .......................................................................................... 19
3.1. Overview ................................................................................................................... 19
3.2. Site Suitability in Virginia Beach ............................................................................ 20
4. EVALUATION AND APPLICATION OF STRATEGIES ..................................................... 24
  4.1. Beach Nourishment and Dune Restoration ............................................................ 26
    4.1.1. Resort Beach ..................................................................................................... 26
    4.1.2. Sandbridge Beach ............................................................................................ 27
    4.1.3. Chesapeake Bay Beaches .................................................................................. 28
    4.1.4. Performance of Recent Nourishment Projects ................................................ 29
    4.1.5. Nourishment Funding ....................................................................................... 31
  4.2. Wetland Restoration, Enhancement, or Creation ................................................... 31
    4.2.1. Beneficial Use of Dredged Materials ................................................................ 34
  4.3. Submerged Aquatic Vegetation Restoration ........................................................... 36
    4.3.1. Lynnhaven River SAV Restoration ................................................................... 36
    4.3.2. Back Bay SAV Restoration .............................................................................. 40
  4.4. Forest Restoration, Enhancement, or Creation ..................................................... 44
  4.5. Living Shorelines / Marsh Sills ............................................................................... 48
  4.6. Living Breakwater Islands ...................................................................................... 51
  4.7. Ecologically-Enhanced Revetments/Bulkheads ...................................................... 56
5. MEASURING PERFORMANCE AND QUANTIFYING BENEFITS ..................................... 57
  5.1. Performance Evaluation Metrics .............................................................................. 57
  5.2. Case Studies ............................................................................................................. 58
  5.3. Cost Benefit Assessment .......................................................................................... 59
6. ASSESSING BENEFITS FOR FLOOD RISK REDUCTION .............................................. 63
  6.1. Projected Changes in Marshes ................................................................................. 64
    6.1.1. Degraded Marsh Islands ................................................................................... 64
    6.1.2. Restored Marsh Islands ..................................................................................... 64
  6.2. Model Grid ................................................................................................................ 65
    6.2.1. Friction Adjustments ......................................................................................... 65
    6.2.2. Elevation Adjustments ....................................................................................... 66
  6.3. Modeling Simulation ................................................................................................ 67
  6.4. Results ...................................................................................................................... 67
6.4.1. How could a marsh island restoration project impact the depth of flooding during a wind tide event? 

6.4.2. Knotts Island

6.4.3. Back Bay and Sandbridge Shorelines

6.4.4. How could a marsh island restoration project impact the timing of flooding during a wind tide event?

7. DESIGN

7.1. Existing Resources

7.2. International NNBF Guidelines

7.3. Sea Level Rise Adaptation

8. PERMITTING

9. NEXT STEPS

10. REFERENCES
LIST OF FIGURES

Figure 1: Integrated approach to flood risk management with multiple lines of defense; illustration adapted from the U.S. Army Engineer Research and Development Center. ..... iii

Figure 2: Potential natural and nature-based flood mitigation strategies for the City of Virginia Beach. ........................................................................................................................................ iv

Figure 3: Integrated approach to flood risk management with multiple lines of defense; illustration adapted from the U.S. Army Engineer Research and Development Center. .......2

Figure 4: Virginia Beach SLAMM analysis results showing wetland response to 1.5 and 3 ft of SLR. ........................................................................................................................................... 4

Figure 5: Land elevations less than 3 ft in Virginia Beach (left panel) and wind-driven tides generated from winds driving water into Back Bay (right panel). .............................................. 5

Figure 6: Green infrastructure network in Virginia Beach identified in the GI Plan for the Hampton Roads Region (2010). ................................................................................................ 7

Figure 7: Green infrastructure vulnerable to development pressures in Virginia Beach identified in the GI Plan for the Hampton Roads Region (2010). ........................................ 8

Figure 8: The Southern Rivers Watershed 50-foot buffer area stipulated in the Southern Rivers Watershed Management Ordinance and the Chesapeake Bay Preservation Act Resource Protection Area 100-foot buffer area. ........................................................................................................ 10

Figure 9: Sandbridge, Virginia Beach nourishment project; photograph obtained from VIMS. 13

Figure 10: Wetlands at Pleasure House Point; photograph courtesy of the City of Virginia Beach photographer. ........................................................................................................................... 14

Figure 11: Maritime forest at First Landing State Park. ................................................................................. 15

Figure 12: Submerged Aquatic Vegetation (SAV). Photograph courtesy of VIMS. ................... 16

Figure 13: Oyster sanctuary on the Lynnhaven River near its inlet to Chesapeake Bay. Photograph courtesy of Dave Harp. ......................................................................................... 16

Figure 14: Example of a floating breakwater island constructed with wetland vegetation from Martin Ecosystems. .................................................................................................................. 17

Figure 15: Example of an ecologically-enhanced revetment. Photograph courtesy of Jon K. Miller (Stevens Institute 2019). ........................................................................................................ 18

Figure 16: Example of a marsh sill. Photograph Courtesy of VIMS. ...................................................... 18
Figure 17: Major watersheds in the City of Virginia Beach........................................................ 20
Figure 18: Potential NNBF strategies in Virginia Beach.................................................................25
Figure 19: Existing beach nourishment projects and direction of sand transport in Virginia Beach. Map courtesy of USACE. ........................................................................................................ 27
Figure 20: Beach nourishment project area at Sandbridge, VA; May courtesy of USACE. ...... 28
Figure 21: Nourishment and dune grass plantings along Chesapeake Beach; photography courtesy of Dewberry.............................................................................................................. 29
Figure 22: Topographic elevation surfaces from Fall 2013 (right panel), Fall 2017 (middle panel), and comparison (left panel) at Sandbridge. This figures shows that as the beach retreated through the nourishment cycle, dunes grew both in height and width resulting in increased storm protection. .................................................................................................... 30
Figure 23: 1869 U.S. Coast Survey of Back Bay, Virginia Beach overlaid on 2016 aerial imagery. ................................................................................................................................................. 32
Figure 24: Jurisdictional boundaries of wetlands in Virginia. ......................................................... 33
Figure 25: Map showing marsh islands and conserved land surrounding the Knotts Island; courtesy of The Nature Conservancy. ........................................................................................................... 34
Figure 26: Simulation of water levels during a 100-year storm generating wind tides in Back Bay. .............................................................................................................................................. 34
Figure 27: Thin-layer marsh restoration project at the Blackwater NRW in Maryland; photographs courtesy of ERDC............................................................ 35
Figure 28: Abundance of SAV in Broad Bay; data obtained from the VIMS SAV Restoration and Monitoring Program.............................................................. 37
Figure 29: Delineation of SAV bed boundaries and estimates of SAV density; data obtained from the VIMS SAV Restoration Monitoring Program.............................................. 37
Figure 30: Mechanical aquatic grass harvester; photograph courtesy of Robert J. Orth. ......... 38
Figure 31: Lynnhaven River Ecosystem Restoration Phase 1 Project Sites................................. 39
Figure 32: Frequency of SAV in Back Bay from 1958 – 1990; graph obtained from Schwab et al. (1990). Y-axis indicates percent coverage of SAV in Back Bay. ................................. 40
Figure 33: Floating turbidity curtain pilot project location in Back Bay................................. 41
Figure 34: 2010 Google Earth image of the deployed floating turbidity curtains on Ragged Island in Back Bay. ................................................................................................................. 42
Figure 35: Pilot project team deploying the floating turbidity curtains in Back Bay ........... 43
Figure 36: Deployed turbidity curtains in Back Bay. ................................................................. 43
Figure 37: Historical comparison of forest coverage from 1937 to 2007. .............................. 44
Figure 38: Forest land area projected to be permanently inundated at high tide with 3 ft of 
SLR. ......................................................................................................................................... 46
Figure 39: Conserved land ownership in Virginia Beach; map courtesy of The Nature 
Conservancy. VOF stands for the Virginia Outdoors Foundation........................................ 47
Figure 40: Living shoreline project; photographs courtesy of Lynnhaven River NOW........... 48
Figure 41: Volunteers with the Virginia Beach Project Green Teens building oyster castle reefs 
along the eastern branch of the Lynnhaven River at Great Neck Park in Virginia Beach in 2015; photograph courtesy of the Virginia Pilot.......................................................... 49
Figure 42: Land elevations in the Southern watershed of Virginia Beach. ............................... 50
Figure 43: Conceptual design of the living breakwater project within Raritan Bay, NY. ........ 51
Figure 44: The Reefmaker concept at Brunswick Town / Fort Anderson in North Carolina. ....52
Figure 45: Example of a reef ball living shoreline project to protect West Bay in Texas; 
photograph courtesy of Reef Innovations.............................................................................. 53
Figure 46: Oyster restoration project in the Lafayette River in Norfolk, Virginia; image courtesy 
of the Elizabeth River Project................................................................................................. 54
Figure 47: Example of a constructed marsh terraces in the Gulf of Mexico; image obtained from 
Brasher (2015). ....................................................................................................................... 55
Figure 48: Characteristics of ecological enhancement hazard mitigation measures for different 
types of revetment/bulkhead retrofit strategies. Table obtained from Zhao et al. (2014). ....57
Figure 49: NOAA framework for assessing GI costs and benefits for flood risk reduction. ...... 60
Figure 50: XBeach model for Magothy Bay Natural Area Preserve, with and without salt marsh 
Figure 51: Flood risk modeling simulation scenarios with and without marsh island restoration. 
.................................................................................................................................................. 64
Figure 52: Comparison of degraded marsh islands (in response to 3 ft SLR), shown on the left, 
and restored marsh islands, shown on the right. ................................................................. 65
Figure 53: Comparison of the reduction in the maximum flood depth during a wind tide event today, between existing conditions (e.g. no action) and a restored marsh island system.

Figure 54: Comparison of the reduction in the maximum flood depth during a future wind tide event with 3 ft of SLR, between the future degraded marsh island conditions (as projected by marsh migration modeling), and a restored marsh island system that is nourished to keep pace with SLR.

Figure 55: Output locations for assessing flood risk reduction at critical access roads.

Figure 56: Comparison of water levels at Muddy Creek Road for the no action simulation versus the restored marsh island scenario at existing sea level condition.

Figure 57: Comparison of water levels at Sandbridge Road for the no action simulation versus the restored marsh island scenario at existing sea level condition.

Figure 58: Comparison of Water Level at the Marsh Causeway for the no action simulation versus the restored marsh island scenario at existing sea level condition.

Figure 59: Comparison of water levels at Sandbridge Road for the no action simulation versus the restored marsh island scenario at the future 3 ft SLR condition.

Figure 60: Comparison of water levels at Muddy Creek Road for the no action simulation versus the restored marsh island scenario at the future 3 ft SLR condition.

Figure 61: Comparison of water levels at the Marsh Causeway for the no action simulation versus the restored marsh island scenario at the future 3 ft SLR condition.

Figure 62: Agencies that may be involved in permitting a natural or nature-based project; image courtesy of the VIMS.

Figure 63: Process for incorporation natural and nature-based flood protection measures into adaptation plans, as adapted from the Word Bank framework.
LIST OF TABLES

Table 1: Process for incorporating nature-based flood protection measures into adaptation plans; graphic adapted from the World Bank.................................................................................................................................vi

Table 2: Living shoreline action items within the Virginia Beach SLR Policy Response Report. 6

Table 3: Floodplain management plan action items within the Virginia Beach SLR Policy Response Report........................................................................................................................................................................... 6

Table 4: Outline of Objectives and Approaches. ................................................................................................. 11

Table 5: Summary of coastal hazard mitigation benefits by strategy type. ................................................. 12

Table 6: Site suitability parameters outlined in the Living Shoreline Design Guidelines for Shore Protection in Virginia’s Estuarine Environments (VIMS 2010). .........................................................21

Table 7: Site suitability parameters for the City of Virginia Beach’s four major watersheds. 22

Table 8: Sources for Non-structural and Hybrid Strategies. ............................................................................ 24

Table 9: Performance Evaluation Metrics; table adapted from the Coastal Green Infrastructure Research Plan for New York City (Zhao et al. 2014).................................................................................................................................................................58

Table 10: Databases of nature-based case study projects. .................................................................................59

Table 11: Design guideline resources ..................................................................................................................77

Table 12: Response of NNBF strategies to rising sea levels. Information obtained from the Stevens Institute of Technology Living Shoreline Engineering Guidelines. .............79

Table 13: USACE Regulatory Program Permit Types; information obtained from the USACE Headquarters. .........................................................................................................................................................81

Table 14: Resources and information on relevant regulations and permitting processes for NNBF projects. .........................................................................................................................................................81
<table>
<thead>
<tr>
<th>ACRONYMS</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>CBPA</td>
<td>Chesapeake Bay Preservation Act</td>
</tr>
<tr>
<td>CCRM</td>
<td>Center for Coastal Resources Management</td>
</tr>
<tr>
<td>CSLRRF</td>
<td>Comprehensive Sea Level Rise and Recurrent Flooding Study</td>
</tr>
<tr>
<td>CY</td>
<td>Cubic Yards</td>
</tr>
<tr>
<td>DEQ</td>
<td>Virginia Department of Environmental Quality</td>
</tr>
<tr>
<td>ERDC</td>
<td>Engineer Research and Development Center</td>
</tr>
<tr>
<td>GHG</td>
<td>Green House Gas</td>
</tr>
<tr>
<td>GI</td>
<td>Green Infrastructure</td>
</tr>
<tr>
<td>GIS</td>
<td>Geographic Information System</td>
</tr>
<tr>
<td>HRPDC</td>
<td>Hampton Roads Planning District Commission</td>
</tr>
<tr>
<td>JPA</td>
<td>Joint Permit Application</td>
</tr>
<tr>
<td>NAACS</td>
<td>North Atlantic Coastal Comprehensive Study</td>
</tr>
<tr>
<td>NEH</td>
<td>National Engineering Handbook</td>
</tr>
<tr>
<td>NNBF</td>
<td>Natural and Nature-Based Features</td>
</tr>
<tr>
<td>NOAA</td>
<td>National Oceanic and Atmospheric Administration</td>
</tr>
<tr>
<td>NRCS</td>
<td>Natural Resources Conservation Service</td>
</tr>
<tr>
<td>NWR</td>
<td>National Wildlife Refuge</td>
</tr>
<tr>
<td>RPA</td>
<td>Resource Protection Area</td>
</tr>
<tr>
<td>SAGE</td>
<td>Systems Approach to Geomorphic Engineering</td>
</tr>
<tr>
<td>SAV</td>
<td>Submerged Aquatic Vegetation</td>
</tr>
<tr>
<td>SLAMM</td>
<td>Sea Level Affecting Marshes Model</td>
</tr>
<tr>
<td>SLR</td>
<td>Sea Level Rise</td>
</tr>
<tr>
<td>SMM</td>
<td>Shoreline Management Model</td>
</tr>
<tr>
<td>SWAMP</td>
<td>Southern Watershed Management Program</td>
</tr>
<tr>
<td>SWEL</td>
<td>Stillwater Elevation Surfaces</td>
</tr>
<tr>
<td>TNC</td>
<td>The Nature Conservancy</td>
</tr>
<tr>
<td>UNCW</td>
<td>University of North Carolina at Wilmington</td>
</tr>
<tr>
<td>USACE</td>
<td>U.S. Army Corps of Engineers</td>
</tr>
<tr>
<td>USDA</td>
<td>U.S. Department of Agriculture</td>
</tr>
<tr>
<td>USFWS</td>
<td>U.S. Fish and Wildlife Service</td>
</tr>
<tr>
<td>UVA</td>
<td>University of Virginia</td>
</tr>
<tr>
<td>VIMS</td>
<td>Virginia Institute of Marine Sciences</td>
</tr>
<tr>
<td>VMRC</td>
<td>Virginia Marine Resources Commission</td>
</tr>
</tbody>
</table>
1. INTRODUCTION

1.1. Background

In 2015, the City of Virginia Beach initiated the Comprehensive Sea Level Rise and Recurrent Flooding Study (CSLRRF). The genesis of the study was both in recognition of increased flooding and the need for a strategic plan to protect the City of Virginia Beach. The goal was to produce the needed information and strategies to enable the City of Virginia Beach to establish long-term resilience to sea level rise (SLR) and associated recurrent flooding. In alignment with the U.S. Army Corps of Engineers’ (USACE) integrated coastal flood risk management approach, the City of Virginia Beach is considering a wide array of physical protection measures: natural, nature-based, nonstructural, and structural interventions. This report focuses on identifying and evaluating opportunities for integrating natural and nature-based adaptation strategies in Virginia Beach, in combination with other structural measures, to provide comprehensive flood protection.

Natural and Nature-Based Features (NNBF), also referred to as “Green Infrastructure” (GI), are features in the landscape that provide flood risk reduction benefits, while also producing additional economic, environmental, and/or social benefits. For example, coastal wetlands provide coastal storm surge protection by attenuating waves and stabilizing sediments, but also provide benefits related to recreation and tourism, clean water, and habitat for threatened or endangered species. These broader benefits to human systems and interests derived from the natural environment are generally known as ecosystem services.

The level of flood protection provided by NNBF will vary across geographic areas due to the type and severity of the flood hazard. For example, at smaller scales such as protecting from recurrent flood events along a neighborhood shoreline reach, a living shoreline may have equal or greater benefits than a traditional rip-rap revetment. In this situation, considering NNBF as an alternative strategy may be appropriate. However, at larger scales such as protecting from...
high storm surges in the Lynnhaven watershed, a storm surge barrier or tide gate at the Lynnhaven Inlet will be much more effective at attenuating high storm surges than a living shoreline. Even in situations where structural measures are necessary to serve as the primary line of defense, NNBF can complement such a system. NNBF can often serve as a second line of defense, and help prolong the useful life and function of the primary structural measures while also providing an array of ecosystem services (Bridges et al. 2015b). Figure 3 illustrates an integrated approach that employs the full array of flood risk mitigation strategies by combining NNBF with more conventional flood defense systems and nonstructural policy measures. This report will explore the suitability of different types of NNBF to mitigate the array of flood risk conditions across City of Virginia Beach’s diverse watersheds. In particular, NNBF might be well suited to the Southern watershed given the low-lying topography, frequent wind tide events, and presence of degrading wetlands.

![Diagram of multiple lines of defense](image)

Figure 3: Integrated approach to flood risk management with multiple lines of defense; illustration adapted from the U.S. Army Engineer Research and Development Center.

When considering the use of NNBF, it is also important to recognize the dynamic and variable nature of NNBF systems. The long-term flood risk reduction and ecosystem benefits provided by NNBF varies 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. Furthermore, NNBF can adapt to changing environmental and risk conditions, thereby potentially exceeding the design lifetime of traditional engineered structures (World Bank 2017).
1.2. Purpose

The purpose of this report is to document best practices for identifying, evaluating, designing, constructing, and monitoring NNBF projects, as determined through a review of relevant local and international case studies, guidelines, and published literature. Based on these findings, this document proposes evaluation metrics and methods for measuring project performance and quantifying benefits. It also presents resources and recommendations for project design, and lays out relevant local, state and federal environmental permitting regulations that NNBF projects would likely need to navigate. This document lays out foundational groundwork for including nature-based strategies in the watershed-level and City-wide implementation plans.

1.3. Context

This report expounds upon the potential strategies outlined in the Analysis of Marsh Response to SLR report (CVB 2018), the Water Resources in the Southern Watershed of Virginia Beach report (CVB 2017), and explores applicable strategies identified in the Virginia Beach Sea Level Rise Policy Response report (CVB 2019).

1.3.1. Marsh Response to Sea Level Rise

Marshes play an important flood attenuation role during storm events as they act as a sponge, slowing down the movement of water. As part of the impact assessment phase of the CSLRRRF study, the City of Virginia Beach performed an analysis on marsh response to future flooding conditions. Wetland changes under conditions of 1.5 and 3 ft of SLR were simulated using the Sea Level Affecting Marshes Model (SLAMM), an industry-standard approach. Simulation results were evaluated to understand what marsh types are most vulnerable or resilient to SLR, and to identify areas in the City of Virginia Beach that are projected to experience marsh loss or gain.

The analysis found that most marshes are projected to sustain substantial losses, especially during the second half of the century under higher rates of SLR. The largest losses are projected to occur in Back Bay, North Landing River, and Lynnhaven Bay within marsh island systems and fringing marshes, shown in Figure 4. In addition to reducing overall marsh extent, the spatial evolution reveals that higher sea levels result in smaller, fragmented wetlands, impacting the provision of ecosystem services such as flood control. Some marsh types, however, were found to be resilient to SLR. These marshes were mostly located in areas without hardened shoreline or heavy upland development, allowing for marsh migration. The analysis results make a compelling case for exploration of strategies that would ensure marshes...
in Virginia Beach can maintain or increase their flood protection services in the present and into the future. The report outlines several of the recommended strategies, including marsh restoration and living shorelines.

Figure 4: Virginia Beach SLAMM analysis results showing wetland response to 1.5 and 3 ft of SLR.

1.3.2. Water Resources in the Southern Watershed

Virginia Beach’s Southern watershed is particularly susceptible to repetitive flooding due to the extensive low-lying areas, poorly draining soils, high groundwater levels and wind-driven tides. The City of Virginia Beach undertook a comprehensive review of water resources in the Southern watershed to better understand these issues, documented here. The Back Bay experiences frequent wind tides, which result in flooding due to the low-lying nature of land surrounding the Back Bay and North Landing River, shown in Figure 5 (left panel). Flooding is worse during periods of southerly winds, which drive coastal waters up into Back Bay from the Pamlico, Albemarle, and Currituck Sounds, shown in Figure 5 (right panel). Historic losses in marshes and native submerged aquatic vegetation (SAV) have sparked interest in preserving and restoring these habitats, in addition to exploring other nature-based solutions to reduce flood risk in the Southern watershed.
1.3.3. Policy Adaptation

The Virginia Beach Sea Level Rise Policy Response report lays out a framework for integrating flood resilience into ongoing policy and planning processes city-wide. The report includes a diverse range of policy action items to guide the implementation phase of the CSLRRF. Each policy action item was ranked and prioritized under a collaborative effort involving numerous departments within the City of Virginia Beach municipal government. Several of the policy objectives relate to integrating nature-based flood mitigation solutions, listed in Table 2 and Table 3. The report also highlights the value of employing engineering and planning practices traditionally used to manage stormwater flooding—including NNBF strategies such as forest restoration—to mitigate both inland and coastal flooding concerns at the same time.
Table 2: Living shoreline action items within the Virginia Beach SLR Policy Response Report.

<table>
<thead>
<tr>
<th>LIVING SHORELINE ACTION ITEMS</th>
<th>PRIORITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Collaborate with the Nature Conservancy, Back Bay Wildlife Refuge, Department of Game and Inland Fisheries, Department of Conservation and Recreation, and other interested stakeholders in marsh and submerged aquatic vegetation restoration.</td>
<td>HIGH</td>
</tr>
<tr>
<td>2. Provide technical assistance, grants, loans, or tax incentives to private landowners to assist in the removal of hardened shorelines and the design and construction of living shorelines, such as through participation in the Commonwealth’s living shoreline loan program.</td>
<td>MED-HIGH</td>
</tr>
<tr>
<td>3. Provide contractor training programs to build the capacity of local contractors to design and construct living shoreline projects.</td>
<td>MED-HIGH</td>
</tr>
<tr>
<td>4. Build pilot soft or living shoreline projects on city-owned properties and replace hardened shorelines to demonstrate the effectiveness of these approaches.</td>
<td>MED-HIGH</td>
</tr>
</tbody>
</table>

Table 3: Floodplain management plan action items within the Virginia Beach SLR Policy Response Report.

<table>
<thead>
<tr>
<th>FLOODPLAIN MANAGEMENT PLAN ACTION ITEMS</th>
<th>PRIORITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Formally adopt the most recent findings regarding sea level rise estimates and increased rainfall provisions into the stormwater design requirements and fully integrate these considerations into stormwater management and design practice.</td>
<td>HIGH</td>
</tr>
<tr>
<td>2. Consider incentives, such as reduced stormwater fees, for residential properties that reduce impervious surface coverage or install green infrastructure features above and beyond BPM or other requirements.</td>
<td>MED-HIGH</td>
</tr>
<tr>
<td>3. Establish an interagency green infrastructure working group to review existing and future capital improvement projects and identify opportunities to integrate green infrastructure practices into projects.</td>
<td>MED-HIGH</td>
</tr>
<tr>
<td>4. Preserve existing tree canopy, encourage re-introduction of tree canopy into existing development, where feasible, and set minimum canopy requirements for new development in the City’s green infrastructure planning documents, recognizing the role that forests can play in flood mitigation. Implement the recommendations proposed in the Urban Forest Management Plan, and improve recognition of the benefits of urban forest in mitigation of flooding.</td>
<td>MED-HIGH</td>
</tr>
<tr>
<td>5. Complete an assessment of relative flood risk from stormwater drainage issues due to future losses from sea level rise to inform capital improvement.</td>
<td>MEDIUM</td>
</tr>
<tr>
<td>6. Explore expanding the current green infrastructure policy for new school construction, which requires the result of a 10 year storm to be retained on site, to all newly constructed City facilities.</td>
<td>MED-LOW</td>
</tr>
</tbody>
</table>

1.3.4. Regional Green Infrastructure Planning

This work also builds upon the previous work of the City of Virginia Beach and regional GI planning documents. The Green Infrastructure Plan for the Hampton Roads Region represents an ongoing effort by the Hampton Roads Planning District Commission (HRPDC) to develop a useful planning tool for local and regional planners. The goal of the plan is to delineate the existing GI network and to identify and prioritize a network of valuable conservation lands.

The GI network model was created using multiple datasets including wetland, riparian corridors, ecological cores, and land cover. A weighted overlay analysis was created using geographic information system (GIS) mapping to identify and rank areas suitable for GI, shown in shown in Figure 6. As significant component of this assessment, the vulnerability to
development model identifies areas of the GI network that are most at risk for development, shown in Figure 7. This model can be used to analyze development pressure as key factor in the prioritization of lands for protection through conservation easements or purchasing when funding is available.

Figure 6: Green infrastructure network in Virginia Beach identified in the GI Plan for the Hampton Roads Region (2010).
The City of Virginia Beach incorporated information from the regional GI planning efforts into its comprehensive plans, growth management strategies, watershed management plans, parks and recreation plans, sustainability plans, and water quality implementation plans. For example, GI recommendations from the Southern Watershed Management Program (SWAMP)
are referenced in the City of Virginia Beach Comprehensive Plan. Building on SWAMP, The Hampton Roads Conservation Corridor Study provided a GI-based approach to identifying important natural resources in the Hampton Roads region. Also as part of SWAMP, the Virginia Department of Conservation and Recreation’s Division of Natural Heritage prepared a Conservation Plan for the Southern Watershed Area, which was adopted as part of the City of Virginia Beach comprehensive plan and implemented by the Southern Rivers Watershed Management Ordinance intended to protect, enhance, and restore water quality in the Southern watershed. The ordinance develops a 50-foot buffer to control development landward of wetlands and shorelines (Figure 8). The northern watersheds of Virginia Beach are subject to the Chesapeake Bay Preservation Act (CBPA) Resource Protection Area (RPA). RPA’s are composed of tidal wetlands, non-tidal wetlands connected by surface flow and contiguous to tidal wetlands or water bodies with perennial flow, tidal shores, such other lands considered necessary to protect the quality of state waters.

All of these efforts lead to a more detailed, multi-jurisdictional GI Plan for the North Landing River Corridor called the Green Sea Blueway and Greenway Management Plan. This effort aimed to develop and implement a collaborative watershed management strategy for blueways (i.e., rivers, creeks, or streams that serve as a wildlife corridor, a means of preserving water quality, and paddle trails) and greenways (i.e., protected corridor of open space that include land and water conservation, recreation, and pedestrian and bicycle access) in the Southern watershed.
Figure 8: The Southern Rivers Watershed 50-foot buffer area stipulated in the Southern Rivers Watershed Management Ordinance and the Chesapeake Bay Preservation Act Resource Protection Area 100-foot buffer area.
1.4. Objectives and Approach

The objective of this research is to identify and evaluate opportunities for implementing natural and nature-based strategies for coastal flood risk mitigation in the City of Virginia Beach. This report focuses on documenting best practices for identifying, evaluating, designing, and monitoring the performance of NNBF projects. Table 4 describes these objectives and outlines the approach used to accomplish these tasks.

Table 4: Outline of Objectives and Approaches.

<table>
<thead>
<tr>
<th>Objective</th>
<th>Description</th>
<th>Approach</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Identify potential NNBF strategies</td>
<td>A menu of potential NNBF that could be used to provide flood risk reduction benefits will serve as a starting point for this review. In addition, a range of factors will determine which measures are appropriate to a given location.</td>
<td>Review best practices for identifying and selecting different types of NNBF based on local conditions, such as site suitability frameworks.</td>
</tr>
<tr>
<td>2) Evaluate application of NNBF strategies within Virginia Beach</td>
<td>The next step is to evaluate which nature-based strategies may be appropriate in different locations in Virginia Beach to achieve flood risk reduction benefits.</td>
<td>Identify strategies that are appropriate to different locations in Virginia Beach using the information obtained in Objective #1. Provide case study examples of strategies that have been successfully implemented in Virginia Beach and identify ongoing research activities and/or innovative pilot projects.</td>
</tr>
<tr>
<td>3) Design NNBF projects.</td>
<td>Design guidelines provide direction to the engineering and regulatory community on how to address the full project life cycle of NNBF projects, including conceptualization, design, engineering, construction, and maintenance</td>
<td>Review best practices and guidelines for designing NNBF projects.</td>
</tr>
<tr>
<td>4) Measure performance of NNBF projects.</td>
<td>Performance metrics can be used to evaluate (either qualitatively or quantitatively) the effectiveness of NNBF projects in providing coastal flood risk reduction benefits.</td>
<td>Review best practices for monitoring and measuring the performance of NNBF; Use case studies with available project monitoring data to highlight project successes, limitations, and lessons learned.</td>
</tr>
</tbody>
</table>

2. IDENTIFICATION OF POTENTIAL STRATEGIES

The first step of this effort was to develop a menu of nature-based flood mitigation strategies for Virginia Beach. The Virginia Institute of Marine Sciences (VIMS) Center for Coastal Resources Management (CCRM) identified a number of design alternatives suitable for coastal areas in Virginia (CCRM 2019). These strategies, along with the full array of coastal risk reduction measures identified by the USACE North Atlantic Coastal Comprehensive Study (NACCS) (Bridges et al. 2015), were evaluated for their ability to provide flood risk reduction services. The following strategies were selected as having the highest potential to provide flood risk reduction benefits in Virginia Beach.
Non-structural methods focus on creating or enhancing the dominant natural features already present and contributing to flood risk reduction, while hybrid techniques 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”—a label which was originally applied only to low profile stone or natural breakwaters known as marsh sills, but has since evolved to encompass a wide variety of projects that incorporate ecological principles into engineering design (Stevens Institute 2016). A summary of the coastal hazard mitigation and ecological benefits provided by these strategies is summarized in Table 5.

Table 5: Summary of coastal hazard mitigation benefits by strategy type.

<table>
<thead>
<tr>
<th>Coastal Hazard Service</th>
<th>Natural and Nature-Based Features</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dunes and Beaches</td>
</tr>
<tr>
<td></td>
<td>Wetlands</td>
</tr>
<tr>
<td></td>
<td>Maritime Forests/Shrub Communities</td>
</tr>
<tr>
<td></td>
<td>Submerged Aquatic Vegetation (SAV)</td>
</tr>
<tr>
<td>Storm surge reduction</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>X*</td>
</tr>
<tr>
<td>Reduce peak flood height and lengthen time to peak flood</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>X*</td>
</tr>
<tr>
<td></td>
<td>X*</td>
</tr>
<tr>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Breaking offshore waves</td>
<td></td>
</tr>
<tr>
<td></td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Wave energy attenuation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Reduce current velocities</td>
<td></td>
</tr>
<tr>
<td></td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Shoreline erosion/stabilization</td>
<td></td>
</tr>
<tr>
<td></td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

*Potential storm surge reduction during smaller storm events.

2.1. Non-Structural Strategies

2.1.1. Beach Nourishment/Dune Enhancement:

Beach nourishment is a soft armoring technique that involves pumping sand on an existing beach to raise its elevation and increase beach width. A wider beach improves storm protection by increasing the distance between the upland bank and waves. This encourages beach and dune formation which can further be enhanced and stabilized with beach and dune plants that can act as a buffer for coastal flooding. A nourished beach is expected to gradually erode away through wind and wave action to other areas of the coast. In order to maintain the level of desired protection, periodic nourishment is often required.
2.1.2. **Wetland Restoration, Enhancement, or Creation**

Wetlands are low-lying ecosystems that accommodate specific types of vegetation adapted to permanent or frequent inundation. Wetlands provide numerous essential functions in an ecosystem, including flood and erosion control, water purification, and food and habitat for wildlife. Crucially, the grasses within coastal or tidal wetlands provide vegetation-induced resistance, which can dissipate wave energy, delay storm surge intrusion, buffer tidal flooding, and alleviate erosion. Degraded wetlands can be restored or enhanced to reestablish or increase wetland functions. Restoration involves returning a wetland habitat to the closest approximation of the original natural condition that existed prior to degradation, while wetland enhancement involves modifying an existing wetland by augmenting specific site conditions to improve one or more wetland functions (NRCS 2008). Wetland connectivity and size is an important aspect of restoration as fragmentation can impact the ability of wetlands to provide ecosystem services. Most importantly, coastal wetlands that are too small or fragmented are unlikely to provide adequate flood control services.

If a natural marsh is absent or too narrow to prevent shoreline erosion, creation of a new wide marsh may be possible. Upland areas with low banks can be excavated and graded to create new tidal marshes. Sand fill can be placed to raise the elevation, but this practice is typically not effective without some type of containment structure, such as using temporary growing materials. Temporary growing materials are manufactured products and geotextiles that provide temporary stabilization for wetland planting areas (CCRM 2019). If sand fill or plants may be washed out by waves or tidal currents, then another type of more permanent containment structure may be needed (see marsh sills in Hybrid Strategies).
2.1.3. Forest Restoration, Enhancement, or Creation

Maritime forests are new or restored forests that can tolerate strong winds, periodic or permanent flooding, high salinity and sandy soils. Maritime forests also provide vegetative-induced resistance, acting as an inland buffer to surge and waves during storms events. When designed and maintained properly, these systems have the capacity to dissipate wave energy, impede flow, retain sediment, and absorb and store flood waters. Additional benefits of these forests include protection from coastal erosion and preservation of wetlands. Furthermore, maritime forests with a healthy vegetative canopy act as natural vegetative barriers to reduce wind speeds which is a particular concern in the Southern watershed in Virginia Beach. Studies show that wind speeds through forests can be reduced by more than 50% at a leeward distance of 20 times the forest height (Zhao et al. 2014).

The most notable limitation to forest restoration is the space requirements related to strategy siting, sediment fill and erosion protection to allow vegetation to become established in higher energy areas. Additionally and similar to wetlands, forest size connectivity is an important factor in determining ecological benefits and flood hazard mitigation potential. For example, studies have shown that miles of healthy forests are required to significantly attenuate inundation caused by hurricanes. However, during smaller storm events, narrow belts of coastal forests can reduce wind and storm wave impact. Understanding the effects of patch dynamics can help improve design to promote a more effective arrangement (Zhao et al. 2014; Fritz and Blunt 2007).
2.1.4. **Submerged Aquatic Vegetation Restoration**

Underwater grass beds, known as submerged aquatic vegetation (SAV), are comprised of rooted flowering plants that have colonized primarily soft sediment habitats in coastal, estuarine, and freshwater habitats (Chesapeake Bay Program). High densities of SAV provide friction in the water column that retards water flow and reduces amplitude and duration of flood events. SAV also provide additional functions such as capturing and filtering sediment and polluted runoff in the water, reducing turbidity and improving water clarity, and providing habitat for fish and other aquatic species.

SAV restoration strategies involve making conditions more suitable for SAV survival. This involves upland land-use planning activities such as riparian buffer planting to control nutrient runoff, thus improving water quality. Activities that aim to reduce turbidity such as controlling boat wake and dredging activities also benefit SAV by improving water clarity. Where water quality is good enough to support SAV survival, hands-on restoration efforts such as seed dispersal and plantings can help establish, expand, or diversify grass communities. Small test plantings can be used to evaluate whether conditions at a particular location can support SAV. If test plantings are successful, larger-scale restoration may accelerate the recovery of SAV (VIMS 2019). SAV restoration is a complimentary strategy to marsh restoration because higher densities of SAV mean less wave action, leading to less fringe marsh and marsh island erosion.
2.1.5. **Shellfish Reefs/Oyster Restoration**

Shellfish reefs are submerged or semi-emergent aquatic habitats that function in a similar manner to constructed breakwaters or marsh sills. Loose, uncontained shell is highly suitable for shellfish recruitment, but is not usually effective for reducing wave height and energy except for very low energy settings. Contained shell in bags or cages can be placed in similar arrangements as stone sills for better wave attenuation. Shell-based reefs located next to natural or planted tidal marshes will increase the living shoreline habitat diversity.
2.2. Hybrid Strategies

2.2.1. Living Breakwaters

Living breakwaters aim to achieve similar flood mitigation functions as conventional breakwaters but incorporate ecological components to achieve multiple benefits. Living breakwaters are built at emergent elevation in offshore shallow water areas, and can either be designed to float or be attached to a bottom substrate. These features can break offshore waves and attenuate storm surge on the protected side of the barrier. When utilized as part of a living shoreline project, constructed breakwater islands are designed to reduce the wave energy to acceptable levels to allow the establishment of a beach or vegetation (typically marsh or SAV) in its lee. The constructed breakwater island appears more natural than traditional breakwaters and provides favorable conditions for other natural features.

Figure 14: Example of a floating breakwater island constructed with wetland vegetation from Martin Ecosystems.

2.2.2. Ecologically-Enhanced Revetments

Revetments are shore-attached structures built along the shoreline to prevent erosion of the bank and dissipate wave energy on their sloping face. These shoreline armoring structures are typically constructed from rock or concrete armor units, but natural elements can be incorporated to achieve additional ecosystem service benefits. As part of a living shoreline strategy, the spaces in a traditional revetment can be planted, resulting in an ecologically enhanced version of a traditional stone revetment. Incorporating vegetation within the revetment can help stabilize the soil under the revetment and provide some flood storage benefits.
2.2.3. Marsh Sills

Marsh sills are one of the most traditional types of hybrid living shoreline project. A marsh sill is typically a low-profile stone structure constructed in the water parallel to the existing shoreline. Suitable construction materials for the sill structure include rip rap stones or clean broken concrete. Oyster castle blocks, constructed concrete blocks that contain 30% oyster shells, are another form of a sill structure that can be used in environments suitable for shellfish recruitment. Sills are used to create a new planted marsh where one does not occur naturally, or to armor or widen an existing marsh. Sills cause waves to break on the offshore structure, creating a protected area designed to allow sediment to accumulate between the structure and the shoreline. Eventually, this process can increase the width and elevation of the marsh platform. To accelerate this process, the area between the sill land shoreline is often filled during construction and marsh plantings are added to further stabilize the new marsh platform.
3. SUITABILITY OF STRATEGIES

3.1. Overview

There are a range of factors, listed to the right, which will determine which measures are appropriate to a given location. In general, the most suitable sites for non-structural methods have only minor erosional problems, shallow slopes and depths, and low wave energy. For higher energy sites with more wave action and severe erosion issues, added structural measures allows for the growth of vegetation and persistence of natural habitat features.

The VIMS CCRM provides several useful resources for evaluating site suitability for nature-based solutions. The VIMS Living Shoreline website provides information on suitable sites for different types of nature-based strategies. VIMS also developed the Living Shoreline Design Guidelines for Shore Protection in Virginia’s Estuarine Environments (VIMS 2010) to provide guidance on where living shoreline strategies are appropriate and what is involved in their design and construction. This guidance includes a site evaluation worksheet to help standardize data collection when evaluating site suitability.

The CCRM also provides a Comprehensive Coastal Resources Management Portal for the City of Virginia Beach which serves as a gateway to information and tools to evaluate shoreline conditions and determine appropriate shoreline best management practices. One such tool is the Shoreline Assessment Mapper for Virginia Beach which provides various geospatial datasets to support site suitability assessments. Another useful tool is CCRM’s Shoreline Management Model (SMM), a geospatial model that determines preferred shoreline practices based on available spatial data. These resources are discussed in further detail in the next section.

<table>
<thead>
<tr>
<th>SITE SUITABILITY PARAMETERS</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Bank vegetation cover &amp; bank height</td>
</tr>
<tr>
<td>- Presence or absence of natural buffers – tidal marshes, beaches, riparian forests</td>
</tr>
<tr>
<td>- Nearshore water depth</td>
</tr>
<tr>
<td>- Wave exposure (fetch)</td>
</tr>
<tr>
<td>- Proximity of coastal development to the shoreline</td>
</tr>
<tr>
<td>- Shore morphology</td>
</tr>
<tr>
<td>- Shoreline orientation</td>
</tr>
<tr>
<td>- Erosion rate</td>
</tr>
<tr>
<td>- Slope</td>
</tr>
<tr>
<td>- Elevation</td>
</tr>
<tr>
<td>- Depth offshore (and offshore bathymetry)</td>
</tr>
<tr>
<td>- Existing nearshore vegetation</td>
</tr>
<tr>
<td>- Water level</td>
</tr>
<tr>
<td>- Tide range</td>
</tr>
<tr>
<td>- Wind direction</td>
</tr>
<tr>
<td>- Storm frequency/surge level</td>
</tr>
<tr>
<td>- Wave climate</td>
</tr>
<tr>
<td>- Boat wakes</td>
</tr>
<tr>
<td>- Bank condition (e.g. erosional, stable, transitional, undercut, etc.)</td>
</tr>
<tr>
<td>- Upland land use</td>
</tr>
<tr>
<td>- Existing shoreline defense structures</td>
</tr>
<tr>
<td>- Property ownership</td>
</tr>
</tbody>
</table>
3.2. Site Suitability in Virginia Beach

Four major watersheds exist across the City of Virginia Beach, as shown in Figure 17.

The variety of physical and hydrodynamic settings across the watersheds provide a range of opportunities for implementation of natural and nature-based flood mitigation strategies. Additionally, while design interventions ultimately occur at the site-scale, the long term viability of flood-reducing NNBF depends on the integrity and health of ecosystems at the landscape scale (Word Bank 2017), such as within watersheds.

Although each of the City of Virginia Beach’s four major watersheds exhibit internal variability, summarizing factors at the watershed-level is a useful initial step for identifying potentially suitable locations for nature-based solutions. Table 6 provides information on ten site suitability parameters identified in the Living Shoreline Design Guidelines for Shore Protection in Virginia’s Estuarine Environments (VIMS 2010). Numerous data sources were consulted to define and populate values for these parameters within the four major watersheds, as summarized in Table 7.
Table 6: Site suitability parameters outlined in the *Living Shoreline Design Guidelines for Shore Protection in Virginia’s Estuarine Environments* (VIMS 2010).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Definition (VIMS 2010)</th>
<th>Data Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shoreline Orientation</td>
<td>Shoreline orientation is the direction the shoreline faces. Measured normal to the shoreline.</td>
<td>Aerial photography</td>
</tr>
<tr>
<td>Shore Morphology</td>
<td>Shore morphology, or structure, includes the following types: pocket, straight, headland, or irregular. This parameter determines the level of protection from wave action.</td>
<td>Aerial photography (VIMS 2010)</td>
</tr>
</tbody>
</table>
| Fetch/Wave Climate                     | Fetch is the horizontal distance over which wave-generating winds blow. Generally, the greater the fetch exposure, the higher the waves for any given wind speed. Hardaway et al. (1984) categorized wave energy acting on a shoreline into three general categories based on fetch:  
  - Low energy: fetch < 1 mile  
  - Medium energy: fetch 1 – 5 miles  
  - High energy: fetch > 5 miles | VIMS (2005)  
  VIMS (2010)  
  Shoreline Management Model            |
| Depth/Slope Offshore                   | The nearshore gradient and depth offshore will influence incoming waves. A broad shallow nearshore area tends to attenuate waves relative to an area with the same fetch but with deeper water offshore. | Bathymetric LiDAR  
  Shoreline Assessment Mapper  
  Shoreline Management Model          |
| Nearshore Morphology                   | Nearshore morphology evaluates the presence of offshore, non-vegetated tidal flats and sand bars, which are typically associated with shallow nearshore areas. Extensive tidal flats and/or sand bars will help reduce wave action against the shoreline. | VIMS (2010)  
  Shoreline Assessment Mapper  
  Shoreline Management Model          |
| Nearshore Submerged Aquatic Vegetation (SAV) | Nearshore SAV have the potentially to efficiently attenuate waves before reaching the shoreline.                                                                                                               | VIMS (2010)  
  Shoreline Assessment Mapper  
  Shoreline Management Model  
  SAV Chesapeake Bay Mapper  
  Expert knowledge                   |
| Wetlands                               | The presence of existing wetlands provides potential at a site for restoration or wetland construction activities.                                                                                              | CVB (2018)                                                                   |
| Tide Range                             | Mean tide range is the difference between mean high and mean lower water levels. Tide range is an important factor because features must be placed at the correct elevation to align with the hydrodynamic regime at the site. | NOAA Tides and Currents  
  VIMS (2010)                                                                   |
| Storm Surge                            | Storm surge refers to the maximum water elevation reached during a 100-year storm. High water levels during a storm can result in shoreline erosion and can affect the performance of the feature. | Stillwater Elevation Surfaces (SWEL) developed for the CSLRRF Study          |
| Erosion Rates                          | Long-term erosion rates indicate shoreline stability at the site.                                                                                                                                               | VIMS Shoreline Change Data  
  Shoreline Management Model          |
| Shoreline Structures                   | Proximity of the site to infrastructure and/or existing shoreline defense structures may affect success of the project. The condition of the structures and their effects on shoreline processes should also be considered. | Shoreline Assessment Mapper  
  Shoreline Management Model          |
Table 7: Site suitability parameters for the City of Virginia Beach’s four major watersheds.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Oceanfront</th>
<th>Lynnhaven</th>
<th>Elizabeth River</th>
<th>Southern</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shoreline Orientation</td>
<td>Northeast</td>
<td>Variable</td>
<td>Variable</td>
<td>Variable along shorelines of Back Bay and North Landing River Northe...</td>
</tr>
<tr>
<td>Shore Morphology</td>
<td>Straight beaches</td>
<td>Headland beach (Fort Story)</td>
<td>Irregular (Elizabeth River shoreline)</td>
<td>Barrier beaches (Sandbridge and Atlantic Ocean side of Back Bay National Wildlife Refuge) Irregular (Back Bay and North Landing River shoreline)</td>
</tr>
<tr>
<td></td>
<td>Tidal inlet (Rudee)</td>
<td>Straight beaches</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fetch/Wave Climate</td>
<td>High energy along Atlantic Ocean-facing shoreline Low to medium energy shorelines along tidally-influenced lakes west of Rudee inlet</td>
<td>High energy along the Chesapeake Bay-facing shoreline Low to medium-energy along shorelines and tidal creeks of Lynnhaven Bay, branches of the Lynnhaven River, Broad Bay, and Linkhorn Bay</td>
<td>Low energy along the Elizabeth River, especially along the tidal creeks</td>
<td>High energy along Atlantic Ocean-facing shoreline Medium to high-energy within Back Bay due to wind tides and large fetch in some areas</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mixed of vertical slopes (bulleheaded areas) and gentle slopes (marsh areas) along shorelines south of Lynnhaven Inlet with depth ranges from 1 to 1.5 feet.</td>
<td>Vertical slopes (bulkheads) dominate along the Elizabeth River with relatively deep offshore depths (2 to 4 feet)</td>
<td>Wide, gentle slopes dominate in Back Bay with shallow offshore depths (1 to 2 feet) Somewhat steeper bank slopes along North Landing River with offshore depths ranging from 2 to 4 feet.</td>
</tr>
<tr>
<td>Depth/Slope Offshore</td>
<td>Steep slope along Atlantic Ocean-facing shoreline (depths range from 1 to 7 feet) Vertical slopes (bulkheads) dominate along Rudee Inlet with relatively deep offshore depths (3 to 4 feet)</td>
<td>Relatively steep slope along Chesapeake Bay-facing shoreline (depths range from 1 to 5 feet) Mix of vertical slopes (bulleheaded areas) and gentle slopes (marsh areas) along shorelines south of Lynnhaven Inlet with depths ranging from 1 to 1.5 feet.</td>
<td>Vertical slopes (bulkheads) dominate along the Elizabeth River with relatively deep offshore depths (2 to 4 feet)</td>
<td>Wide, gentle slopes dominate in Back Bay with shallow offshore depths (1 to 2 feet) Somewhat steeper bank slopes along North Landing River with offshore depths ranging from 2 to 4 feet.</td>
</tr>
<tr>
<td>Nearshore Morphology</td>
<td>None</td>
<td>Expansive coverage of tidal flats and offshore sandbars along Lynnhaven and Broad Bay and branches of the Lynnhaven River Sand bars along the Chesapeake Bay-facing shoreline</td>
<td>A few tidal flats along the Eastern Branch of the Elizabeth River</td>
<td>None</td>
</tr>
<tr>
<td>Nearshore SAV</td>
<td>None</td>
<td>Minimal</td>
<td>None</td>
<td>Historically present (88% coverage in the 1970s), but generally absent today</td>
</tr>
<tr>
<td>Parameter</td>
<td>Oceanfront</td>
<td>Lynnhaven</td>
<td>Elizabeth River</td>
<td>Southern</td>
</tr>
<tr>
<td>--------------------</td>
<td>---------------------------------------------------------------------------</td>
<td>---------------------------------------------------------------------------</td>
<td>--------------------------------------------------------------------------------</td>
<td>--------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Wetlands</td>
<td>Now: salt marsh dominates Future: significant loss of salt marsh and expansion of tidal flats in Lake Rudee</td>
<td>Now: high marsh dominates Future: significant loss of high marsh in Lynnhaven Bay, expansion of tidal flats and salt marsh (Broad Bay)</td>
<td>Now: high marsh dominates with some coverage of salt marsh, woody wetlands, and shrub/scrub Future: persistence of marsh, but salt marsh replaces high marsh</td>
<td>Now: salt marsh dominates Future: significant loss of salt marsh, expansion shrub/scrub and tidal flats</td>
</tr>
<tr>
<td>Tide Range</td>
<td>3 – 3.5 feet</td>
<td>3 – 3.5 feet (north of Lynnhaven inlet) 2 – 2.5 feet (south of the Lynnhaven inlet)</td>
<td>2.5 – 3 feet</td>
<td>3.5 – 4 feet (along Atlantic Ocean) Negligible within Back Bay; dominated by wind tides</td>
</tr>
<tr>
<td>Storm Surge (average 100-year elevation, rounded to whole foot)</td>
<td>7 feet</td>
<td>7 feet</td>
<td>8 feet</td>
<td>4 feet</td>
</tr>
<tr>
<td>Erosion Rates</td>
<td>Atlantic Ocean-facing shoreline advancing (likely due to nourishment activities)</td>
<td>Generally low erosion rates along Lynnhaven Bay and Broad Bay shorelines Chesapeake Bay-facing shoreline advancing (likely due to nourishment activities)</td>
<td>Generally low erosion rates along Elizabeth River shoreline</td>
<td>Low to medium erosion rates along Atlantic-Ocean facing shoreline</td>
</tr>
<tr>
<td>Shoreline Land Use</td>
<td>Mostly residential</td>
<td>Mostly residential</td>
<td>Mixed residential, industrial, and undeveloped</td>
<td>Mixed light residential and undeveloped</td>
</tr>
<tr>
<td>Shoreline Structures</td>
<td>Seawall along resort area of the Atlantic Ocean-facing shoreline Rudee Inlet shoreline contains a jetty, bulkheads, marsh toe revetments, and riprap</td>
<td>Majority of shoreline contains a mixture of bulkheads, riprap, and marsh toe revetments</td>
<td>Majority of shoreline contains a mixture of bulkheads, riprap, and marsh toe revetments</td>
<td>Majority of shoreline does not contain shoreline structures; some bulkhead, marsh toe revetment, and riprap.</td>
</tr>
</tbody>
</table>
4. EVALUATION AND APPLICATION OF STRATEGIES

After identifying potential NNBFs, the next step is to evaluate which strategies may be appropriate in different locations in Virginia Beach to achieve flood risk reduction benefits. Results of the VIMS SMM in combination with the site suitability parameters estimated in the previous section, were used as a starting point for identifying appropriate strategies within the four major watersheds of the City of Virginia Beach. SMM uses decision-tree logic based on various parameters to determine appropriate design interventions.

The SMM modeling framework does not include several of the priority strategies evaluated in this study (e.g. SAV, living breakwaters, forest restoration, etc.) and were therefore evaluated in addition to SMM outputs. Sources for each strategy are outlined in Table 8, and a map summarizing potentially suitable locations for these strategies is provided in Figure 18. The circled areas on the map show areas of high flood risk, identified by the economic flood risk analysis conducted as part of the CSLRRF study.

Table 8: Sources for Non-structural and Hybrid Strategies.

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Restore, Enhance, or Create Marsh / Marsh Islands</td>
<td>Marsh restoration areas were identified from the SMM; areas for marsh island restoration were identified using aerial imagery</td>
</tr>
<tr>
<td>Marsh and Forest Migration</td>
<td>Areas for forest/wetland migration potential were identified within the future high tide floodplain with 3 feet of SLR</td>
</tr>
<tr>
<td>Beach Nourishment / Dune Restoration</td>
<td>Beach nourishment / dune restoration shorelines were identified from the SMM</td>
</tr>
<tr>
<td>Living Shoreline / Marsh Sill</td>
<td>Shorelines where living shorelines may be appropriate were identified from the SMM</td>
</tr>
<tr>
<td>Living Breakwaters</td>
<td>Potentially suitable locations for living breakwaters were identified from the site suitability parameters (specifically, wave climate and depth)</td>
</tr>
<tr>
<td>Ecologically-Enhanced Revetments</td>
<td>Shorelines where ecologically-enhanced revetments may be appropriate were identified from the SMM</td>
</tr>
</tbody>
</table>

NNBF in areas of special concern, shown in Figure 18, will depend on the need for and limitation posed by navigation access or unique development areas such as marinas, canals, industrial or commercial areas with bulkhead or wharf.
Figure 18: Potential NNBF strategies in Virginia Beach.
Evaluation of strategies at the citywide and watershed-level scales sets the stage for a nature-based infrastructure network that could address current and future flood risk. The objectives of the following sections are to:

- Evaluate the application of these strategies in different locations across Virginia Beach.
- Provide case study examples of strategies already being implemented in Virginia Beach’s four major watersheds.
- Explore pilot projects and identify ongoing research activities that utilize innovative nature-based flood mitigation strategies in Virginia Beach, the surrounding region, or other localities.

4.1. Beach Nourishment and Dune Restoration

Beach nourishment and dune restoration offers a soft-infrastructure strategy for the high-energy sandy shorelines of Virginia Beach. Ongoing beach nourishment projects in Virginia Beach have historically focused on the Resort Area beach and Sandbridge Beach, shown in Figure 19, although there have also been nourishment projects along the Chesapeake Bay facing shorelines. The nourishment projects within these areas is described in the following sub-sections.

4.1.1. Resort Beach

Nourishment of the Resort Beach began in the 1950’s, primarily using sand from the Lynnhaven Inlet maintenance dredging project, which occurs on a three to four-year cycle. The Resort Beach replenishment program, however, dramatically changed in 2001 with the implementation of the beach restoration component of the Virginia Beach Erosion Control and Hurricane Protection (BECHP) project. From this point forward, the Resort Beach is programmed to be replenished through the mining of beach sand from offshore areas. During the last nourishment event in 2012, contractors added 1.25 million cubic yards (CY) of sand from 15th to 70th Streets. The project is next scheduled for nourishment in 2019.
4.1.2. Sandbridge Beach

Nourishment of Sandbridge Beach began in 1998 and the latest nourishment was completed in 2013 where 2.18 million CY of sand was placed on the beach between Back Bay National Wildlife Refuge and Dam Neck Naval Facility, shown in Figure 20. 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 next nourishment cycle is planned for 2018-19.
4.1.3. Chesapeake Bay Beaches

Nourishment of the Chesapeake Bay Beaches has been accomplished through smaller scale projects than those at the Resort and Sandbridge Beaches. Several of the beaches adjacent to the Lynnhaven Inlet, such as the Cape Henry and Ocean Park beaches, have been nourished multiple times using sand from the Lynnhaven Inlet maintenance dredging project. Ongoing and upcoming Capital Improvement Project (CIP) nourishment projects are discussed below.

The Chesapeake Beach Nourishment project (CIP 8-409) began in May 2018 where over 350,000 CY of sand were dredge from a nearshore borrow site and place on the beach to create a wider beach berm and dune features (Figure 21). Based upon background erosion rates, a 6 to 8 year re-nourishment interval is planned for the entire beach with erosion “hot spots” requiring additional material every 3 to 4 years.
Nourishment restoration projects are being designed for Ocean Park and Cape Henry Beaches through CIP 8-020. These projects will provide a level of storm protection that will require more sand that is currently available from the dredging at Lynnhaven Inlet. Additional sources of sand include nearshore borrow sites (e.g. shoals) and the Thimble Shoals and Atlantic Ocean federal navigation channels.

4.1.4. Performance of Recent Nourishment Projects

In the most last round of beach nourishment projects for the Resort Beach and Sandbridge, lower than expected sand costs offered the opportunity to place additional material on the beaches. The City and the USACE seized this opportunity, and applied an “advance maintenance” strategy during the original restoration and at each nourishment interval. This has allowed the project nourishment cycle to be lengthened from an originally planned 3 to 4 year cycle to a much long 8 to 11 year cycle. This larger critical mass of sand has resulted in several short- and long-term benefits including:

- A wider recreation beach and greater than designed level of storm protection
- Cost savings due to a less frequent re-nourishment cycle and associated mobilization of equipment
- Less disruption to the benthic habitat and recreational beach uses

Another benefit from placement of additional nourishment fill is accelerated dune growth. For example, monitoring of Sandbridge beach and dune elevations between 2013 and 2017 shows that these larger amounts of sand have resulted in growth of the dune features, shown in green on the left panel in Figure 22. Re-emergence and growth of a dune system provides a higher level of storm protection along with habitat creation. These outcomes demonstrate the value of advance maintenance strategy.

Figure 22: Topographic elevation surfaces from Fall 2013 (right panel), Fall 2017 (middle panel), and comparison (left panel) at Sandbridge. This figure shows that as the beach retreated through the nourishment cycle, dunes grew both in height and width resulting in increased storm protection.
4.1.5. Nourishment Funding

The City of Virginia Beach funds beach nourishment projects through 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 the 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. In Sandbridge, the Sandbridge Special Service Tax District helps fund replenishment efforts within the community. The Sandbridge Tax Incremental Financing (TIF) designated nearly $10 million in FY2016-17 for beach replenishment. Relative SLR influences shoreline erosion, with higher rates of SLR attributed to higher rates of shoreline recession (i.e., Bruun, 1962; Zhang, Douglas and Leatherman, 2004). Acceleration of the rate of SLR is already evident in the Hampton Roads areas (Boon et. al 2018). Continued acceleration may start to increase shoreline recession rates, and in turn, result in potential increased frequency of nourishment placement in the long-term.

4.2. Wetland Restoration, Enhancement, or Creation

There are opportunities for wetland restoration, enhancement and creation within each of the City of Virginia Beach watersheds. Fringing marshes and marsh island systems within Back Bay, North Landing River, and Lynnhaven Bay should be given priority due to their vulnerability to inundation with rising sea levels, and their ability to attenuate wave action driven by storms and wind tides. For fringing marsh restoration, areas with upland migration opportunities are likely to have enhanced longevity under SLR conditions.

There are several degrading marsh island systems within Back Bay that have potential for restoration or enhancement. Figure 23 shows the historical marsh extent in 1869 compared to today’s marsh extent, illustrating moderate losses of fringing marsh along the shoreline and more significant losses within the marsh island systems in the Back Bay.

Restoration of these riparian and island marsh systems could provide flood mitigation benefits, especially with the ability to provide significant resistance to water flows, dissipating wave momentum and energy. However, recent research has shown that marsh island restoration typically works better for smaller, or shorter events. If the height of the water moving over the marsh increases during larger wind-driven events in Back Bay, and marshes become partially or fully inundated, the benefit of friction from these systems would have less of an impact (Parquier et. al 2017).
Existing wetland restoration strategies in Virginia are outlined in the Virginia State Wetland Program Plan for 2015-2020 (DEQ et al. 2018). The strategies can be summarized by the following activities:

- **Upland Land Use Planning**: The capacity of marshes to migrate landward is limited by hardened shorelines and upland land uses. Strategies include using legal and policy tools to intentionally leave room for upland marsh migration.

- **Voluntary Protection and Restoration**: There are numerous voluntary activities that occur outside of a regulatory program. Various non-governmental groups and federal government entities restore, purchase, and protect wetland. Restoration projects
have been undertaken by groups such as The Nature Conservancy (TNC), the Chesapeake Bay Foundation (CBF), Lynnhaven River NOW, and the Living River Restoration Trust (formerly, the Elizabeth River Project), among others.

- **Permitting and Compensatory Mitigation:** Functions of impacted wetland must be replaced through compensatory mitigation, such as with mitigation banks.

- **Setbacks/Buffers:** Buffers such as the 100-foot buffer stipulated by the CBPA RPA (shown in Figure 24) and the 50-foot buffer in the Southern watershed are used to protect tidal and non-tidal wetlands from development pressures. Current research is exploring the concept of a “rolling” RPA to allow this buffer to migrate naturally with SLR as the shoreline and wetland migrate landward.

![Jurisdictional Boundaries](image)

Figure 24: Jurisdictional boundaries of wetlands in Virginia.

In addition to the more traditional wetland restoration strategies described above, there are several new marsh restoration strategies being explored in Virginia Beach. For example, TNC conservation partners are investigating creative nature-based approaches for stabilizing degraded marsh islands within Back Bay, such as planting native Bald Cypress seedlings in strategic locations on the marsh islands. The vision involves using these Bald Cypress trees to stabilize and gradually raise the marsh platform to be more resilient to SLR and wind tide flooding events. The Knotts Island channel was identified as a critical gateway for floodwaters moving from Currituck Sound into and out of Back Bay, shown in Figure 25. During a strong wind tide event in Back Bay, many of these marsh islands are overtopped due to their low elevations, shown in Figure 26. Therefore, the ability of these marsh islands to provide flood attenuation is limited to smaller events.
Another opportunity to focus marsh restoration efforts includes restoration and enhancement of marsh island systems inside Lynnhaven Bay. Similar to Back Bay, marsh island systems in the Lynnhaven Bay area projected to become fragmented with 1.5 ft of SLR and almost completely submerged with 3 ft of SLR. Lynnhaven River NOW recently developed the Marsh Island Task Force to evaluate strategies to slow down erosion and promote accretion of the marsh island systems that are projected to be especially vulnerable to rising sea levels.

### 4.2.1. Beneficial Use of Dredged Materials

A relatively new strategy for creating, restoring, and maintaining coastal marshes is building marsh elevations with sediment delivered from nearby dredging projects. Dredged material on coastal wetlands provides a natural means of increasing the elevation of sediment-impaired wetlands when their ability to adapt to SLR is threatened. In this process, sediment removed from navigation channels during dredging projects is transported to a marsh restoration site, where it is applied to the surface of the marsh by spraying a slurry of water, sand and silt, a process known as “thin-layer sediment addition.” Challenges to the success of thin-layer
marsh restoration projects include accounting for consolidation and erosion of newly deposited sediment, and maintaining a hydrologic regime that distributes water and nutrients throughout the marsh to ensure plant growth. Some of these challenges can be addressed by using silt fences to prevent sediment erosion, planting marsh seedlings to stabilize new sediment, and excavating new channels within the marsh to ensure proper tidal flooding and drainage (VIMS 2014).

The USACE Engineer Research and Development Center (ERDC) maintains a database of thin-layer placement marsh restoration projects. While the pilot projects have achieved varying degrees of success, a notable case is the marsh restoration project within the Blackwater National Wildlife Refuge (NWR) along Maryland’s eastern shore with a history of significant wetland loss. In 2003, the USFWS, in partnership with the USACE, restored fifteen acres of wetland in three different locations in the Blackwater NWR using dredged material from the Blackwater River and planting native marsh vegetation. By 2005, post project monitoring showed that the site completely revegetated, shown in Figure 27. The total cost of the project was $300,000. Through a recent partnership, USACE, FWS, the Audubon Society, the Conservation Fund and others are using a Hurricane Sandy Relief Grant from the National Fish and Wildlife Foundation (NFWF) to add an additional 26 thousand cubic feet of sediment to 40 additional acres within the refuge, costing a total of approximately $1.1 million.

Figure 27: Thin-layer marsh restoration project at the Blackwater NWR in Maryland; photographs courtesy of ERDC.
Despite the success of these pilot projects, it is estimated that between 13 and 65 million CY of material will be required to fully restore Blackwater marshes. The only source for such a large quantity of material is the Baltimore Harbor approach channels in the Chesapeake Bay, which require the removal and placement of 4 million cubic yards of sediment per year. These sediments are currently deposited at the Poplar Island Environmental Restoration Project. The Blackwater NWR restoration project has been proposed as one of several dredged material placement sites to be used when Poplar Island reaches capacity.

4.3. Submerged Aquatic Vegetation Restoration

The two key areas of opportunity for SAV restoration are within the Lynnhaven and Back Bay, given the historical presence and loss of aquatic habitat. The suitability conditions within these two areas for SAV restoration are unique and therefore require different approaches. However, the common critical threat to SAV across Virginia Beach is poor water quality. Increasing amounts of nutrients and sediments resulting from development of the shoreline and watersheds can lead to diminished water clarity that blocks sunlight from reaching underwater plants. Sunlight penetrates deeper in clear water than in cloudy water and SAV depend on sunlight for reproduction (Dennison et al. 1993). Therefore, an overarching strategy for SAV restoration in Virginia Beach should focus on continued water quality improvements to make conditions more suitable for SAV survival.

4.3.1. Lynnhaven River SAV Restoration

The VIMS SAV Monitoring and Restoration Program was established in 1978 to monitor, restore, and reintroduce *Zostera marina* (eelgrass) and other SAV species, such as *Ruppia maritime* (widgeon grass) in Virginia’s coastal bays. Annual aerial surveys and field studies are used to monitor the distribution and abundance of underwater grasses. While the overall abundance is increasing across the Chesapeake Bay and tributaries, SAV acreage has declined within the Lynnhaven watershed in Virginia Beach. The abundance of SAV beds from 1984 through 2017 in Broad Bay, located in the northeastern portion of the Lynnhaven River watershed, is plotted on a graph in Figure 28 and shown on a map in Figure 29. SAV beds of moderate density composed of eelgrass and widgeon grass existed along a narrow fringe surrounding Broad Bay. However, the density of these beds became sparser and eventually declined altogether. In Lynnhaven Bay, there has been no SAV except for one translate site of eelgrass located inshore of an oyster reef planted by the Virginia Marine Resources Commission (VMRC) around 1998, however this bed disappeared over time and was no longer visible by the 2000 field study.
Researchers at VIMS’ SAV Monitoring and Restoration Program are exploring creative SAV transplant techniques to introduce grasses into areas where they have been eliminated. Their recent experiments show that using eelgrass seeds can be much more efficient and effective for large-scale restoration efforts than transplanting adult plants given the laborious and costly
process of manual seagrass planting. SAV restoration efforts using seeds are being increasingly recognized as a viable option for both small- and large-scale restoration projects. However, many young seedlings fail to develop into adult plants because waves and currents can remove them before they can become established. Therefore, the program’s current experimental work is focused on the following areas:

1. Investigating seed planting as a tool to enhance seedling establishment
2. Understanding how different physical factors influence seedling establishment at different restoration sites
3. Investigating the potential importance of high-density, repeated seeding

A recent study to evaluate the above questions shows that mechanized seed harvesting (shown in Figure 30) has been an effective approach for seed collection because many grass species produce and release large quantities of seeds over a period of weeks. When paired with immediate seed distribution techniques, this approach reduces the infrastructure requirements for processing and holding large number of seeds and improves seed survival. However, the experiments found that if seeds are collected in the spring or summer, it is optimal to hold and maintain them through the summer at high salinity and cool temperatures, and then disperse them in the fall (Orth and Marion 2007). The study also compared the effectiveness of different approaches for seed dispersal. One such method is deploying seed-bearing shoots in buoys and another involves injecting seeds directly into sediments over large areas using machinery.

Figure 30: Mechanical aquatic grass harvester; photograph courtesy of Robert J. Orth.
In addition to the restoration efforts led by VIMS, the USACE Norfolk District and the City of Virginia Beach are partnering on the $34 million Lynnhaven River Basin Ecosystem Restoration Project. The project is intended to restore approximately 38 acres of wetlands, 94 acres of SAV, and 31 acres of reef habitat within the Lynnhaven River and will be constructed in several phases over the coming years. The SAV restoration will focus on restoring populations of eelgrass and widgeon grass in areas where seagrass was historically abundant. Implementation will involve hand broadcasting SAV seeds at a density of approximately 300,000 seeds/acre.

Phase 1 of the project includes the restoration of approximately 7.1 acres of wetlands along Thalia Creek, 6.3 acres of submerged aquatic vegetation in Broad Bay, and up to 8 acres of reef habitat near Dix Creek in the Lynnhaven Bay, shown in Figure 31. Implementation of Phase 1 of the project is anticipated to begin in spring 2019. While the extent of these SAV restoration sites are relatively small, these pilot projects can be evaluated to accomplish more extensive SAV restoration that would provide greater flood risk reduction benefits, namely slowing down the movement of water. Post-planting monitoring of the pilot project will provide insight into potential benefits and how well two grass types are establishing.

Figure 31: Lynnhaven River Ecosystem Restoration Phase 1 Project Sites.
4.3.2. Back Bay SAV Restoration

SAV density began to decline in Back Bay in the 1920’s. In 1958, the U.S. Fish and Wildlife Service (USFWS) and the states of Virginia and North Carolina began an extensive survey of SAV in the Back Bay. The SAV in Back Bay has shown two periods of high frequency and two of decline during the years 1954-1990 (Schwab et al. 1990). The second period of growth was driven by the explosion in growth of Eurasian watermilfoil, an invasive, non-native plant first documented in in the bay in 1966. Since the monitoring ended in 1990, SAV distribution has remained sparse, covering somewhere between 10 and 15% of the bay. It is likely that a combination of changes in land use, runoff, dredging and water clarity issues, as well as disease and other factors, drove the decline (CVB 2017).

![Figure 32: Frequency of SAV in Back Bay from 1958 – 1990; graph obtained from Schwab et al. (1990). Y-axis indicates percent coverage of SAV in Back Bay.]

Today, SAV restoration in Back Bay is challenged by both poor water quality due to nutrient and sediment inputs from agricultural operations and other upland land uses as well as 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. One promising strategy currently being explored in Back Bay is the use of floating turbidity curtains.
In the spring of 2010, a floating turbidity curtain pilot project was implemented in Back Bay to evaluate the value of this strategy for improving water clarity and encouraging the growth of SAV. The curtains were placed on the southern side of Ragged island, positioned at an angle to provide shelter from the southwesterly winds that are dominant in the spring and summer to see if wind direction and/or fetch played a role in SAV dispersal in Back Bay. The location of the pilot project is shown in Figure 33. Figure 34 provides a Google Earth image of the curtains deployed.

Figure 33: Floating turbidity curtain pilot project location in Back Bay.
The project was monitored on a weekly basis from March through June, 2010. Data collection involved using a Secchi disk, an instrument used for measuring turbidity. The depth at which the disk is no longer visible is taken as a measure of the transparency of the water. Secchi disk readings were taken on both sides of the curtain, windward and leeward. General water quality parameters such as dissolved oxygen, temperature and salinity, and wind speed and direction were also recorded for each sample day. In general, there was an 11- to 12-inch difference in Secchi disk readings on the leeward side of the curtain meaning that water clarity was much improved because of the curtains. While the pilot project did not quantify SAV abundance before the curtains were deployed, the project team noted growth of SAV on the leeward side of the curtains demonstrating the potential usefulness in using this strategy for larger SAV restoration efforts. More photographs of the pilot project are shown in Figure 35 and Figure 36.
Another potential strategy to encourage the growth of SAV in Back Bay is the use of living breakwaters that are designed to break up wave energy and reduce turbidity. This strategy will be explored in more detail in Section 4.6.
4.4. Forest Restoration, Enhancement, or Creation

Forest conservation and restoration offers a robust flood mitigation strategy across the City of Virginia Beach. Observations of aerial photographs over time show an overall decrease in tree canopy cover over the past 75 years in Virginia Beach. This trend is strongly tied to increases in residential and urban development, despite some localized gains due to changes in land uses. Figure 37 provides an example of historical versus modern canopy cover in the Bay Colony neighborhood at the Oceanfront. The top figure shows an aerial photograph from 1937 in which the area is dominated by open fields, forested areas, and coastal habitats along the oceanfront - light residential development is along the coast. The bottom figure shows an aerial photograph from 2007 in which residential development expands and while the forested areas lost tree cover, the open fields and areas along the coast increased in tree cover.

Figure 37: Historical comparison of forest coverage from 1937 to 2007.
As mentioned earlier in this report, there have been efforts at the regional and local levels to develop a protected GI network, such as delineating conservation corridors and riparian buffer areas to preserve and expand valuable forest habitat. The City of Virginia Beach Urban Forest Management Plan, for example, recognizes the role urban forests play in flood mitigation. In particular, the plan emphasizes the threat that forest fragmentation has on the ability of forests to provide flood storage services. The plan provides the following recommendations:

- Actively maintain trees on public property to ensure that they increase in size
- Continue to educate and encourage the planting of trees on private property
- Replace dead or diseased trees on public property
- Work cooperatively with developers to preserve existing trees during development
- Educate the public to plant trees that contribute to species diversity, minimizing the chance of species ‘meltdowns’
- Identify and preserving publicly-owned open space that can be allowed to regenerate to forest
- Manage pests and diseases effectively

In addition to the City of Virginia Beach’s existing GI planning documents, there are numerous other research initiatives aimed at identifying innovative techniques to forest conservation. One such initiative is the Virginia Beach Forest Conservation Working Group, a collaborative effort between TNC, Lynnhaven River NOW, Virginia Tech, and various City of Virginia Beach departments. The working group is exploring contemporary strategies for forest restoration with the goal of achieving flood risk reduction. The group is evaluating strategic locations for planting salt and flood-tolerant vegetation as well as identifying land area that could be conserved for forest migration in response to future flood conditions. Figure 38 shows forested areas in the Southern watershed that are expected to be inundated by daily tidal flooding under the 3 ft SLR scenario. Bald cypress trees, which germinate on land but can tolerate wet soil and salinity increases, could be planted in advance of this condition.
The Forest Hydrology Study is another forest restoration initiative led by researchers at Virginia Tech. The objective of the study is to develop a decision-support tool that will help the City of Virginia Beach identify the most important forested areas that can be restored to minimize flood risk. The tool will focus on evaluating the potential of implementing forest restoration projects on conserved lands, shown in Figure 39.
Figure 39: Conserved land ownership in Virginia Beach; map courtesy of The Nature Conservancy. VOF stands for the Virginia Outdoors Foundation.
4.5. Living Shorelines / Marsh Sills

A commonly constructed form of a living shoreline is a marsh area that is protected by a low-lying structure called a sill. Marsh sills can be used in Virginia Beach to armor or create new fringe marshes that require a higher degree of protection. Sills dissipate wave energy by causing waves to break on the offshore structure, rather than upon the natural, more fragile shore. Sills are typically constructed from stone structures, but alternative materials such as coconut fiber logs or oysters can also be used.

There are several examples of marsh sill living shoreline pilot projects in Virginia Beach. In fact, living shorelines have become a widely accepted strategy for shoreline management as identified in the Lynnhaven River Shoreline Management Plan (Hardaway et al., 2013). Figure 40 provides an example of a successful marsh planting project in Little Haven Creek assisted by installation of fiber logs to stabilize the bank toe and newly established marsh vegetation.

Figure 40: Living shoreline project; photographs courtesy of Lynnhaven River NOW.
Another type of sill structure commonly used in Virginia Beach and other areas are oyster castle blocks. These features are constructed concrete blocks that contain 30% oyster shell, which can be assembled in varying formations to fit the particular depth and contour of the shoreline. In addition to providing valuable habitat for oysters, these castle blocks help protect the shoreline from wave action, erosion, and encourage the spread of wetland grasses behind the castle. In May and June of 2018, Lynnhaven River NOW moved more than 87,000 pounds of oyster castle blocks to build 58 castles in 6 different locations in Virginia Beach and Norfolk. Figure 41 shows an oyster castle living shoreline project implemented in 2015 in Virginia Beach. The project involved placing 30 concrete oyster castles along the eastern branch of the Lynnhaven River at Great Neck Park.

![Figure 41: Volunteers with the Virginia Beach Project Green Teens building oyster castle reefs along the eastern branch of the Lynnhaven River at Great Neck Park in Virginia Beach in 2015; photograph courtesy of the Virginia Pilot.](image)

Similar to the discussion of marsh restoration strategies in Section 3.2, techniques such as allowing for migration of living shorelines into upland areas can also be used to enhance the long-term resilience of living shoreline projects. The Southern watershed is particularly suitable for resilient living shoreline projects given the wide, gradual slopes along Back Bay, the
North Landing River and West Neck Creek (shown in Figure 42), with mostly rural upland development. These areas may be potential opportunities for marsh migration – places where current wetlands are likely to end up in the future based on landscape topography and hydrology. Although migration of these wetlands will provide flood risk reduction benefits to upland landowners, it may also lead to loss of important land as wetlands infringe on agricultural fields. Strategic marsh migration will need to involve the agricultural community in providing technical assistance and identifying programs that can help transition these areas such as planting transitional crops.

Figure 42: Land elevations in the Southern watershed of Virginia Beach.
4.6. Living Breakwater Islands

Living offshore breakwater islands are most suitable when placed within larger bodies of water such as open coast or larger bays that experience higher wave energy because of their ability to attenuate storm waves. In Virginia Beach, there are currently only traditional breakwaters on the eastern side of Fort Story and along the shoreline to the west of the Chesapeake Bay Bridge Tunnel. Although there are no cases of existing living breakwater projects in Virginia Beach, there are some local examples from neighboring communities as well as examples from the Gulf Coast and Northeast.

Virginia Beach’s higher energy shorelines present opportunities for the enhancement or creation of offshore living breakwater systems that incorporate natural features that provide more structural stability, such as rocky or hard structured habitat which can function much like oyster reefs. For example, the Raritan Bay, New Jersey living breakwater project, shown in Figure 43, is located in a shallow estuary that historically supported shell fisheries. The project involves constructing approximately 3,200 linear feet of a near-shore living breakwater located between 730 and 1,200 feet from shore, designed not only to reduce flood risk, but also to provide habitat enhancements through the specialized design of the breakwater structure and the materials used. Closely spaced rock called “reef fingers” are being used to add habitat complexity for recruitment or species such as shellfish and fish. The project designers anticipate that the calmer near shore waters and wider beaches created by the breakwaters will not only help reduce risk from coastal storms, but will also enhance recreational opportunities along the shoreline including boating, fishing, and general beach use.

Figure 43: Conceptual design of the living breakwater project within Raritan Bay, NY.
Another example of a living breakwater project that can withstand higher wave energy is the Atlantic Reefmaker concept. The Reefmaker concept uses a series of wave attenuation structures, termed “EcoSystem Units” comprised of a stack of concrete molded trays set with natural rock material such as granite. These systems attenuate wave energy while allowing for water and sediment exchange and passage of organisms through the structure. The Reefmaker concept was implemented to protect the shoreline within Brunswick Town in North Carolina from erosion and flooding, shown in Figure 44. The University of North Carolina at Wilmington (UNCW) is currently conducting monitoring of the structure. In August 2018, about one year after construction of Phase 1 was completed, there was 3 feet of accretion behind the structure. Three areas of *Spartina alterniflora* recruitment were also noted. From September 13-16, 2018, the structure withstood Hurricane Florence’s landing near the site.

![Figure 44: The Reefmaker concept at Brunswick Town / Fort Anderson in North Carolina.](image)

Reef ball living breakwater projects are also designed to attenuate wave energy but are typically submerged or placed semi-emergent in shallow water and are therefore more suitable for low to medium wave climates. Individual units are typically placed close together and parallel to the shoreline. Artificial reefs can be designed for a variety of goals including wave
attenuation or the creation of fish or shellfish habitat. Ideally, generations of reef species can grow on these structures over time to form larger reef structures, allowing for increases in elevation of the structure with rising sea levels. When placed at emergent (high wave-crest) elevations, artificial reefs can function as breakwaters and provide both wave attenuation and shoreline stabilization benefits. Furthermore, artificial reefs can provide similar functions as marsh sills if the reef ball units are placed in a manner where a beach or marsh platform can be created behind the units, as illustrated in Figure 45.

Figure 45: Example of a reef ball living shoreline project to protect West Bay in Texas; photograph courtesy of Reef Innovations.

The Chesapeake Bay Foundation (CBF), with support of a National Fish and Wildlife Foundation (NFWF) grant, constructed a reef ball project in 2010. 1,500, 100-pound reef balls were placed between the Hermitage Museum and Gardens and Norfolk Yacht and Country Club in Norfolk, Virginia, shown in Figure 46. A healthy oyster reef must have at least 50 oysters per square meter to sustain itself and meet standards set by the Environmental Protection Agency’s (EPA) Chesapeake Bay Program. All of the reef balls surveyed by the CBF
in November 2017 had densities over that threshold, with one reef as high as 152 oysters per square meter. This project provides an example of a successful oyster restoration project that provides both shellfish habitat as well as potential flood risk reduction benefits. Similar projects may be suitable to the Elizabeth River and the Lynnhaven River in Virginia Beach.

Living breakwater islands that incorporate wetland vegetation are likely more suitable to the low and medium wave energy environments of Virginia Beach that have expansive shallow water environments with limited navigational obstacles, such as Back Bay. Examples of living breakwater that incorporate vegetated wetland features include floating wetland islands or marsh terraces, shown in Figure 47, which could be implemented in these areas to achieve multiple objectives including:

- Reduce fetch/surge height on the protected side of the breakwater because surge overtopping can be limited or redirected during low-intensity, frequently occurring storms.
- Reduce turbidity to increase light penetration into the water column to promote growth of SAV, similar to the floating turbidity curtain strategy.
- Protect marsh islands and fringing marshes from erosion.
Marsh terraces or marsh islands offer a potentially suitable strategy in Back Bay to prevent future projected losses of marsh with SLR, particularly because of their potential ability to interrupt the negative feedback cycle of marsh erosion/drowning that is initiated once interior marshes begin to fragment. In this cycle, as an intact marsh begins to fragment and convert to open water, fetch increases and enables greater wave energy, which in turn increases marsh erosion rates, ultimately accelerating conversion to an ever-expanding body of open water (Brasher 2015). Marsh terraces are segmented ridges of bare soil and emergent marsh constructed from excavated subtidal substrates in shallow, open water areas. Terraces are typically designed and constructed with a height equal to surrounding marsh elevations to enable periodic tidal inundation of the terraces and associated vegetation. Vegetation planting includes *Spartina alterniflora* (smooth cordgrass) in saline and brackish waters. Marsh terracing has become increasingly common in coastal Louisiana and Texas, and are most often constructed in large water bodies that were once emergent marsh but have since been converted to open water (Brasher 2015). Since 1990, marsh terraces have been constructed at over 80 sites in Louisiana and Texas, encompassing over 4,000 individual terrace ridges.

Similar to the discussion on turbidity curtains, the value of terraces for encouraging the growth of SAV has been measured directly through estimation of SAV habitat expansion and indirectly through assessment of how terraces affect turbidity. Terraces have been
demonstrated to reduce fetch and resulting wave energy as well as reduce turbidity, although this pattern is not consistent across project sites and varies temporally. Furthermore, direct measures of SAV growth in terraced sites have been generally positive, but the magnitude of this effect may vary significantly among sites and throughout the year (Brasher 2015). The primary challenges associated with marsh terracing includes the permitting, construction, and maintenance of a large in-water structure that requires an underwater installation along with the potential for a large volume of sediment fill.

4.7. Ecologically-Enhanced Revetments/Bulkheads

Ecologically-enhanced revetments can be used at both open coastal locations as well as lower energy sheltered shorelines. Revetments have been implemented as coastal protection on many coastlines where the expected wave heights far exceed anything likely to be experienced at a living shorelines site (Miller et al. 2016). Furthermore, these features are often used in urban areas, in marinas, or along rivers and coasts where space is limited. In locations where living shoreline projects are not possible because wave energy, land ownership, or other factors, ecologically-enhanced revetments are preferred over vertical bulkheads (VIMS 2010). However, in urban harbors that are lined with hardened bulkheads where living shorelines or ecologically-enhanced revetments are not possible, alternatives could be explored such as a new type of vertical wetland, termed the “Green Bulkhead.” The system consists of a porous recycled plastic fabric that is draped over the surface of an existing bulkhead. Wetland plants are grown in artificial growth media that is placed in pockets of the plastic fabric. Two successful demonstration projects were implemented in Baltimore’s Inner Harbor and along the Anacostia River in the District of Columbia.

This strategy could be explored across the City of Virginia Beach in locations with existing revetments or bulkheads through replacement or incorporation of ecologically-friendly materials and vegetation to reduce wave energy and further prevent shoreline erosion. As part of the Hudson River Sustainable Shorelines Project, ten strategies that can be used as alternatives or retrofits to traditional bulkheads and revetments were evaluated for different hazard mitigation services, shown in Figure 48 (Rella and Miller 2012; Zhao et al. 2014). Enhancements take a variety of forms ranging from simply incorporating vegetation into an existing structure (e.g. joint planted revetment) to completely changing the geometry and composition of the structure. Of these strategies, green (bio) walls, vegetated geogrids, and joint plantings were found to be most applicable for ecological enhancements to traditional bulkheads or revetments. For more information and illustrations of these various strategies, refer to the Hudson River project report.
Figure 48: Characteristics of ecological enhancement hazard mitigation measures for different types of revetment/bulkhead retrofit strategies. Table obtained from Zhao et al. (2014).

5. MEASURING PERFORMANCE AND QUANTIFYING BENEFITS

Identifying appropriate and effective nature-based flood mitigation strategies should be guided by the benefits and services these features can provide. There are several knowledge gaps regarding the performance of nature-based interventions for flood risk management. These gaps are mostly related to their performance under extreme storm conditions, especially their persistence over longer time scales and after exposure to multiple storm events. Although numerical models can be used to investigate performance and benefits, validation data from experiments or from pilot projects is often lacking. Standardized performance metrics will also enable comparison with conventional engineering interventions (World Bank 2017). The following sections will explore performance metrics that have been identified as well as other sources for evaluating potential success, such as pilot project case studies, field observations, laboratory experiments, and numerical simulation results.

5.1. Performance Evaluation Metrics

A performance metric is an indicator that can be used to consistently estimate and report the anticipated effect of an alternative or engineering design with respect to a particular
objective (Bridges et al. 2015). Performance metrics help decision-makers compare the expected performance across alternatives or engineering designs.

The USACE developed a set of relevant performance metrics for NNBF, expressed in terms of ecosystem goods and services, that can be used to characterize (either qualitatively or quantitatively) the benefits generated by these features. In total, 72 quantitative performance metrics were developed that capture a full suite of social, environmental, and economic benefits. Table 9 provides a simplified summary of these performance evaluation metrics.

Table 9: Performance Evaluation Metrics; table adapted from the Coastal Green Infrastructure Research Plan for New York City (Zhao et al. 2014).

<table>
<thead>
<tr>
<th>Benefits</th>
<th>Performance Evaluation Metrics</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Hazard mitigation</strong></td>
<td></td>
</tr>
<tr>
<td>Storm surge/tide</td>
<td>Surge height and/or flood depth, flood limit of target event (e.g., 100-yr return period), phased delay of surge peak</td>
</tr>
<tr>
<td>Wind wave</td>
<td>Wave height reduction, wave power/energy of wave heights at shoreline</td>
</tr>
<tr>
<td>Shoreline erosion</td>
<td>Shoreline retreat/accretion distance or rate, bathymetric and topographic variation</td>
</tr>
<tr>
<td><strong>Ecological benefits</strong></td>
<td></td>
</tr>
<tr>
<td>Water purification</td>
<td>Concentration of total suspended solids, harmful substances (e.g., harmful bacteria, heavy metal), dissolved oxygen, and nutrients (N, P, K), pH value; extent of water quality impairment; primary production (chlorophyll a)</td>
</tr>
<tr>
<td>SAV habitats</td>
<td>Density, biomass, diversity index, characteristic species abundance</td>
</tr>
<tr>
<td>Marsh habitats</td>
<td>Density, biomass above and below ground, vegetation morphology (height, diameter), characteristic species abundance, diversity index</td>
</tr>
<tr>
<td>Forest habitats</td>
<td>Density, biomass above and below ground, vegetation biomass, morphology (height, diameter, foliage), characteristic species abundance, diversity index</td>
</tr>
<tr>
<td>Wildlife habitats</td>
<td>Bird diversity, characteristic species abundance</td>
</tr>
<tr>
<td>Habitat diversity</td>
<td>Spatial heterogeneity, species richness, species abundance</td>
</tr>
<tr>
<td>Carbon sequestration</td>
<td>Greenhouse gas (GHG) removal, GHG emission</td>
</tr>
<tr>
<td>Air quality improvement</td>
<td>Concentration of ozone, particulates, and SO2/NO2</td>
</tr>
</tbody>
</table>

5.2. Case Studies

Data from case studies—including project location, motivations, goals and objectives, design, monitoring and evaluation—can be critically important to planning and design of new NNBF projects. A virtual laboratory of pilot projects utilizing various innovative strategies could be used to understand lessons learned and create design guidelines for future projects. There are several existing databases that can be leveraged for this purpose, summarized in Table 10.
Table 10: Databases of nature-based case study projects.

<table>
<thead>
<tr>
<th>Name</th>
<th>Source</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Living Shorelines Demonstration Sites</td>
<td>VIMS</td>
<td>VIMS provides a list of locations and project descriptions for a number of living shoreline projects in Virginia. The site also contains more general information on the characteristics and benefits of living shorelines.</td>
</tr>
<tr>
<td>SAGE Interactive Mapper</td>
<td>SAGE USACE</td>
<td>This map displays completed projects from the Systems Approach to Geomorphic Engineering (SAGE) Database with known locations. The inset map on the lower left shows the area depicted in the map window.</td>
</tr>
<tr>
<td>The Nature Conservancy’s Natural Infrastructure Restoration Projects</td>
<td>TNC</td>
<td>This resource contains a map that currently has 209 restoration sites that have been submitted to the database. The sites can be accessed either by pressing on a location or by scrolling through the project list. Each location includes a summary, photos and details such as techniques used, data collected, habitats, species, and project objectives. There is also an option to filter search by project type.</td>
</tr>
<tr>
<td>Green Infrastructure Effectiveness Database</td>
<td>NOAA</td>
<td>This online database of literature sources contains information on the effectiveness of GI to reduce the impacts of coastal hazards, such as inundation and erosion from tropical storms and cyclones, more frequent precipitation events, and SLR. The database contains records from a wide range of sources, such as peer-reviewed journals, online tools, and gray literature, and includes information on 32 different coastal GI types. The GI techniques referenced cover a full range of approaches to coastal management, including natural, nature-based (e.g., low-impact development), structural, and policies.</td>
</tr>
<tr>
<td>Living Shorelines Highlighted Projects</td>
<td>Living Shorelines Academy</td>
<td>The Living Shorelines Academy, a partnership between Restore America’s Estuaries, North Carolina Coastal Federation, EPA, and the Southern Environmental Law Center, collected a highlighted list of living shoreline projects from around the country. Each of the highlighted case studies includes the project description, location, site photos, technical details, funding and contact information.</td>
</tr>
</tbody>
</table>

5.3. Cost Benefit Assessment

Although traditional risk assessment methods can be applied to nature-based solutions, they do not incorporate the full range of benefits. To appreciate the full potential of nature-based measures, risk assessments should be extended with a benefit assessment to quantify their ecosystem and socio-economic benefits. This would enable a more holistic comparison to traditional engineering approaches (World Bank 2017), however, these metrics can be difficult to quantify.
NOAA developed A Guide to Assessing Green Infrastructure Costs and Benefits for Flood Reduction. The purpose of this guide is to provide a process that communities can use to assess the costs and benefits of GI to reduce flooding. The guide takes a step-by-step, watershed-based approach to documenting the costs of flooding; projecting increased flooding and associated costs under future land use and climate conditions; and calculating benefits and costs of reducing flooding with GI over the long term. Figure 49 lays out the framework established by NOAA to assess the costs and benefits of GI for flood risk reduction.

Figure 49: NOAA framework for assessing GI costs and benefits for flood risk reduction.
Numerical models can be used to quantify flood risk reduction potential of NNBF projects. For example, the numerical model XBeach (Roelvink D., 2009) quantifies nearshore hydrodynamic and morphodynamic behavior. XBeach will simulate different storm scenarios to calculate the risk of flooding and erosion during extreme events. Another feature of XBeach is its ability to add vegetation to represent nature-based defenses in the simulations, which quantifies the potential of the nature-based features reducing flooding and waves (Roelvink et al. 2009).

Numerical models like XBeach and MIKE21 are extremely valuable in quantifying the costs and benefits of a nature-based solution to coastal erosion and flooding. With XBeach, a storm event can be simulated both with and without vegetation, showing the benefits/costs of using vegetation as a nature-based solution. When validated with sensor data that provides actual water level and wave attenuation during an event, the amount of damage to a coastal area can be quantified based on the model outputs and the data collected by the sensors. An example application is a study conducted at George Mason University to quantify the wave attenuation due to vegetation in a coastal salt marsh in Magothy Bay Natural Area Preserve on the Eastern Shore of Virginia, shown in Figure 50. The top panel displays an example of existing vegetation in the marsh while the bottom panel represents a hypothetical example of the marsh where the vegetation is removed from the system. During storm events, the model shows the vegetation reducing up to 83% of wave height within and landward of the marsh edge (Miesse and Ferreira 2018).

In addition to using numerical models to quantify flood risk reduction potential, social/environmental benefits can be derived based on the amount of vegetation added to a model in XBeach. If the volume and type of vegetation is known, benefits such as carbon sequestration can be estimated.

Using numerical models falls under steps 4 and 5 of the NOAA framework laid out in Figure 49. Other numerical models have similar features to quantify the risk of storm events, and the ability to simulate different features to reduce the risk of these events. Numerical models can be used to simulate a specific type of NNBF before it is implemented, allowing its potential costs and benefits to be quantified. By doing this, the best solution to reducing flood risk can be identified and put in to practice. This is key when identifying how to have the largest impact with the amount of funds available for a project.
Figure 50: XBeach model for Magothy Bay Natural Area Preserve, with and without salt marsh vegetation. Graphic courtesy of Garzon et al. (2018).
6. ASSESSING BENEFITS FOR FLOOD RISK REDUCTION

Coastal numerical model simulations were completed to estimate the flood risk reduction potential of proposed natural and nature-based flood mitigation projects presented in this report. The modeling exercise focused on the influence of marsh island systems in Back Bay and northern North Carolina on flooding in southern Virginia Beach. This area was chosen for several reasons. First, as mentioned earlier in this report, the marsh islands in Back Bay are projected to be particularly vulnerable to fragmentation or drowning in response to SLR. It is therefore valuable to evaluate the flood risks associated with conversion of these systems to open water, and assess the benefits of restoration for flood risk reduction. Secondly, the Southern watershed is particular susceptible to recurrent flooding during periods of prolonged southerly winds. The marsh island systems, especially along the Knotts Island Channel, are thought to provide a barrier to flood pathways, delaying time to peak flooding while also dissipating wave energy. The purpose of this analysis was to assess the flood risk reduction benefits these marsh island system provide during a wind-driven flood event.

To accomplish this, we leveraged the MIKE21 coastal hydrodynamic model. This model was developed under the CSLRRF study to simulate the effectiveness of various large-scale flood protection structures. The MIKE21 model is specifically oriented towards establishing flow patterns in complex water systems, such as coastal waterways, estuaries, and wide floodplains (Dewberry 2016). The current geographic extent of the model was sufficient for incorporating the influence of the marshes at Knotts Island and marsh island systems along the Knotts Island Channel, a critical flood pathway into Virginia Beach.

A total of four MIKE21 wind tide flooding simulations were evaluated, illustrated in Figure 51. The first two simulations reflect today’s existing sea level, with and without marsh island restoration. The second two simulations reflect the future water levels with 3 ft of SLR, where the future marsh island habitat has degraded in response to SLR as well as a future restored condition where marsh islands are nourished to keep pace with SLR. The 3 ft SLR scenario was selected over the 1.5 ft SLR scenario because of the significant amount of marsh island system that is projected to convert to open water in response to the higher SLR rate.
6.1. Projected Changes in Marshes

6.1.1. Degraded Marsh Islands

The SLAMM modeling outputs developed under the CSLRRF study and associated with the 3 ft SLR scenario were used for the future degraded marsh island condition in Virginia Beach. For the North Carolina portion of the study area, marsh migration data from the NOAA Sea Level Rise Viewer was obtained. The NOAA approach to mapping marsh response to SLR attempts to account for local and regional tidal and estimated marsh accretion (NOAA 2016). The 2 ft SLR NOAA marsh migration output was selected for its alignment with the magnitude of marsh loss projected under the Virginia Beach SLAMM analysis. The degraded marsh island system is shown in Figure 52 (left panel).

6.1.2. Restored Marsh Islands

For the restored marsh island scenarios, a historical NOAA National Geodetic Survey shoreline from 1868 was used to estimate a restored condition of marsh island systems in Back
Bay, and along the Knotts Island Channel. The restored marsh island system is shown in Figure 52 (right panel).

**Figure 52: Comparison of degraded marsh islands (in response to 3 ft SLR), shown on the left, and restored marsh islands, shown on the right.**

### 6.2. Model Grid

The MIKE21 model grid (or mesh) was modified to reflect the different marsh island scenarios. Both elevation and friction parameters were adjusted to reflect changes to land cover or open water areas. The land class coverage from the SLAMM and NOAA-sourced outputs were simplified into three sub-classes as changes of grass or woody marsh to open water, or marsh to tidal flat were deemed most applicable to the modeling effort.

#### 6.2.1. Friction Adjustments

The hydraulic roughness (also referred to as bottom bed roughness) is the measure of the amount of frictional resistance water experiences when passing over different land or channel features. Heavily vegetated or densely developed areas are assigned a higher hydraulic roughness coefficient, while paved or open areas are assigned a lower roughness coefficient. A
detailed discussion of the MIKE21 model can be found in the Numerical Modeling for Coastal Flood Risk Reduction Strategy Development Report (working document)

6.2.2. Elevation Adjustments

Although SLAMM can generate output elevations for land classes, this data was not available for the entire study area. Given the lack of elevation data, proxies were established to provide values for grid modification as follows:

- **Grass and woody marsh**: areas of grass and woody marsh were isolated, respectively, and an average elevation value from the LiDAR-derived digital elevation model (DEM) was extracted to represent an average elevation for these marsh classifications. In general, woody marsh has a higher marsh platform (computed to be located approximately 2.2 feet above the North American Vertical Datum of 1988 (NAVD88) than areas dominated by grass marsh (computed to be located 1.2 ft above NAVD88). This was expected because of the lower tolerance of woody marsh plants to frequent inundation.

- **Intertidal areas (e.g. flats)**: tidal flats are typically found at elevations between the average water level and the average low water level. A proxy elevation was defined as the mid-point elevation between the two. This value was calculated using the water-level time series from the Beggars Bridge water-level gauge maintained by the City of Virginia Beach and the USGS. The average water level was computed to be 0.29 ft above NAVD88 and the computed low water elevation (e.g. the bottom 5th percentile of water elevations over the gauge record) was computed to be 1.16 ft below NAVD88.

- **Open water areas**: a proxy elevation for open water areas was derived by extracting an average offshore depth near the existing marsh islands from the LiDAR data, computed to be approximately 0.8 ft below NAVD88. This agrees with the very shallow nature of Back Bay, especially in near-shore areas.

Prior to implementation into the grid, a secondary proxy elevation was developed for the marsh classifications to account for the simulations with SLR. To represent how these systems would keep pace with SLR supported by restoration activities, 3 ft was added to the proxy area elevations. It should be noted that marsh restoration techniques discussed in this report, such as thin layer placement, would likely be required to help maintain marsh platform elevation with respect to rising water levels.
6.3. Modeling Simulation

A southern wind with constant speed at 20 MPH for 5-6 days, can raise the water level in northern Back Bay by 2-2.5 ft, which is very close to the wind surge level that has been observed recently in May 2017 and July 2018. To incorporate this event into the MIKE21 model, water level time series at the canal near Dam Neck Road and at Back Bay near Currituck were extracted from simulations of wind tide conditions completed as part of the Numerical Modeling of Wind Tides in Back Bay and North Landing River (working document).

6.4. Results

The modeling simulations were evaluated to assess flood risk reduction benefits in two ways: 1) flood depth reduction and 2) timing of the maximum flood event. The benefits associated with these elements are discussed in the following sections.

6.4.1. How could a marsh island restoration project impact the depth of flooding during a wind tide event?

Both the existing and future condition modeling simulations showed an overall positive affect of marsh island restoration with wind-driven flooding, shown in Figure 53 for today’s condition, and in Figure 54 for the 3 ft SLR condition. The results are summarized for Knotts Island and the Back Bay/Sandbridge shorelines separately due to the patterns of changes in flooding within these areas.

6.4.2. Knotts Island

The greatest reduction in flooding occurs on Knotts Island, lowering flood depths by approximately 0.5 to 1.8 ft today and 1 to 5 ft for the 3 ft SLR condition. This is a result of the large amount of marsh island restoration potential within the Mackay Island National Wildlife Refuge and the Knotts Island Channel. This suggest that the marsh system on Knotts Island, if restored and nourished to maintain its elevation with respect to SLR, could provide significant benefits to northern North Carolina.

6.4.3. Back Bay and Sandbridge Shorelines

The simulations of wind tide today show that marsh island restoration could result in minor to moderate reductions in maximum flood depths along the Back Bay shoreline and Sandbridge. Most areas show only 1 – 2 inches of reduction, however, other areas show larger reductions ranging from 0.5 and 1.5 feet. Further inland, the simulations show reductions in flood depths along some of the critical access roads, which will be discussed in more detail in
the following section. There are also some reductions in flood depths within the most low-lying portions of neighborhoods, such as Sandbridge where depths are reduced on average 1 inch to 4 inches.

Along the western shoreline of Back Bay, the 3 ft SLR simulation shows positive, but lesser flood risk reduction benefits as compare to today’s conditions, providing on average less than an inch reduction in flood depths. This is expected because some of the marsh island systems in Back Bay become overtopped with the elevated water level, given their lower elevations compared to the water surface elevation.

Along the edge of the marsh islands of Back Bay and some small sections of undeveloped shoreline in False Cape State Park, there are minor increases in flood depths under the existing sea level condition simulation, ranging from just a few inches to up to half a foot. This effect is not surprising, as documented in other literature, often referred to as the damming or blocking effect where the marsh islands slow down the movement of water and causing some local water setup (referred to as hydraulic jump) along the edge of the fringe marsh. This effect is not as noticeable for the 3 ft SLR scenario, as the low-lying fringing marsh is overtopped by the elevated water level as mentioned in the previous paragraph.
Figure 53: Comparison of the reduction in the maximum flood depth during a wind tide event today, between existing conditions (e.g. no action) and a restored marsh island system.
Figure 54: Comparison of the reduction in the maximum flood depth during a future wind tide event with 3 ft of SLR, between the future degraded marsh island conditions (as projected by marsh migration modeling), and a restored marsh island system that is nourished to keep pace with SLR.
6.4.4. How could a marsh island restoration project impact the timing of flooding during a wind tide event?

In addition to evaluating the impact of marsh on floodplain in the study area, the timing of water levels through the model simulation period (Tuesday 1/2/2018 – Tuesday 1/9/2018) was also evaluated at three locations adjacent to Back Bay: Sandbridge Road, Muddy Creek Road and Marsh Causeway (shown in Figure 55). These locations were chosen given their propensity to flood during wind tide events. It should be noted that water surface elevation changes, rather than depth of flooding, is presented in this section.

Figure 55: Output locations for assessing flood risk reduction at critical access roads.
For a wind tide event using current conditions, the model showed restoring marsh islands has a positive effect on the timing of the event at all three locations. At Muddy Creek Road, where elevations along the road are as low as 0.8 ft, maximum water surface elevations reached 2.2 ft under the no action scenario. Under the restored marsh scenario, the road did not flood for the entire length of the wind tide event (Figure 56). Although maximum water surface elevations were only reduced by 0.1-0.2 ft at Sandbridge Road (Figure 57), the duration of flooding was significantly reduced. In the restored condition, the road was not flooded until the 7th day of the simulation. This represents a 3-day delay as compared to the flooding that would have started on of the 4th day of the no action simulation. Similarly, along the Marsh Causeway (Figure 58), maximum water surface elevations were only reduced by 0.2 - 0.3 ft. However the duration of flooding was significantly reduced. In the restored condition, the road was not flooded until the 6th day of the simulation. This represents a 4-day delay as compared to the flooding that would have started on the 2nd day of the simulation under the no action scenario.

![Figure 56: Comparison of water levels at Muddy Creek Road for the no action simulation versus the restored marsh island scenario at existing sea level condition.](image)

Dewberry
Figure 57: Comparison of water levels at Sandbridge Road for the no action simulation versus the restored marsh island scenario at existing sea level condition.

Figure 58: Comparison of Water Level at the Marsh Causeway for the no action simulation versus the restored marsh island scenario at existing sea level condition.
For the future 3 ft SLR wind tide event, restoring marsh islands showed a less noticeable positive affect. At Sandbridge Road (Figure 59) and Muddy Creek Road (Figure 60), while the maximum water level was not reduced, the timing of flood waters was delayed. Water levels were reduced by approximately 0.5 ft during the first three days of the event. Along the Marsh Causeway, the maximum water surface elevations were reduced by approximately 0.1 – 0.2 ft and flooding was delayed by 4 days.

Figure 59: Comparison of water levels at Sandbridge Road for the no action simulation versus the restored marsh island scenario at the future 3 ft SLR condition.
Figure 60: Comparison of water levels at Muddy Creek Road for the no action simulation versus the restored marsh island scenario at the future 3 ft SLR condition.

Figure 61: Comparison of water levels at the Marsh Causeway for the no action simulation versus the restored marsh island scenario at the future 3 ft SLR condition.
These results show that marsh island restoration provides the greater overall flood risk reduction benefit in Back Bay during a wind tide today, as compared to the 3 ft SLR scenario where the baseline water level is elevated. Even if marsh islands are restored and nourished to keep pace with SLR, a prolonged wind tide event with 3 ft SLR can still push enough water into Back Bay to flood low-lying land. The simulation results also suggest that during a shorter duration wind-tide event, marsh island restoration could provide even greater flood risk reduction benefits. This is because the water elevation during a shorter event might not reach an elevation capable of overtopping the marsh islands, thus allowing the marshes to still provide more frictional resistance to water movement. Overall, the modeling simulations suggest that marsh island restoration likely provides the greatest flood risk reduction benefits for smaller, shorter duration events.

This modeling exercise focused on restoring marsh islands to their historical coverage. However, there are other types of nature-based strategies that could be explored such as assessing the benefits of different configurations of marsh terraces, living shorelines, or restoration of fringing marshes in Back Bay. Additional numerical modeling could provide insight into how different types of strategies compare against one another with respect to flood risk reduction benefits.

7. DESIGN

The design phase of an NNBF project is one of its most essential components, especially when attempting to maximize all of its benefits. This phase is when all of the key decisions which impact a projects effectiveness are made. There are many existing resources, as laid out in Section 7.1, which come from private, federal, and state entities. The resource with the most potential, the International NNBF Guidelines, is still under development. This effort is a collaborative one aimed at addressing all aspects of an NNBF projects full life-cycle. The International NNBF Guidelines are summarized below, in Section 7.2. Furthermore, there are several resources focused specifically on NNBF design amidst SLR. The two most notable of these come from NOAA and the Stevens Institute of Technology, and are further explored in Section 7.3.

7.1. Existing Resources

Several guidance documents have been published to help policy makers, regulators, property owners, architects and engineers effectively design and construct NNBF projects.
<table>
<thead>
<tr>
<th>Organization/Author</th>
<th>State/Region</th>
<th>Title</th>
<th>Resource Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Resources Conservation Service (NRCS)</td>
<td>National</td>
<td>Wetland Restoration Enhancement, or Creation Engineering Field Handbook</td>
<td>Chapter 13, Wetland Restoration, Enhancement, or Creation is one of the 19 chapters of the U. S. Department of Agriculture (USDA), Natural Resources Conservation Service (NRCS) National Engineering Handbook (NEH), Part 650. This chapter is intended to provide field personnel with guidance in restoring, enhancing, or creating wetlands.</td>
</tr>
<tr>
<td>NOAA</td>
<td>National</td>
<td>Considering the Use of Living Shorelines</td>
<td>This guidance is intended to provide information on NOAA’s perspective and roles regarding living shorelines implementation. It starts by describing NOAA living shorelines guiding principles, then highlights NOAA’s role in providing science, tools, and training to help inform the selection of appropriate techniques. It also discusses the agency’s role in reviewing living shoreline projects, depending on their location and potential effect on habitats of concern to NOAA, such as critical habitat, essential fish habitat, or protected areas.</td>
</tr>
<tr>
<td>USACE EWN Initiative</td>
<td>National</td>
<td>A Design Manual: Engineering with Nature Using Native Plant Communities</td>
<td>This design manual identifies and documents the use of native plants to provide engineered design elements that consider the diverse range of USACE’s water resource projects. The goal of this manual is to describe how to utilize plant communities within the built environment to create sustainable landscapes.</td>
</tr>
<tr>
<td>VIMS</td>
<td>VA</td>
<td>Living Shoreline Design Guidelines for Shore Protection in Virginia’s Estuarine Environments</td>
<td>These guidelines provide site evaluation criteria, design considerations, and case studies regarding living shorelines in Virginia.</td>
</tr>
<tr>
<td>VIMS</td>
<td>VA</td>
<td>Shoreline Best Management Practices: Self-Guided Decision Tools</td>
<td>VIMS developed a series of decision trees that leads users through questions about shoreline conditions to produce a best practice recommendations. These tools are broken down into two categories: undefended shorelines and failed defense structures and currently defended shorelines.</td>
</tr>
<tr>
<td>VIMS</td>
<td>VA</td>
<td>Design Alternatives for Living Shorelines</td>
<td>This website provides a variety of living shoreline techniques that include best practices/design guidelines.</td>
</tr>
<tr>
<td>VIMS</td>
<td>VA</td>
<td>Native Plants for Living Shorelines</td>
<td>Native plants adapted to local soil, salinity, wind, and tidal flooding conditions should be the foundation for living shoreline projects. These native plant lists and other resources will help guide the selection of the best native plants to use for different habitat features.</td>
</tr>
<tr>
<td>Stevens Institute of Technology</td>
<td>NJ</td>
<td>Living Shorelines Engineering Guidelines</td>
<td>Guidance for engineers and regulators on living shoreline design.</td>
</tr>
<tr>
<td>NOAA</td>
<td>Northeast</td>
<td>Planning for Sea Level Rise in the Northeast: Considerations for the Implementation of Tidal Wetland Habitat Restoration Projects</td>
<td>This document presents draft guidelines on how to assess and incorporate sea level rise impacts into site-specific tidal wetland restoration planning and design.</td>
</tr>
</tbody>
</table>
7.2. International NNBF Guidelines

The purpose of the International NNBF Guidelines Project, initiated by the USACE, is to develop an authoritative international guidance that draws upon best practices from the international community for using NNBF to provide engineering functions relevant to flood risk management. The guidelines are planned to address the full project life cycle, including conceptualization, design, engineering, construction, and maintenance. One of the key criteria for the success of the guidelines will be their ability to support technically sound use of NNBF based on best science and engineering practices. Developing these international guidelines will be a multi-author effort that draws from organizations across all of the relevant sectors, including government, academia, NGOs, engineering firms, and construction companies. To facilitate clear communication within and across the participating organizations and define scope and content for the final guidance document, a Scoping Document was prepared. The document sets out both the business case for producing the NNBF Guidelines as well as the overall plan for producing them. The finalized guidelines will be published in spring 2020.

7.3. Sea Level Rise Adaptation

Nature-based projects are particularly sensitive to SLR due to the living elements and therefore it is critical to take SLR information into account during project design. Two resources for accounting for SLR into the design of different type of NNBF projects are highlighted below.

1. NOAA also developed a draft guidance in 2011 on how to assess and incorporate sea level rise impacts into site-specific tidal wetland restoration planning and design. Recommendations for incorporating SLR into project design include:

   • At a minimum, projects should plan for the predicted impacts of the current rate of relative sea level rise (the “low” scenario). However, the “medium” and “high” scenarios should also be fully considered and the risks assessed for each design alternative. The CLSRRF study is evaluating the 1.5 and 3 ft SLR scenarios for short- and long-term planning and a 5 ft SLR scenario to support longer-term decision-making.

   • Design elevation of wetland restoration/creation projects should be based on the current biological benchmarks (i.e., growth range of wetland plant communities) and predicted future tidal levels. For many sites, NOAA should recommend targeting elevations for the high end of the desired wetland community in order to add resiliency to potential accelerating sea level rise impacts.

   • To allow for inland/landward migration of marsh from relative sea level change, projects should consider maintaining or protecting transition/buffer zones,
incorporating gradual slopes where appropriate, and removing barriers where possible.

2. The Stevens Institute of Technology Living Shoreline Engineering Guidelines provides information on how the effectiveness of different strategies are expected to change with SLR, summarized in Table 12.

Table 12: Response of NNBF strategies to rising sea levels. Information obtained from the Stevens Institute of Technology Living Shoreline Engineering Guidelines.

<table>
<thead>
<tr>
<th>Feature</th>
<th>Expected response to sea level rise</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marsh Sills</td>
<td>Sills themselves are adaptable in that their crest elevations and widths can be modified relatively easily to reduce some of the problems associated with SLR; however, the marsh systems that develop behind the sill can be less capable of adapting. Recommendations suggest including SLR in the project design in a way that maximizes ecological benefits, while minimizing adverse consequences such as risks to human life and safety over the life of the project.</td>
</tr>
<tr>
<td>Living Breakwater</td>
<td>Living reef breakwaters have some capacity to adapt to changing conditions; however, they are particularly sensitive to changes in water quality. As long as parameters such as water temperature, salinity, and turbidity, remain within the range required by the constituent species, living reefs can adapt naturally to slow changes in water level (e.g. lower rates of SLR) through natural growth/migration.</td>
</tr>
<tr>
<td>Living Breakwater (Cont.)</td>
<td>If the changes are rapid however, they may outpace the ability of the natural system to respond (Rella &amp; Miller, 2012). If the increase in reef elevation lags behind the increase in sea level, the effectiveness of the living reef in dissipating wave energy will be reduced as well and larger waves will impact the reef and marsh. Marsh vegetation which may be included as a part of a living reef project, is also highly susceptible to the changes associated with sea level rise, i.e., drowning of root systems and salt intrusion.</td>
</tr>
<tr>
<td>Ecologically-Enhanced Revetment</td>
<td>As sea level rises, an ecologically-enhanced revetment will provide less protection and overtopping will become more frequent. SLR will also allow larger waves to impact the structure and may change the location and characteristics of the breaking waves. While revetments themselves are adaptable in that their crest elevations and widths can be modified relatively easily to reduce some of the problems associated with SLR, joint plantings will eventually die out as they become submerged. These possibilities should be considered during design.</td>
</tr>
</tbody>
</table>

8. PERMITTING

NNBF projects are often subject to multiple local, state, and federal environmental regulations. These regulations manifest themselves in the form of permits. Acquiring the necessary permits for an activity or project is often a cumbersome task. The number of different permitting agencies that may have jurisdiction over a given project are shown in Figure 62.
The USACE, the VMRC, and the Virginia Department of Environmental Quality (DEQ) have created a standardized permitting process that streamlines many of the typically burdensome and hard-to-navigate regulatory processes through their Joint Permit Application (JPA). The JPA is used to apply for permits from the Norfolk District USACE, which includes Virginia Beach, for work in the waters of the United States. The USACE Federal Regulatory Program involves regulating of discharges of dredged or fill material into waters of the United States and structures or work in navigable waters of the United States, under section 404 of the Clean Water Act and section 10 of the Rivers and Harbors Act of 1899. The project’s proposed impacts to these areas will determine what permit type is required. Projects that are anticipated to have more than minimal adverse impacts are required to obtain an individual (or standard) permit, which are evaluated using additional environmental criteria and involve a more comprehensive public interest review. A general permit is issued for structures, work or discharges that will result in only minimal adverse effects. There are three types of general permits – Nationwide Permits (NWP), Regional Permits, and Programmatic General Permits, summarized in Table 13.
Table 13: USACE Regulatory Program Permit Types; information obtained from the USACE Headquarters.

<table>
<thead>
<tr>
<th>General Permit Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nationwide Permits</td>
<td>Nationwide permits are issued by USACE on a national basis and are designed to streamline Department of the Army authorization of projects such as commercial developments, utility lines, or road improvements that produce minimal impact the nation’s aquatic environment. More information on nationwide permits can be found <a href="#">here</a>.</td>
</tr>
<tr>
<td>Regional Permits</td>
<td>A regional general permit is issued for a specific geographic area by an individual USACE District. Each regional general permit has specific terms and conditions, all of which must be met for project-specific actions to be verified.</td>
</tr>
<tr>
<td>Programmatic General Permits</td>
<td>Programmatic general permits are based on an existing state, local, or other federal program and designed to avoid duplication of that program. A State Programmatic General Permit (SPGP) is a type of permit that is issued by USACE and designed to eliminate duplication of effort between USACE districts and state regulatory programs that provide similar protection to aquatic resources. In some states, the SPGP replaces some or all of the USACE nationwide permits, which results in greater efficiency in the overall permitting process.</td>
</tr>
</tbody>
</table>

The JPA is also used as an application for the corresponding permits from the VMRC, DEQ, and Local Wetland Boards. There are two different JPAs available depending on the type of activity being proposed. One of these two versions, the Tidewater JPA, is an abbreviated version of the JPA. According to the USACE, the Tidewater JPA covers a wide array of eligible activities, including “piers, boathouses, boat ramps, moorings, marinas, aquaculture facilities, riprap revetments, bulkheads, marsh toe stabilizations, breakwaters, beach nourishment, groins, jetties, road crossings over tidal waterways, and utility lines over or under tidal waterways,” (USACE Regulatory Branch - Joint Permit Application). These permits, as well as information and resources regarding them, are summarized and linked below, in Table 14.

Table 14: Resources and information on relevant regulations and permitting processes for NNBF projects.

<table>
<thead>
<tr>
<th>Organization/Author</th>
<th>State/Geography</th>
<th>Title</th>
<th>Resource Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>VMRC</td>
<td>VA</td>
<td>Living Shoreline Group 1 General Permit for Certain Living Shoreline Treatments Involving Tidal Wetlands</td>
<td>Streamlines the permitting process in Virginia for living shoreline projects that involve activities in tidal wetlands (landward of mean low water) that require authorization from the VMRC or local wetlands board.</td>
</tr>
<tr>
<td>VMRC</td>
<td>VA</td>
<td>Living Shoreline Group 2 General Permit for Certain Living Shoreline Treatments Involving Submerged Lands, Tidal Wetlands, or Coastal Primary Sand Dunes and Beaches</td>
<td>Streamlines the permitting process in Virginia for living shorelines projects that involve activities involving submerged lands, tidal wetlands, or sand dunes and beaches requiring authorization from the VMRC or local wetlands board. The Group 2 Permit is similar to the Group 1 Permit but differs in that Group 2 permits may allow for filling on state-owned bottomlands.</td>
</tr>
<tr>
<td>Organization/Author</td>
<td>State/Geography</td>
<td>Title</td>
<td>Resource Description</td>
</tr>
<tr>
<td>---------------------</td>
<td>-----------------</td>
<td>-------</td>
<td>----------------------</td>
</tr>
<tr>
<td>VIMS</td>
<td>VA</td>
<td>Education: Wetlands Self Taught Education Units</td>
<td>Self-paced educational seminars regarding permit processes in VA, coastal defense structures, wetlands ecology, and more.</td>
</tr>
<tr>
<td>VIMS</td>
<td>VA</td>
<td>Living Shorelines: Permitting Steps</td>
<td>Lists steps and provides links to permits and forms that may be required for different type of living shoreline projects, specifically involving activities that modify riparian buffers, tidal wetlands, and subaqueous lands.</td>
</tr>
<tr>
<td>VMRC</td>
<td>VA</td>
<td>Applying for a General Wetlands Permit to Address Catastrophic Erosional Situations</td>
<td>This regulation describes the qualifications, procedures and manner of applying for a general wetlands permit to address catastrophic erosional situations which are attributable to a specific storm event or natural calamity.</td>
</tr>
<tr>
<td>Habitat Management Division</td>
<td>VA</td>
<td>Resources for Habitat Management Division Permitting</td>
<td>Information and resources regarding environmental permits issued by the Habitat Management Division, of which there are three types; subaqueous or bottomlands, tidal wetlands, and coastal primary sand dunes.</td>
</tr>
<tr>
<td>USACE, VMRC, VA DEQ, Local Wetlands Board</td>
<td>VA</td>
<td>Standard Joint Permit Application Form, Joint Permit Application Information, VA Beach JPA Guidelines</td>
<td>The Joint Permit Application (JPA) process and Standard JPA are used for permitting purposes involving water, wetlands, and dune/beach resources, including, but not limited to, major water supply and water withdrawals projects (as defined in DEQ Regulation 9 VAC 25-210).</td>
</tr>
<tr>
<td>VA DEQ</td>
<td>VA</td>
<td>Virginia Water Protection Permit Information</td>
<td>Information regarding the VA DEQ’s use of the Joint Permit Application.</td>
</tr>
<tr>
<td>USACE</td>
<td>Regional</td>
<td>USACE Letters of Permission, Regional and State General Permit Program Information and Resources</td>
<td>List of permits provided through the USACE with information and resources for each.</td>
</tr>
<tr>
<td>USACE</td>
<td>Regional</td>
<td>Regional Permit 02 (18-RP-2)</td>
<td>Used to authorize both new maintenance dredging (channels and basins) for certain navigation related dredging projects.</td>
</tr>
<tr>
<td>USACE</td>
<td>Regional</td>
<td>17-SPGP-01</td>
<td>Used to authorize the discharge of dredged or fill material in non-tidal waters, including wetlands, associated with certain residential, commercial, and institutional developments and linear transportation projects.</td>
</tr>
<tr>
<td>USACE</td>
<td>Regional</td>
<td>Regional Permit 05 (16-RP-05)</td>
<td>For construction of certain small impoundments except stormwater management ponds.</td>
</tr>
<tr>
<td>USACE</td>
<td>Regional</td>
<td>Regional Permit 15 (18-RP-15)</td>
<td>Used to authorize certain activities associated with the maintenance of existing drainage ditches.</td>
</tr>
<tr>
<td>Organization/ Author</td>
<td>State/ Geography</td>
<td>Title</td>
<td>Resource Description</td>
</tr>
<tr>
<td>----------------------</td>
<td>-----------------</td>
<td>-------</td>
<td>----------------------</td>
</tr>
<tr>
<td>USACE</td>
<td>Regional</td>
<td>Regional Permit 17 (18-RP-17)</td>
<td>Used to authorize the installation and/or construction of open-pile piers, mooring structures/devices, fender piles, covered boathouses/boat slips, boatlifts, osprey pilings, platforms, accessory pier structures, and certain devices associated with shellfish gardening, for private use.</td>
</tr>
<tr>
<td>USACE</td>
<td>Regional</td>
<td>Regional Permit 18 (18-RP-18)</td>
<td>Used to authorize the installation and/or construction of open-pile piers, mooring structures/devices, fender piles, covered boathouses/boat slips, boatlifts, osprey pilings/platforms, accessory pier structures, and certain devices associated with shellfish gardening, for private, commercial, community, and government use.</td>
</tr>
<tr>
<td>USACE</td>
<td>Regional</td>
<td>Regional Permit 19 (18-RP-19)</td>
<td>Used to authorize living shorelines, riprap revetments, bulkheads, breakwaters, groins, jetties, spurs, baffles, aquaculture activities and boat ramps.</td>
</tr>
<tr>
<td>USACE</td>
<td>Regional</td>
<td>Regional Permit 20 (17-RP-20)</td>
<td>For certain state owned, operated, or managed artificial reefs.</td>
</tr>
<tr>
<td>USACE</td>
<td>Regional</td>
<td>Regional Permit 22 (18-RP-22)</td>
<td>Used to authorize specific activities within the Virginia portion of Lake Gaston.</td>
</tr>
<tr>
<td>USACE</td>
<td>Nationwide</td>
<td>Nationwide Permit 13: Bank Stabilization</td>
<td>This permit lays out criterial for bank stabilization activities necessary for erosion control or prevention, such as vegetative stabilization, bioengineering, sills, rip rap, revetment, gabion baskets, stream barbs, and bulkheads, or combinations of bank stabilization techniques.</td>
</tr>
<tr>
<td>USACE</td>
<td>Nationwide</td>
<td>Nationwide Permit 54: Living Shorelines</td>
<td>This permit lays out criteria for the placement of sandy fill material, including the placement of sandy fill material landward of the sills provided the fill is for erosion control and/or wetland enhancement (and not solely recreational activities). The maximum fill area within waters of the United States that can be authorized under this NWP is one (1) acre.</td>
</tr>
<tr>
<td>VMRC</td>
<td>VA</td>
<td>Information on permits for Submerged Aquatic Vegetation Transplantation</td>
<td>Provides regulatory information regarding Submerged Aquatic Vegetation Transplantation, directing the use of the JPA.</td>
</tr>
<tr>
<td>VMRC</td>
<td>VA</td>
<td>Information on VA Subaqueous Guidelines</td>
<td>Provides regulatory information regarding the Subaqueous Guidelines, directing the use of the JPA.</td>
</tr>
</tbody>
</table>

Although general permits and the JPA process may streamline the permit application process, they do not preclude the need to acquire additional permits from agencies. For example, FEMA requires a Federal Development Permit (FDP) for mining, dredging, filling, grading or excavating for major landscaping projects in the regulatory floodplain. Additionally,
it is very difficult to receive Community Rating System (CRS) credit under the NFIP for a living shoreline project. Living shoreline projects may qualify for up to 120 points for CRS credit as a Natural Shoreline Protection (NSP) providing that several conditions are met. In Virginia, however, one of the requirements to receive credit is that there must be a prohibition on shoreline armoring including the construction of bulkheads. Currently in Virginia, there are no current prohibitions on shoreline armoring given that living shorelines are not the ideal shoreline stabilization practice at every location (Antoine 2018).

In summary, consultation with all appropriate regulating entities is essential to ensure regulatory compliance for natural and nature-based flood mitigation projects. If regulatory compliance is not achieved, there is potential for fines and litigation. This highlights the importance of acquiring all necessary permits prior to any type of construction, especially in water ways, wetlands, marshes, or coast lines of any kind, where regulations are often quite strict.

9. NEXT STEPS

NNBF’s ability to provide adequate and reliable flood risk protection in Virginia Beach varies across geographic areas and conditions. The suitability of NNBF depends on the location, scale, and desired level of flood protection. In some locations, such as at the parcel-level or a neighborhood shoreline reach, NNBF may offer an appealing and cost-effective alternative to traditional structural measures with the added advantage of bringing multiple co-benefits. At larger scales, such as protection at the watershed or City-wide scale, NNBF will not be able to provide a sufficient level of flood reduction and would need to be a complimentary feature to harder structural measures. Including a solution set of potential NNBF strategies will be an important component of both the City-wide and watershed action plans for strategy implementation.

While the research documented in this report provides a high-level conceptual evaluation of NNBF strategies, more work is needed to systematically apply the evaluation framework and suitability parameters against other considerations. Other factors that will determine where NNBF can be implemented include design costs, stakeholder needs and public perception, and regulatory considerations.

Furthermore, to fully appreciate the potential of nature-based measures, cost-benefit assessments should be extended to quantify their full risk reduction benefits. While numerical models and other tools can be used to estimate flood risk reduction against performance
metrics as demonstrated by the modeling expertise presented in this report, this assessment could be taken one step further by accounting for infrastructure, social, and environmental loss avoided. Furthermore, as discussed earlier, NNBF can provide complimentary benefits to adjacent structural measures — enhancing protective functionality and extending the useful life of structures. NNBF benefits with respect to reduction in Operation and Maintenance (O&M) costs to adjacent structures can and should be quantified. For example, NNBF such as oyster reefs have been shown to reduce wind generated wave hazard by approximately 20 – 50%. This reduction can be used to estimate the reductions in O&M to adjacent structural measures (USACE and the City of Norfolk 2018). This would enable a more holistic assessment of the benefit of implementing multiple lines of defense. Additionally, as there may be several suitable alternatives at a given location in Virginia Beach, the broad portfolio of measures should be evaluated in this fashion. This approach will avoid implementation of suboptimal solutions in critical locations.

Assessments should also account for the dynamic nature of the risk reduction functions of natural ecosystems, including the evolution of nature-based measures over time especially in response to SLR. As nature-based strategies evolve over time, they require continuous management and monitoring of their effectiveness. As such, implementation of nature-based solutions should be accompanied by an adaptive management plan. Adaptive management is an iterative process in which management actions are followed by targeted monitoring and assessment, permitting project refinement as performance becomes better understood.

The World Bank provides an 8-step process to guide for the planning, assessment, design, implementation, monitoring, management, and evaluation of nature-based solutions for flood risk management, presented in Figure 63. Much of the work already completed under the CSLRRF study addresses the requirements of Steps 1 and 2, such as hazard analysis and mapping and stakeholder engagement. The research presented in this report accomplishes the requirements of Step 3 by developing an initial list of measures and a strategy map. This document also lays foundational work for the following steps through identification of best practices for evaluating, designing, constructing and monitoring NNBF projects, as determined through a review of relevant local and international case studies, guidelines, and published literature. Moving forward, additional work will need to be done to estimate costs, benefits, and effectiveness (Step 4), which will determine which design interventions are selected for implementation (Steps 5 – 8).
Figure 63: Process for incorporation natural and nature-based flood protection measures into adaptation plans, as adapted from the World Bank framework.
10. REFERENCES


Bridges, T., P. Wagner, K. Burks-Copes, J.R. Vietri. (Bridges et al. 2015b) Natural & Nature-Based Features [Brochure]. U.S. Army Engineer Research and Development Center, Vicksburg, MS. (PDF)


Center for Coastal Resources Management (CCRM) (2019). Living Shoreline Design Alternatives. (Website)

City of Virginia Beach (CVB) Department of Public Works (2017). Water Resources in the Southern Watershed of Virginia Beach. (PDF)

CVB Department of Public Works (2018). Analysis of Marsh Response to Sea Level Rise. (PDF)


NOAA (2015b). Guidance for Considering the Use of Living Shorelines. (PDF)


Stevens Institute of Technology (2016). Living Shorelines Engineering Guidelines. (PDF)

Stevens, R., Hill, K., Burgess, N. and Grady, A. (2016). New Beach Designs as Urban Adaptation to Sea Level Rise. Landscape Research Record No. 1. (PDF)


USACE (2013b). Final Feasibility Report and Integrated Environmental Assessment for the Lynnhaven River Ecosystem Restoration. (PDF)

USACE (2015). North Atlantic Coast Comprehensive Study: Resilient Adaptation to Increasing Risk. (PDF)


USACE and the City of Norfolk (2018). Final Integrated City of Norfolk Coastal Storm Risk management Feasibility Study / Environmental Impact Statement. (PDF)
USACE and the City of Norfolk (2018). Final Integrated City of Norfolk Coastal Storm Risk Management Feasibility Study / Environmental Impact Statement. (PDF)


Virginia Institute of Marine Sciences (VIMS) (2005). Shoreline Evaluation Chesapeake Bay Shoreline City of Virginia Beach, VA. (PDF)


VIMS (2016). Shoreline Assessment Mapper (SAM) Description of Data Layers. (PDF)

VIMS 2018. Creating Living Shorelines: a Course for Contractors, Module 2: Understanding and Predicting Site Suitability. (Module)


Zhao, H. et al. (2014). Coastal Green Infrastructure Research Plan for New York City. (PDF)