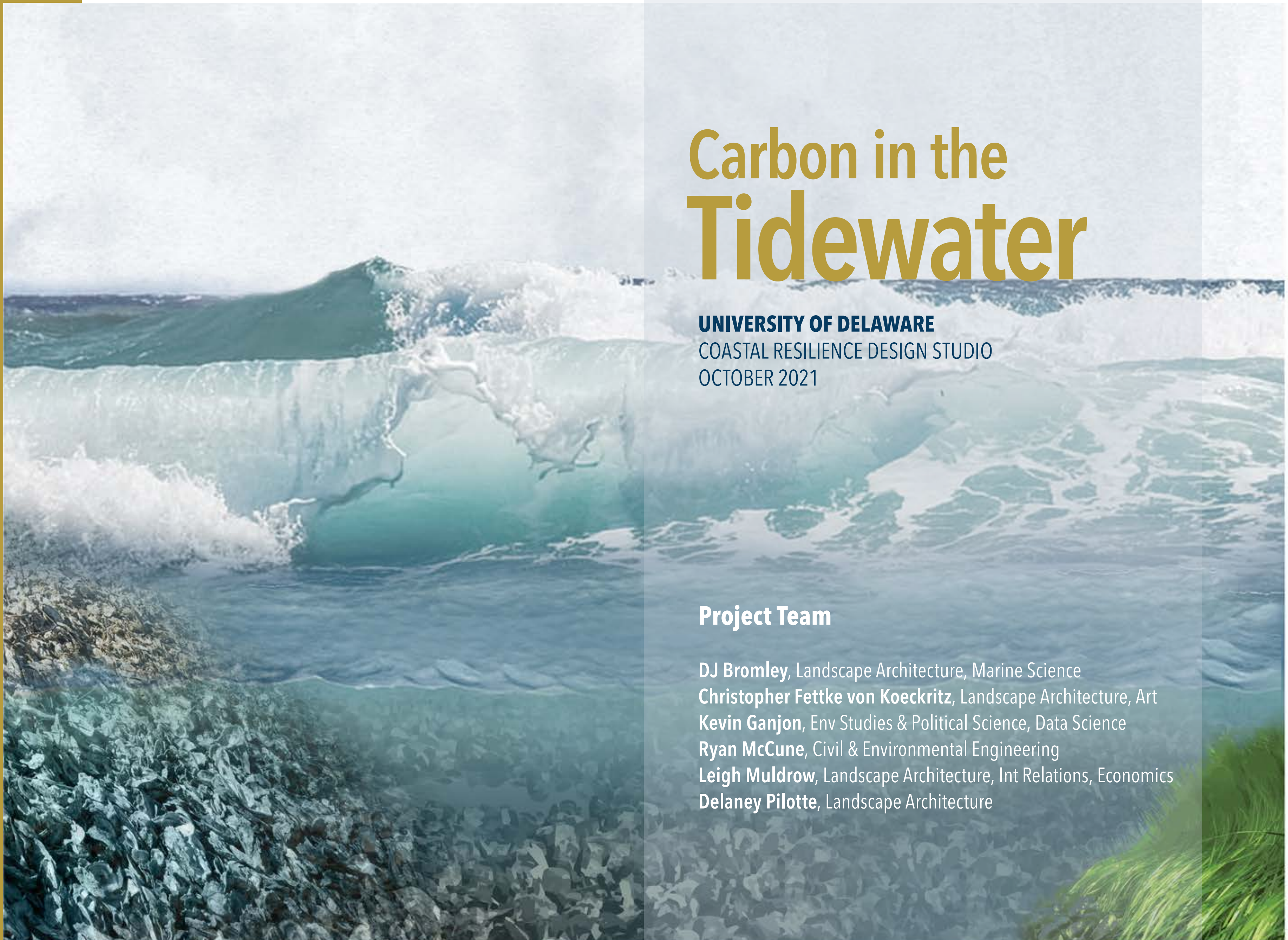

Carbon in the Tidewater

UNIVERSITY OF DELAWARE
COASTAL RESILIENCE DESIGN STUDIO
OCTOBER 2021

Project Team

DJ Bromley, Landscape Architecture, Marine Science
Christopher Fettke von Koeckritz, Landscape Architecture, Art
Kevin Ganjon, Env Studies & Political Science, Data Science
Ryan McCune, Civil & Environmental Engineering
Leigh Muldrow, Landscape Architecture, Int Relations, Economics
Delaney Pilotte, Landscape Architecture

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Cover Image Source: https://www.maxpixel.net/Splash-Waves-Wind-Beach-Blue-Foam-Spray-Sea-2327158

Abstract

This is a place of firsts. The first colonial settlers chose this place for its comfortable waters and protective cape. It was here that the first villages of the Kecoughtan were displaced in 1610. It was here that the first African slave ships touched shore in 1619 and it was here that the first Union Army Camp would be the first to free enslaved African Americans in 1861. From the ramparts of Fort Monroe to the diverse streets of Phoebus, this place has withstood war, fires, hurricanes, and floods. Here, pivotal change in America's story has occurred before. It is here that the story of **our relationship with nature must evolve.**

The nature that surrounds us is ever-changing, but as warming climate alters coastlines and increases the intensity of storm events, innovative adaptive solutions are required to protect people and place. It is time once again for this place to be the first. Hampton, Virginia is particularly susceptible to early impacts due to low elevation, land subsidence, proximity to the open ocean, and hurricane impacts. This project aims to address the immediate need to protect Hampton residents and infrastructure from future storm events, and sea level rise by developing a comprehensive plan to lead in the creation of nature-based solutions for resilience. This plan addresses the overall resilience of Hampton by developing adaptive and responsive coastal and urban ecosystems that are certifiable through the Blue Carbon and Resilience Credit Market Economy. Carbon and Resilience credits become part of the economic driver to build and restore valuable ecosystems that will sequester carbon, filter water, protect Hampton, and ultimately help cool the planet.

This project is a call to change American infrastructure investment. Projects of the future must take a human-ecological approach to prioritize public investment in ways that both protect today's population and contribute to tomorrow through the development of productive carbon sequestering ecosystems as a core component of every infrastructure design. Hampton is a place of firsts and so it is fitting that **Carbon in the Tidewater**, a carbon-based investment in future adaptable infrastructure, starts here. Our solution is to implement a four layer series of **Resilient Self-Generative Infrastructure** as a new living coastal edge, designed to be adaptive over time, ecologically productive, and economically protective.

A Team Effort

Our interdisciplinary team consists of Landscape Architecture students DJ Bromley, Christopher Fettke von Koeckritz, Leigh Muldrow and Delaney Pilotte, Civil and Environmental Engineering student Ryan McCune, and Environmental Policy and Political Science student Kevin Ganjon, working together as the Coastal Resilience Design Studio under Co-Principals Dr. Jules Bruck and Ed Lewandowski.

Site Analysis
DJ Bromley • Christopher Fettke von Koeckritz • Kevin Ganjon • Ryan McCune • Leigh Muldrow • Delaney Pilotte

GIS Mapping
DJ Bromley • Christopher Fettke von Koeckritz • Kevin Ganjon • Ryan McCune • Leigh Muldrow

3D Modeling
Christopher Fettke von Koeckritz

Report Development
DJ Bromley • Leigh Muldrow

Design Calculations
DJ Bromley • Ryan McCune • Leigh Muldrow

Graphic Development
DJ Bromley • Christopher Fettke von Koeckritz • Leigh Muldrow

Technical Review
Dr. Eric Bardenhagen • Dr. Jules Bruck • Dr. Michael Chajes • Andrew Hayes • Dr. Monique Head • Ed Lewandowski • Ben Muldrow
with special thanks to
Kshitija Karmarkar • Zachery Hammaker

Schematic Design
DJ Bromley • Christopher Fettke von Koeckritz • Kevin Ganjon • Ryan McCune • Leigh Muldrow • Delaney Pilotte

Over the course of the design phase, the team spoke with several experts in the fields of coastal resilience and natural sciences. We would like to thank these individuals for their help and encouragement.

Doug Janeic, Sovereign Consulting & former Army Corps project manager

Emma Ruggiero, University of Delaware-Living Shoreline Design

Stefanie Simpson, The Nature Conservancy- Resilient Funding Markets

Rodrigo Vargas, University of Delaware- Carbon Sequestration

Jocelyn Wardrup, University of Delaware -Soil Carbon Stocks

Neils Lindquist, University of North Carolina- Oyster Substrate

A Team Effort
Community Discovery

After attending the first CERF competition meeting with Hampton community representatives, the University of Delaware's multidisciplinary team immediately fell in love with Phoebus and Fort Monroe. The synergy between Phoebus's small-town charm, diverse composition, and can-do neighborhood attitude, as well as Fort Monroe's guarding offshore presence, drew us into their shared story.

In June, the team visited Hampton, meeting with community representatives, local business owners, and visitors to the Fort Monroe's outdoor park areas. After touring the neighborhoods and striking up conversations with locals in Mango Mangeaux Café and El Diablo Loco Cantina, we began to understand a deep-felt pride shared by residents of this community. We recognize this is a place of diversity and inclusion, with an unparalleled significant history. We came home feeling this is a place worth protecting.

We decided that we would not let our engagement end with one visit. We kept in touch with several local leaders and also shared UD's coastal observer phone application with several community members. The app allows citizens to document weather and water events, which are then uploaded and geo-located on a publicly viewable map. This tool allowed us to keep up with the experiences of residents throughout the summer as we designed our plan.

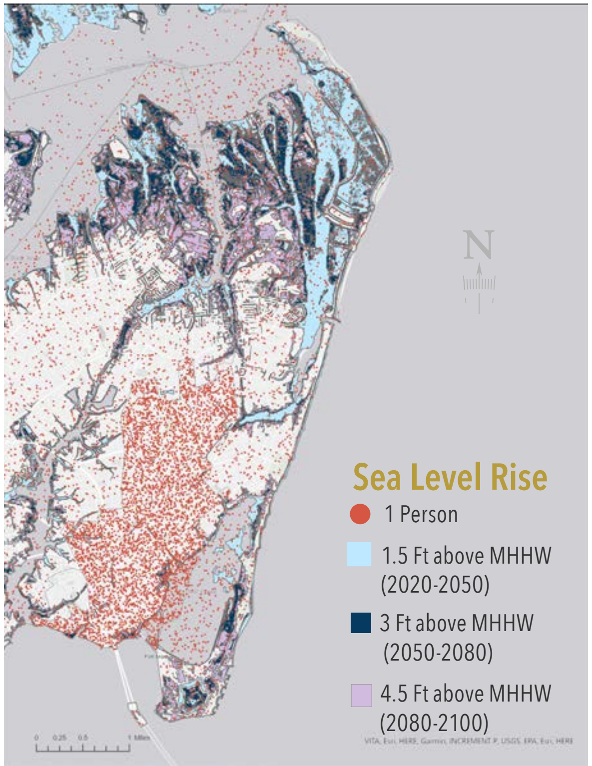
After a thorough analysis, we determined the protection of Phoebus and Fort Monroe was not feasible without consideration of the entirety of the coastal area from Grandview to Phoebus, resulting in a four layer approach to a resilient future.

The Problem

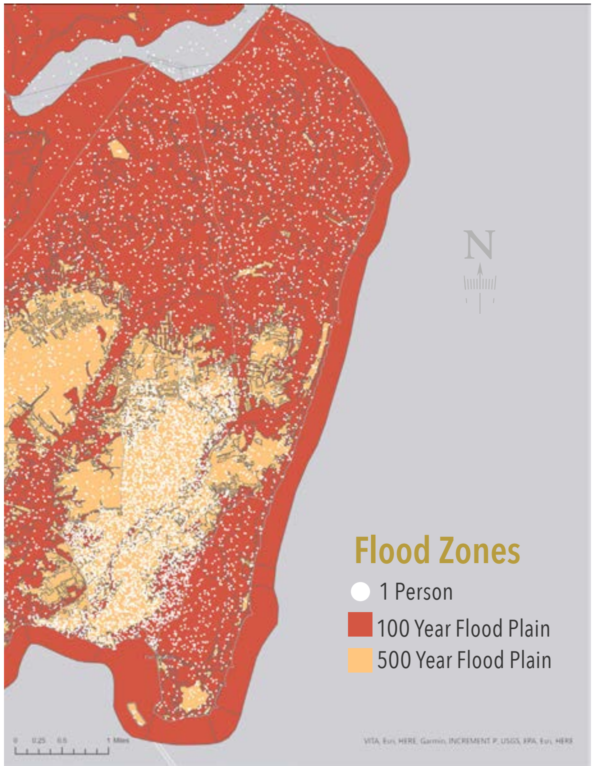
The Hampton, Virginia coastline is at **significant risk of future storm event damage** that includes but is not limited to flooding, property damage, human life risk, economic disruption, and large scale ecological destruction. Population growth and urban pressure leave both residents and adjacent threatened ecosystems with nowhere to migrate as climate change alters the landscape, and relatively small infrastructure investment to protect the coastline.

Human Risk Analysis

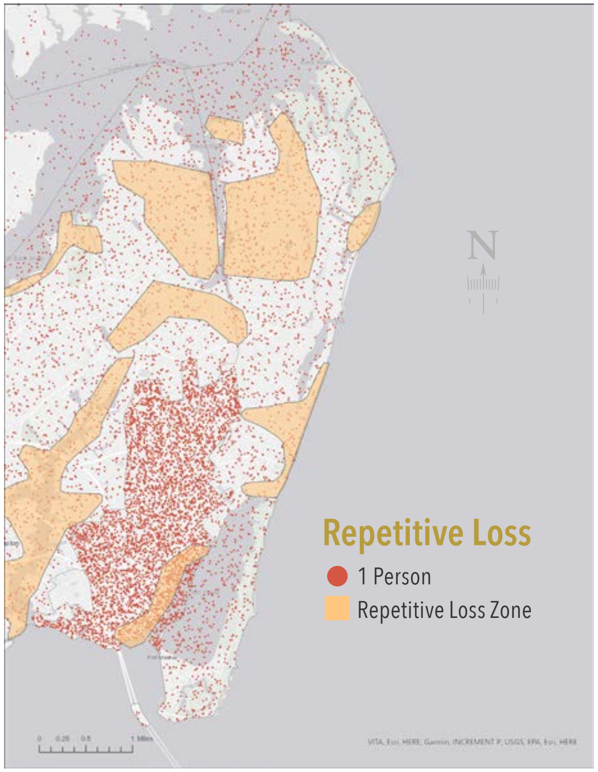
NOAA estimates the cost of weather and climate related disasters in the United States since 1980 exceeds $1.975 trillion and is responsible for 14,492 deaths in that time. Considering the risk to human life and economic impacts of disaster, the design team analyzed **population density risk** along the coastline of Hampton, Virginia as it relates to future sea level rise, the current floodplain, and repetitive zones of loss (full size maps available in Appendix). Although the population density is concentrated in the area of lower risk, there is still **significant numbers of population in high loss zones with little room to grow in the already densely populated higher elevation areas**.



Population Density data from the 2019 Community Survey living in the City of Hampton SLR zones indicate the largest area affected will occur at the 1.5' level



Population Density living in the FEMA designated 100 and 500 Year Floodplain show high density in the lower risk zone, however, this limits increased capacity in that area



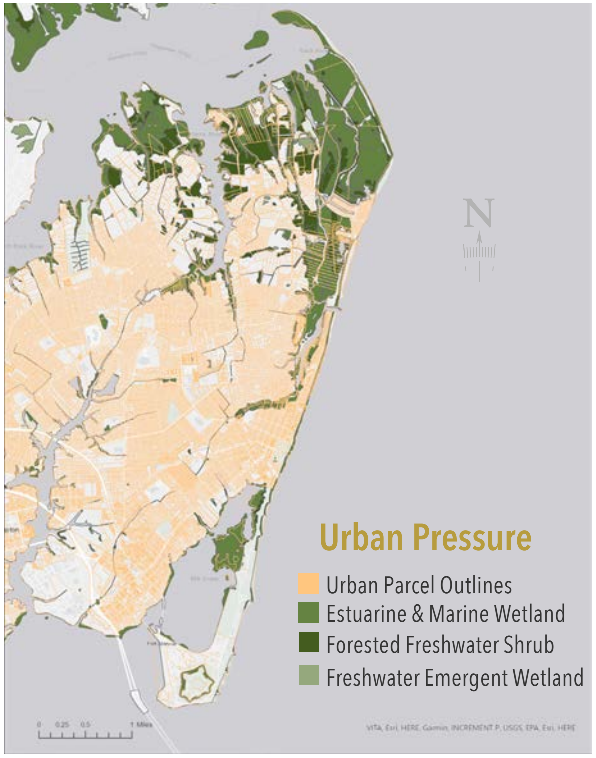
Clusters of Repetitive Loss & Insurance Claims indicate that population density does not directly correlate with recurrent property loss and recovery payouts

Design Approach

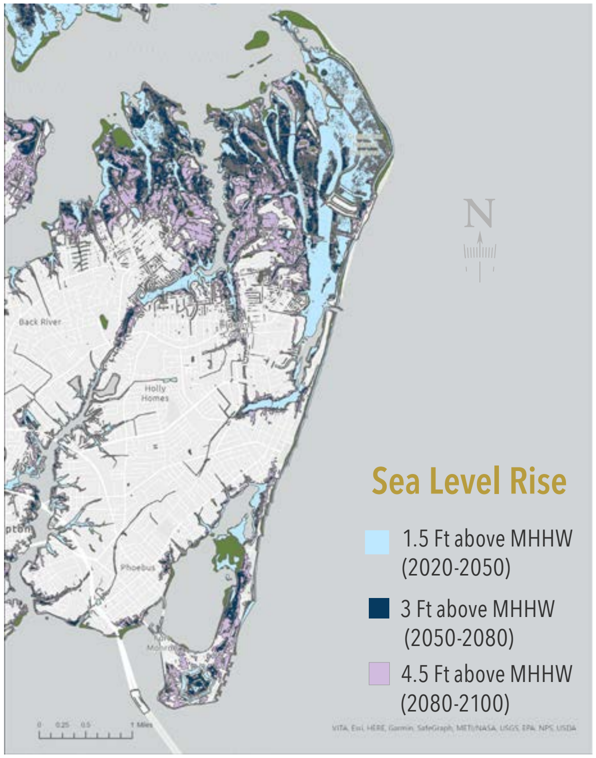
We approached the design solution by examining human risk, ecological systems and associated risks, and economic and environmental policies affecting the coastline of Hampton, Virginia. The team synthesized scientific research, emerging engineering technologies, resilience based case studies, policy, and interviewed experts in the field of resilience, soils, engineering, and carbon capture. The result is a four tiered approach that addresses the need for coastline protection that is regenerative and adaptive, harnessing the global carbon market as a finance tool.

Ecological Risk Analysis

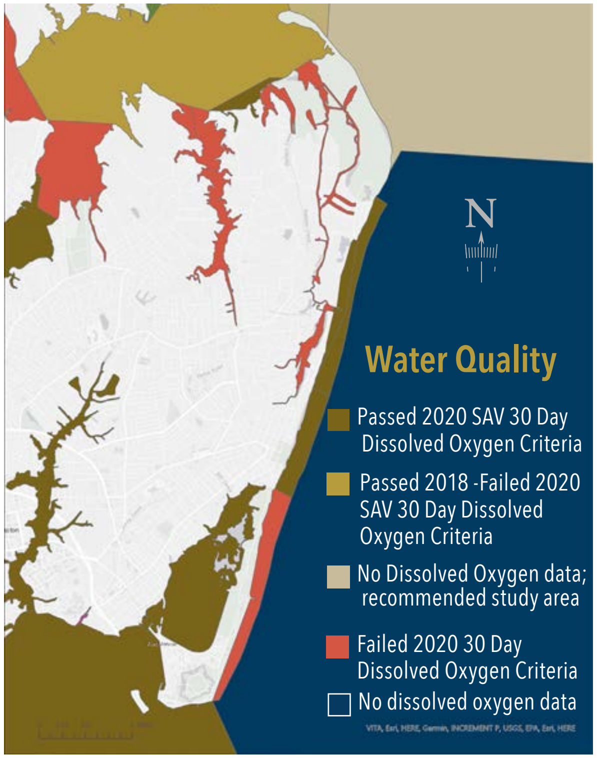
Considering how to incorporate climate change mitigation into the project design, the team analyzed **multiple ecological threats** including urban pressure on existing wetlands, the risk of sea level rise to existing wetlands, and the Virginia 2020 Department of Environmental Quality reports to identify areas where water quality improvement can assist habitat restoration, creation, and expansion. **The existing protective wetland areas are at high risk for significant loss and water quality continues to be an issue of great concern.**



Analysis of urban pressure on existing wetlands shows the existing parcel lines encroaching on wetlands from the west leaving no space for migration due to sea level rise.



Sea level rise impacts on existing wetlands indicate the greatest area of loss to vital wetland ecosystems will occur at the lowest level of predicted sea level rise

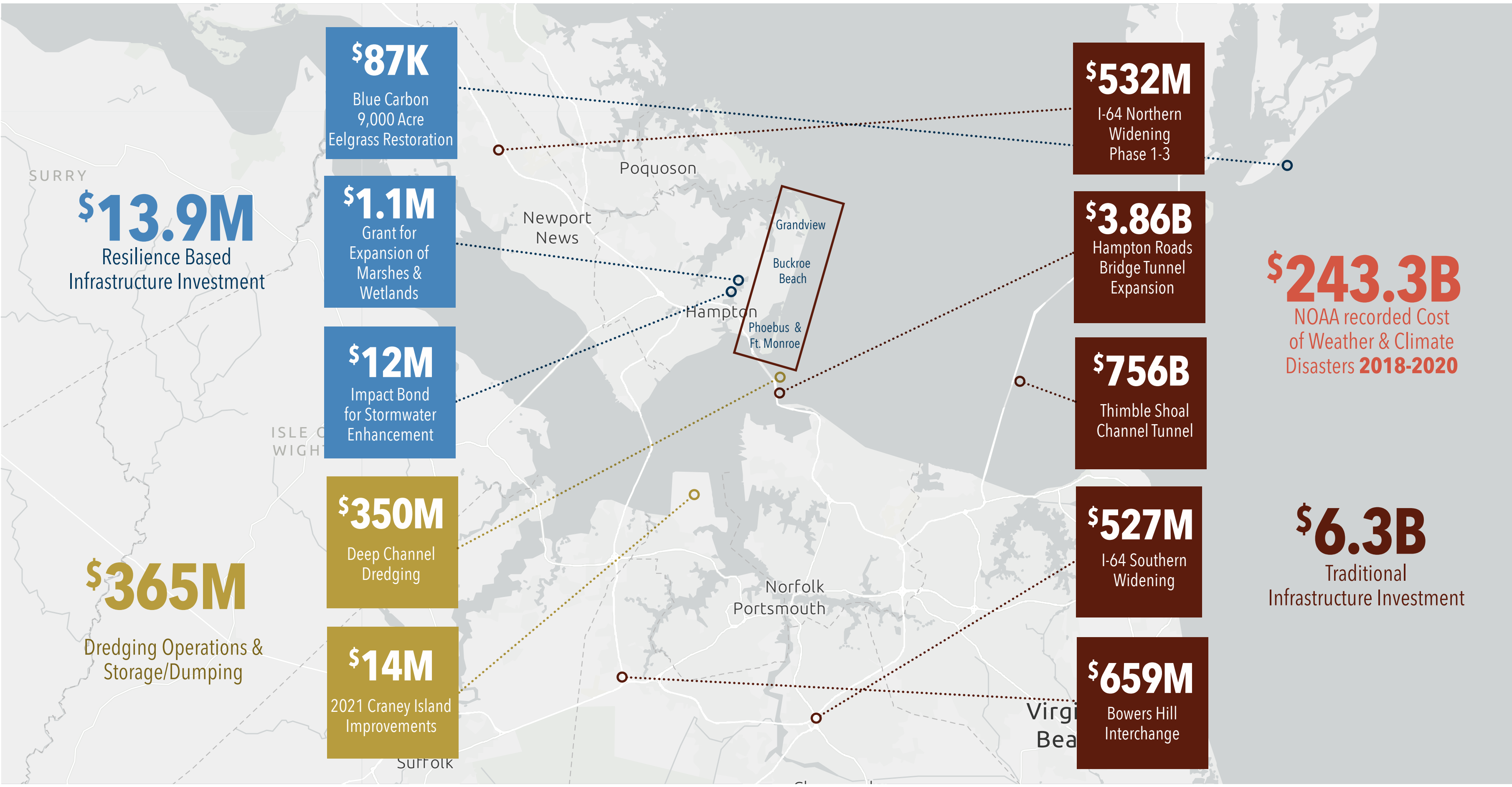


Data from the Virginia DEQ 2020 facilitated a water quality analysis to evaluate areas of potential for future SAV restoration and creation

Analysis of Existing Alternative Infrastructure

Regional Investment

During the site visit, the team noticed a remarkable number of cranes and large construction equipment in nearly every viewshed. An evaluation of the current and future public infrastructure plans reveal the current funding priority is on increasing the vehicular and shipping accessibility. There is little evidence to suggest a matched investment being made to protect the places being opened to more traffic. Additional infrastructure is required to protect the land and people of this region, however it requires an acknowledgment of risks and priorities which are shown in the graphic below.



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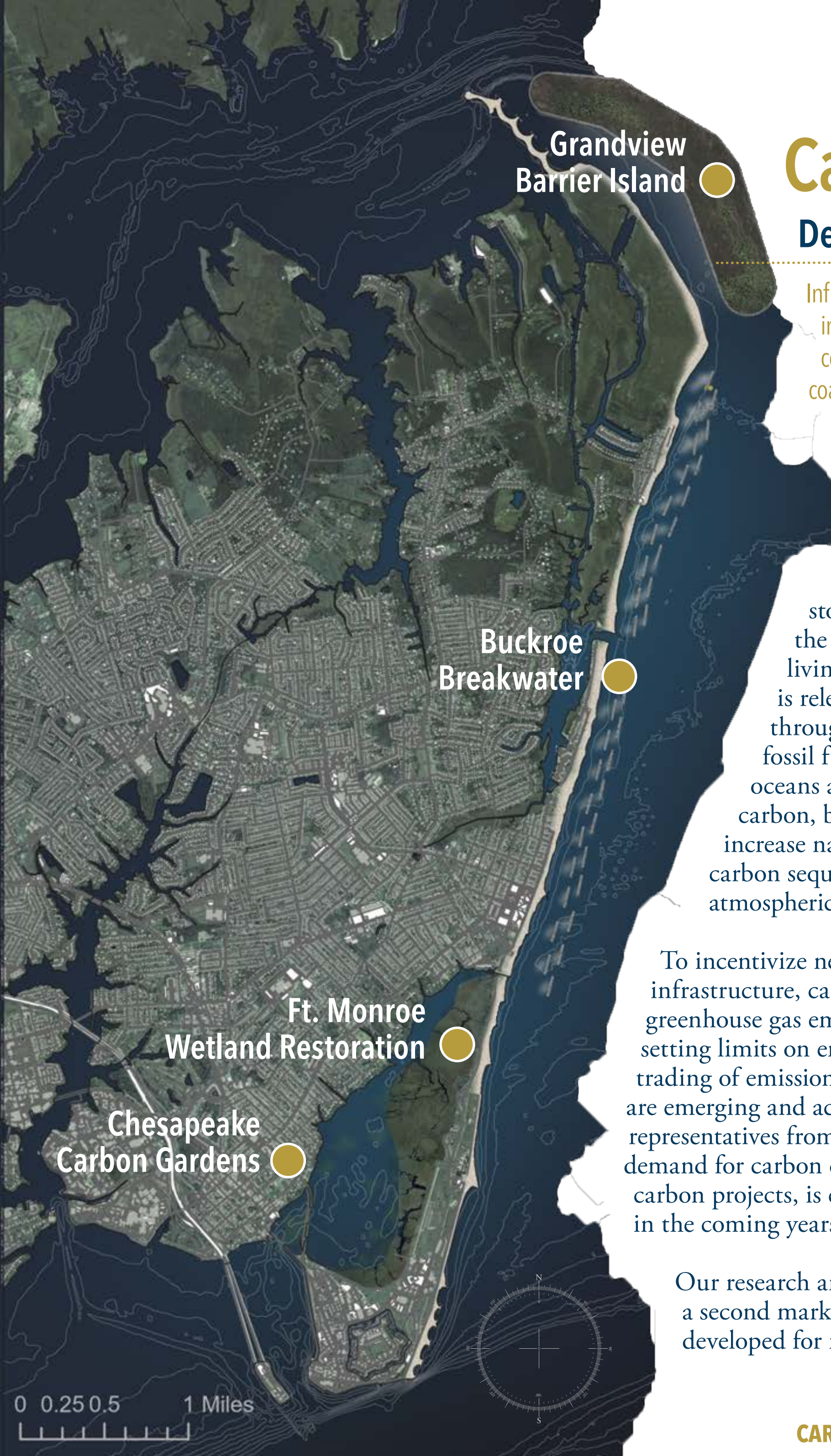
https://www.portofvirginia.com/who-we-are/newsroom/dredging-to-make-virginia-the-east-coasts-deepest-port-is-underway/ http://www.cbbt.com/project-description/



Carbon in the Tidewater

Design: Resilient Self-Generative Infrastructure

Infrastructure is the basic physical and organizational structures and facilities needed for the operation of a society including roads, bridges and power. Coastal Infrastructure refers to structures, systems, and facilities built along coastlines. "Currently, most artificial structures in coastal environments are built for a single purpose, such as coastal protection, tourism, energy or food production" (Pinto, 2019). There is an urgent need to consider multi-functional coastal infrastructure that lessens the impact of impending climate change scenarios while working toward US climate carbon neutrality goals. Infrastructure of the future must serve its intended purpose and also accomplish additional services including capturing carbon and enhancing biodiversity.

Carbon is a naturally occurring element that is stored in rocks and sediments, the ocean, atmosphere, and in living organisms. Carbon dioxide is released into the atmosphere through natural processes and when fossil fuels are burned. Plants and oceans are able to absorb and sequester carbon, but more work is needed to increase natural and man made forms of carbon sequestration given current levels of atmospheric greenhouse gases.

To incentivize new carbon capture infrastructure, carbon markets aim to reduce greenhouse gas emissions cost-effectively by setting limits on emissions and enabling the trading of emission units (credits). These markets are emerging and according to interviews with representatives from The Nature Conservancy, the demand for carbon credit projects, specifically blue carbon projects, is expected to grow exponentially in the coming years.

Our research and interview process revealed a second market opportunity being actively developed for resilience credits with evaluation and design standards that focus on risk to human life, property, and protective ecological zones. Carbon and Resilience Markets represent a viable funding mechanism for coastal infrastructure projects that work to protect future generations from climate change.

We propose four treatments along a 5.2 mile portion of Hampton's coastline. These self-generative infrastructure treatments rely on ecological processes to protect the urban environment, clean water, sequester carbon, and generate carbon credits for the benefit of Hampton through the year 2100.

After evaluating Virginia's recent blue carbon submerged aquatic vegetation (SAV) project on the Eastern Shore, we used current verified carbon wetland and seagrass project methodologies from Verra and proprietary Nature Conservancy Resilience Credit standards to guide our risk analysis, project scale, scope, and measurable outcomes. All Carbon and Resilience Credit Projects are held to strict evaluation, methodology, greenhouse gas accounting and verification processes. Project development to sale of credit can take 20 years or more to complete. Our four layer approach allows the city of Hampton and the state of Virginia to develop a phased plan to completion with revenue from the carbon market helping to offset future phase project costs.

Carbon in the Tidewater

I. Grandview Barrier Island

Analysis revealed the importance of maintaining the integrity of Grandview Nature Preserve to protect more urbanized areas from storm and sea level rise impacts. Remote sensing technology from Google Earth Engine revealed that approximately 127.2 acres of wetlands out of 190.4 acres total have been lost since 1990 (Fig. AA-11). Breakwaters were extended north as additional protective measures.

During community interviews, Grandview residents expressed concern about coastal erosion from intense winter storms and regular flooding events.

Inspired by *The Disappearing Islands of the Chesapeake* (Cronin, 2005) and sited on the location of a former dredge dump site (USGS), this newly created 600 acre reclaimed dredge barrier island provides new protected habitat, carbon sequestration potential, addresses water quality issues, and provides strong protection to the critical, existing 677 acre wetland system at Grandview Nature Preserve. The existing wetland provides critical flood protection and management, and is a valuable blue carbon stock and storage resource that will be lost to early levels of SLR.

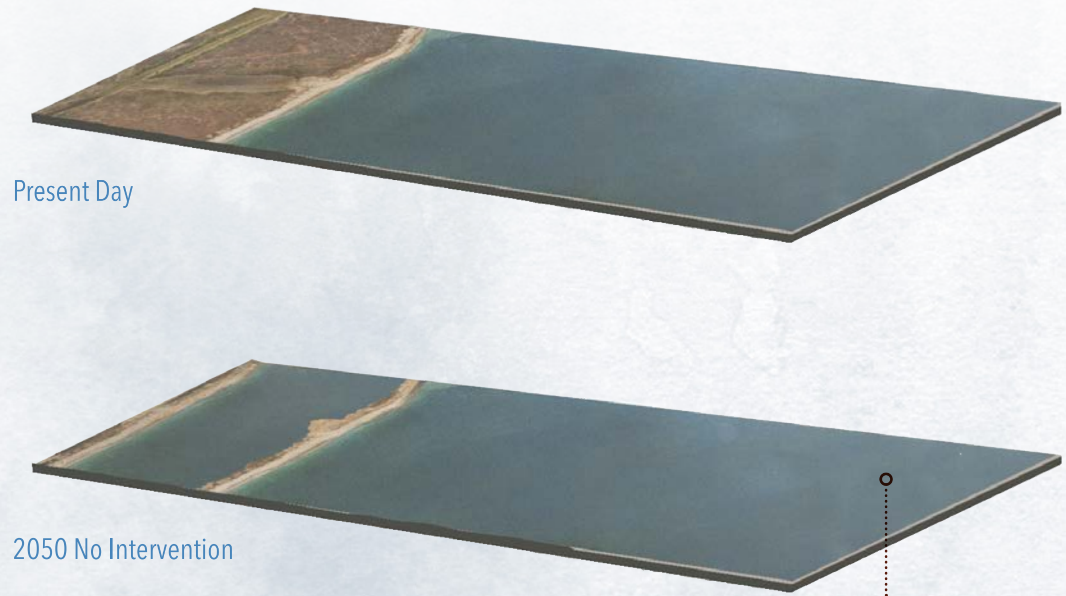
The island is sited in response to historic use and visible sedimentation patterns, perpendicular to the strongest average winds affecting the coast (Fig. AA-19) and located along the -10' contour (Fig. AA-20).

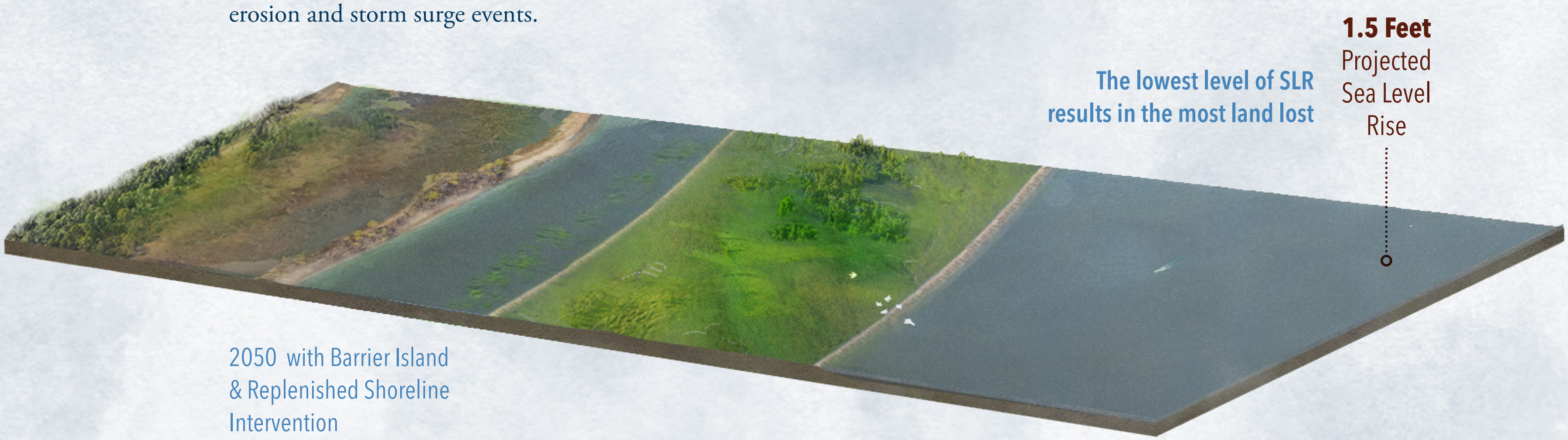
Grandview Barrier Island

Risk Mitigation

Urban pressure creates a squeeze where existing wetlands are unable to migrate in response to sea level rise. The newly designed barrier island protects Grandview Nature Preserve from being fully inundated as water levels rise which serves to protects the more densely populated inland areas.

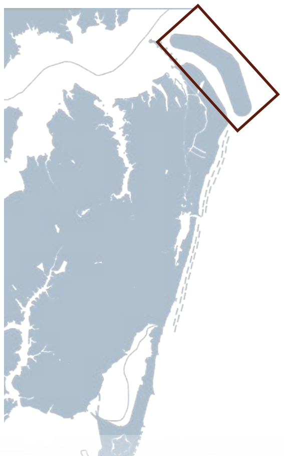
Located 2000 feet offshore, the reclaimed dredge barrier island attenuates wave energy, which along with coastal replenishment will provides multiple levels of protection from restored shoreline, dunes, and wetlands offering protection from erosion and storm surge events.





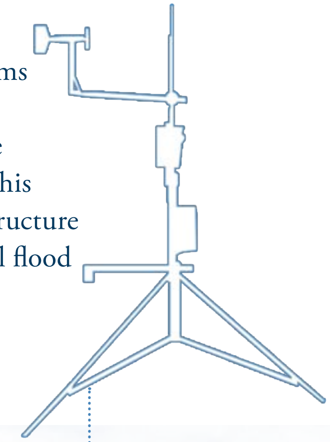
Grandview Barrier Island

Protect Existing Wetlands & Grow New Ecosystems



To construct this 600 acre resilient self generative island infrastructure, the edges of two connecting oyster reef barriers with a top elevation of 20.7' above current MHHW, form the offshore island. It is designed above sea level rise and anticipated significant wave heights through 2100. Over time the island becomes fully vegetated, making the barrier a protective infrastructure solution that sequesters carbon, provides prime habitat for wildlife, and supports shoreline restoration and subsequent accretion to account for the rising water. It's location enables placement of remote climate and wildlife monitoring and early warning alert system applications for the community.

Remote weather and climate monitoring systems are placed on the island, creating a new warning system and a way for residents to interact with the protected offshore habitat.

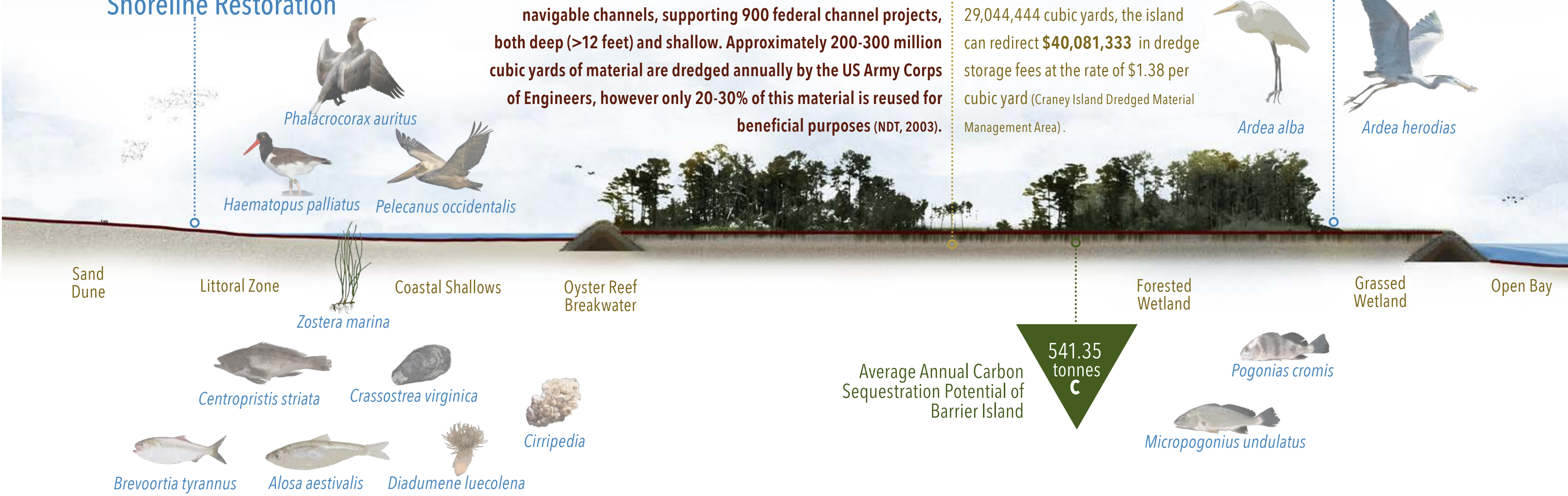


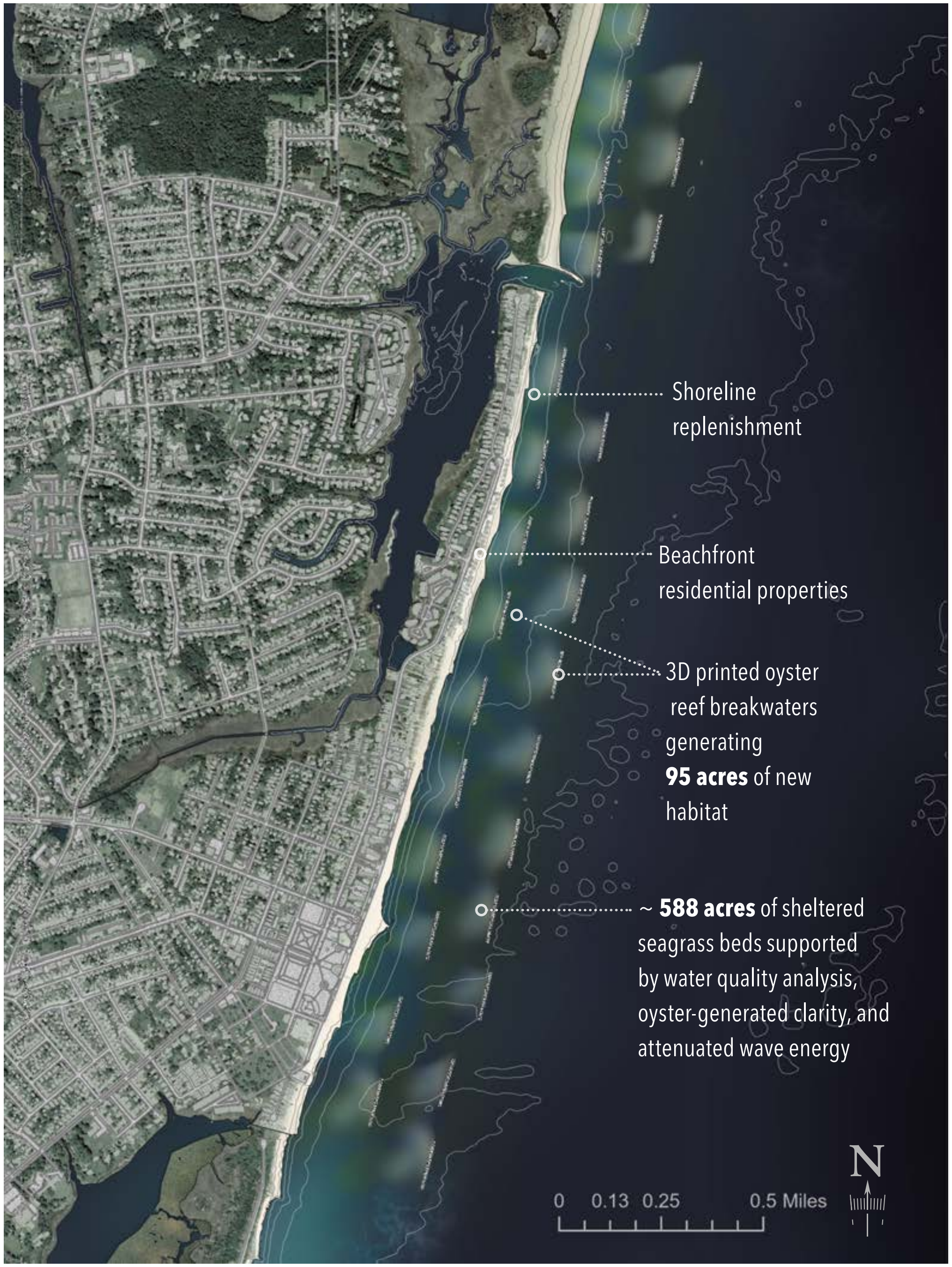
Monitoring systems improve local connection to the value and joy of this protective infrastructure and improve local flood response.

29,044,444 cubic yards
Dredge Spoils Reuse

The U.S. Marine Transportation spans about 25,000 miles of navigable channels, supporting 900 federal channel projects, both deep (>12 feet) and shallow. Approximately 200-300 million cubic yards of material are dredged annually by the US Army Corps of Engineers, however only 20-30% of this material is reused for beneficial purposes (NDT, 2003).

Comprised of approximately 29,044,444 cubic yards, the island can redirect **$40,081,333** in dredge storage fees at the rate of $1.38 per cubic yard (Craney Island Dredged Material Management Area).





Carbon in the Tidewater

II. Buckroe Breakwater

Designed to serve as an adaptive protected edge for Hampton's vulnerable coastline, this resilient Oyster Reef Breakwater is sized to last through 2100 and beyond. Hosting 95 acres of oyster habitat, and capable of filtering 2.3 billion gallons of water per day, this reef also provides a clean, sheltered zone for 588 acres of eelgrass meadow.

This coastal engineering design innovation synthesizes scientific research on oyster habitat supporting structures, SAV supporting conditions, related carbon sequestration rates, and emerging construction technologies. We focused on addressing community concerns provided in the project brief, including a request for resilient solutions for a high rate of climate change, the related shocks and stressors from storm damage including business disruption. From there, we aimed to resolve the stated loss of aquaculture economy due to poor water quality.

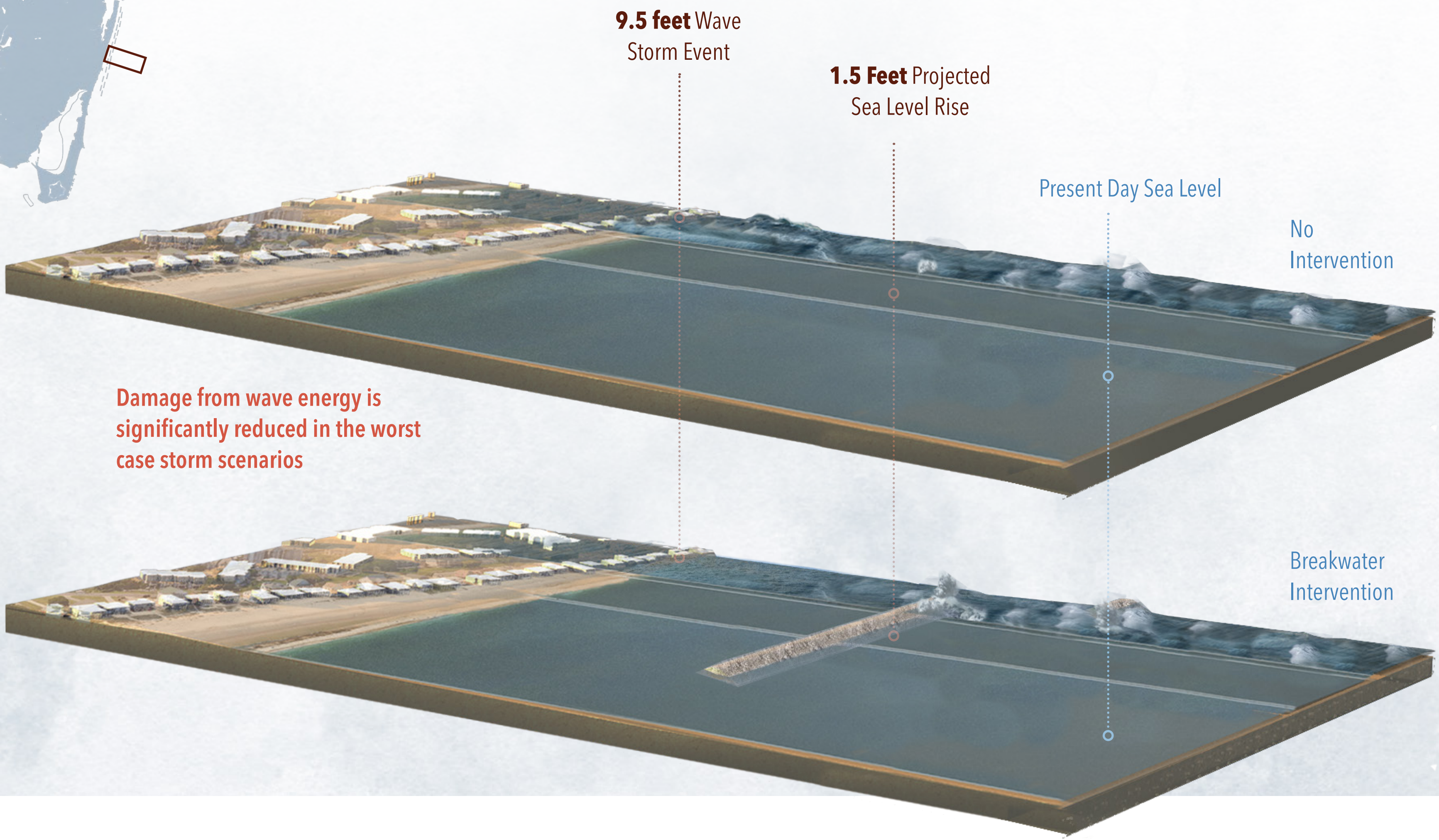
The team used a soon to be released Living Shoreline Feasibility Model (LSFM) created by the Partnership for the Delaware Estuary (PDE) to assess The shoreline conditions. The models scores and weights the physical characteristics, biological components, accessibility (for ease of installation), and community engagement to predict whether a shoreline should be natural, hybrid, or structural. The model also projects the approximate complexity of both the design and implementation of a living Shoreline solution. The LSF predicted a hybrid solution and generated an overall feasibility of 75%. The design complexity was rated 42% and implementation complexity was 24% both representing relatively low scores.

Additional calculations determined the overall size and spacing as shown on the plan to protect the coastline from a 100 year storm event including 80 years of projected sea level rise.

Buckroe Breakwater

Risk Mitigation

Staggered oyster covered breakwaters measuring 720 feet in length attenuate wave energy to protect the Buckroe Beach residential community. The breakwater height accommodates for sea level rise of 4.5 feet, storm sea level rise of 5 feet and storm event significant waves of 9.5 feet. In addition, the breakwaters provide protection and suitable habitat for eelgrass growth which will contribute carbon sequestration and provide habitat for recreational fishing. When partnered with a dredge material beach replenishment program, this system will protect the community, its people and investments from rising water and storm surge.



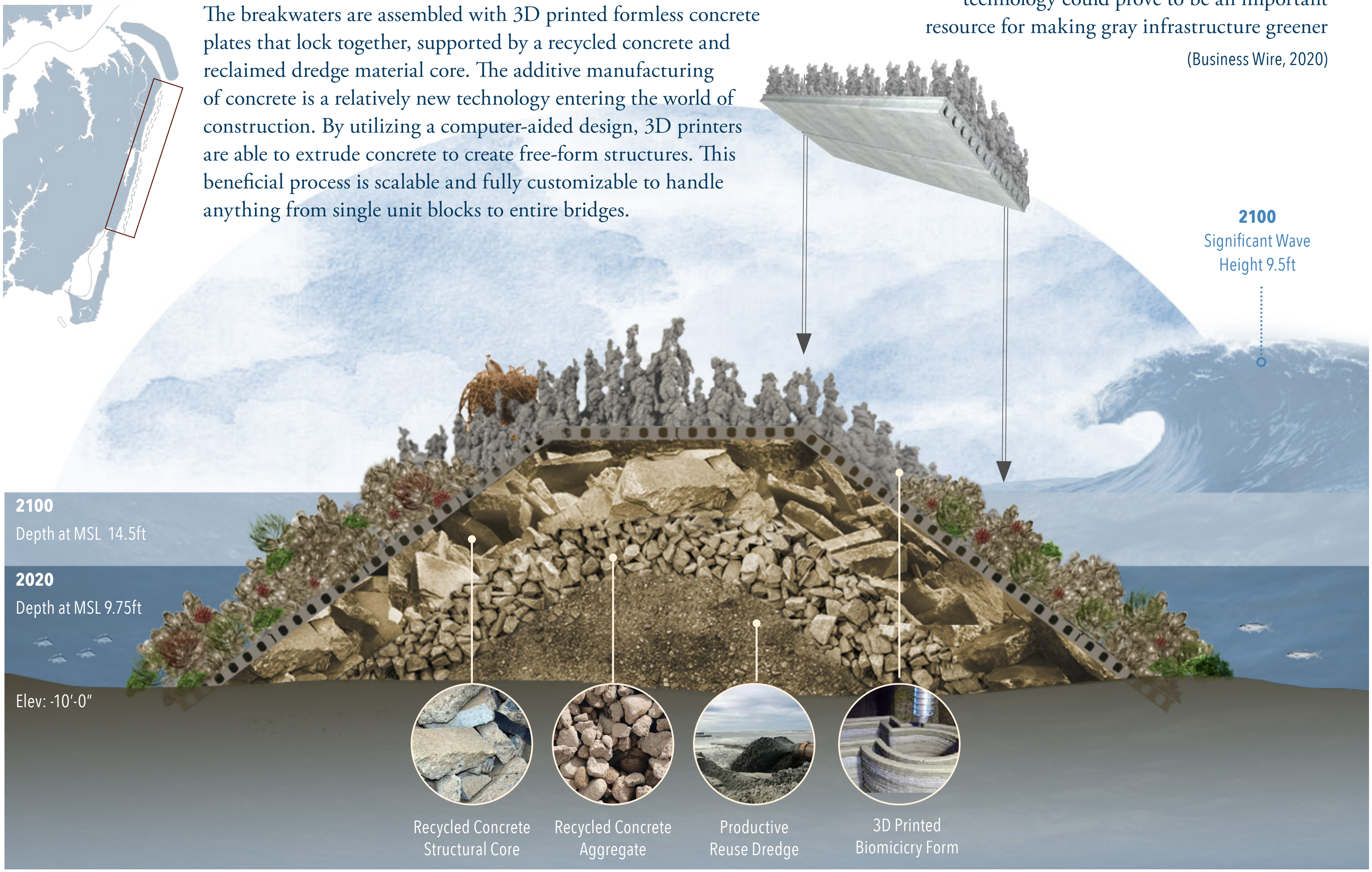
Buckroe Breakwater

Historic Tradition, Modern Technology

The breakwaters are assembled with 3D printed formless concrete plates that lock together, supported by a recycled concrete and reclaimed dredge material core. The additive manufacturing of concrete is a relatively new technology entering the world of construction. By utilizing a computer-aided design, 3D printers are able to extrude concrete to create free-form structures. This beneficial process is scalable and fully customizable to handle anything from single unit blocks to entire bridges.

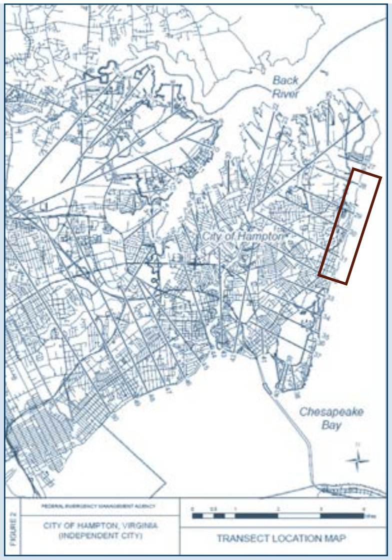
With a projected market size of **$40.6 billion** by 2027, this quickly evolving 3D printed concrete market and reduced carbon emission technology could prove to be an important resource for making gray infrastructure greener

(Business Wire, 2020)



Buckroe Breakwater

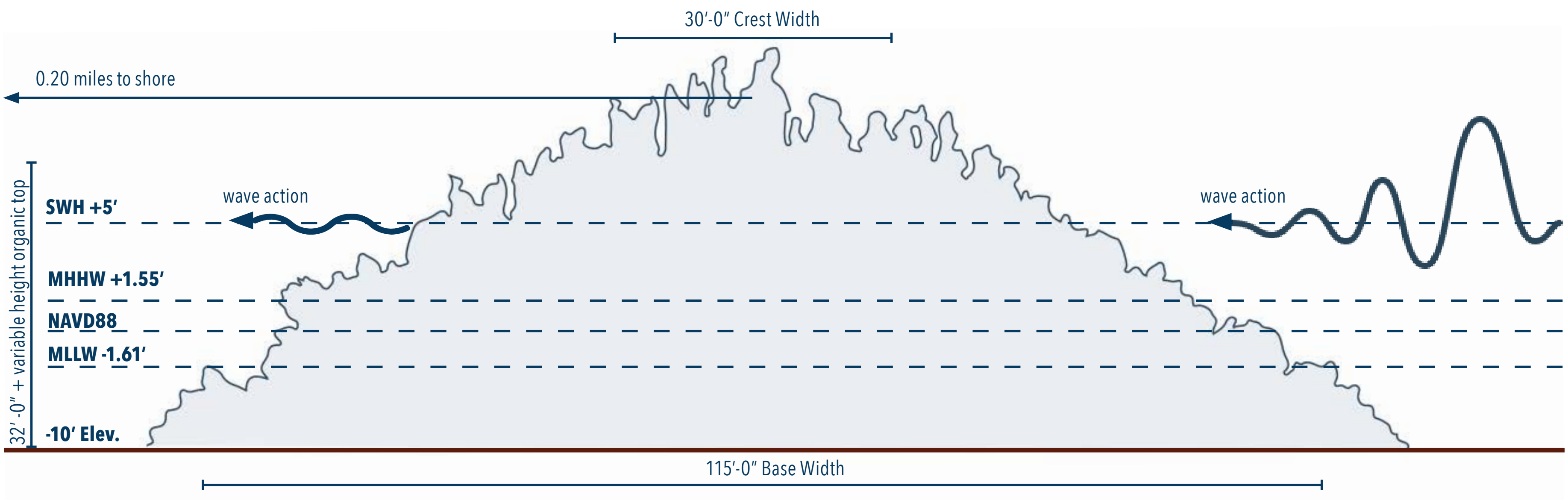
Technical Specifications



FEMA Flood Insurance Transect Map

The breakwater design is intended to protect the shoreline of Hampton from significant damage during future storm events and allow the existing shoreline to accrete additional landmass. Based on data from a 2016 areawide flood insurance study (FEMA, 2016), the breakwater was designed to serve as a non-over topping rubble-mound style structure that accounts for a 100 year storm event for up to 80 years of current sea level rise estimates. The specifications will potentially protect this coastline at higher sea level rise estimates further into the future as an over-topping breakwater. Oyster populations serve as a major component of the structure allowing the reef to grow and adapt over time to maintain pace with future sea level rise.

Flood Source	Transect	Significant Wave Height (ft)	Peak Wave Period (sec)	Starting Stillwater Elevation (feet NAVD 88)				Sea Level Rise			Minimum Breakwater Crest Elevation (Non-overtopping)						Slope Width	Crest Width	Total Width
				10% Annual Chance	2% Annual Chance	1% Annual Chance	0.2% Annual Chance	30-year	60-year	80-year	Current - 10 yr	Current - 100 yr	30 yrs - 10 yr	30 yrs - 100 yr	80 yrs - 10 yr	80 yrs - 100 yr			
Back River	25	2.7	2.6	5.0	6.4	7.0	8.4	1.5	3.0	4.5	7.7	9.7	9.2	11.2	12.2	14.2	48.4	30.0	126.8
Chesapeake Bay	26	8.9	7.3	4.7	6.0	6.6	7.7	1.5	3.0	4.5	13.6	15.5	15.1	17.0	18.1	20.0	60.0	30.0	150.0
Chesapeake Bay	27	9.1	7.4	4.8	6.2	6.7	7.8	1.5	3.0	4.5	13.9	15.8	15.4	17.3	18.4	20.3	60.6	30.0	151.2
Chesapeake Bay	28	8.1	7.5	5.0	6.3	6.8	8.1	1.5	3.0	4.5	13.1	14.9	14.6	16.4	17.6	19.4	58.8	30.0	147.6
Chesapeake Bay	29	9.4	7.5	5.0	6.3	6.9	8.1	1.5	3.0	4.5	14.4	16.3	15.9	17.8	18.9	20.8	61.6	30.0	153.2
Chesapeake Bay	30	9.8	7.4	5.0	6.4	6.9	8.2	1.5	3.0	4.5	**14.8**	**16.7**	**16.3**	**18.2**	**19.3**	**21.2**	62.4	30.0	154.8
Chesapeake Bay	31	9.8	7.5	5.0	6.4	6.9	8.2	1.5	3.0	4.5	**14.8**	**16.7**	**16.3**	**18.2**	**19.3**	**21.2**	62.4	30.0	154.8
Chesapeake Bay	32	9.7	7.6	5.0	6.5	7.0	8.2	1.5	3.0	4.5	14.7	16.7	16.2	18.2	19.2	21.2	62.4	30.0	154.8
Chesapeake Bay	33	9.6	7.5	5.0	6.5	7.0	8.3	1.5	3.0	4.5	14.6	16.6	16.1	18.1	19.1	21.1	62.2	30.0	154.4
Chesapeake Bay	34	9.2	7.4	5.1	6.5	7.1	8.4	1.5	3.0	4.5	14.3	16.3	15.8	17.8	18.8	20.8	61.6	30.0	153.2
Chesapeake Bay	35	9.0	7.4	5.0	6.5	7.1	8.3	1.5	3.0	4.5	14.0	16.1	15.5	17.6	18.5	20.6	61.2	30.0	152.4
Chesapeake Bay	36	2.1	2.6	5.0	6.5	7.1	8.5	1.5	3.0	4.5	7.1	9.2	8.6	10.7	11.6	13.7	47.4	30.0	124.8
Chesapeake Bay	37	8.8	7.3	5.1	6.6	7.1	8.4	1.5	3.0	4.5	13.9	15.9	15.4	17.4	18.4	20.4	60.8	30.0	151.6
Hampton Roads	38	7.7	6.7	5.1	6.5	7.1	8.3	1.5	3.0	4.5	12.8	14.8	14.3	16.3	17.3	19.3	58.6	30.0	147.2
Hampton Roads	39	2.1	2.7	5.1	6.7	7.4	8.8	1.5	3.0	4.5	7.2	9.5	8.7	11.0	11.7	14.0	48.0	30.0	126.0
Hampton Roads	40	5.2	6.6	5.1	6.5	7.1	8.4	1.5	3.0	4.5	10.3	12.3	11.8	13.8	14.8	16.8	53.6	30.0	137.2
Hampton Roads	41	2.9	2.8	5.1	6.5	7.0	8.3	1.5	3.0	4.5	8.0	9.9	9.5	11.4	12.5	14.4	48.8	30.0	127.6



Buckroe Breakwater

Resilient Self Generative Infrastructure

Inspired by historic Virginia oyster middens, this adaptive breakwater is designed to reestablish the oyster reefs that once defined the Chesapeake Bay. Full of life, these structural habitats address multiple ecological challenges, contribute to local recreational fishing, and protect the coast and community from sea level rise.

The Hampton Roads Sanitation district has a total capacity of 249 million gallons per day, serving 1.7 million people.

The oyster reef breakwater design, with 4.15 million square feet of oysters, each one filtering 50 gallons per day, has the potential to clean

9.5 times more water.

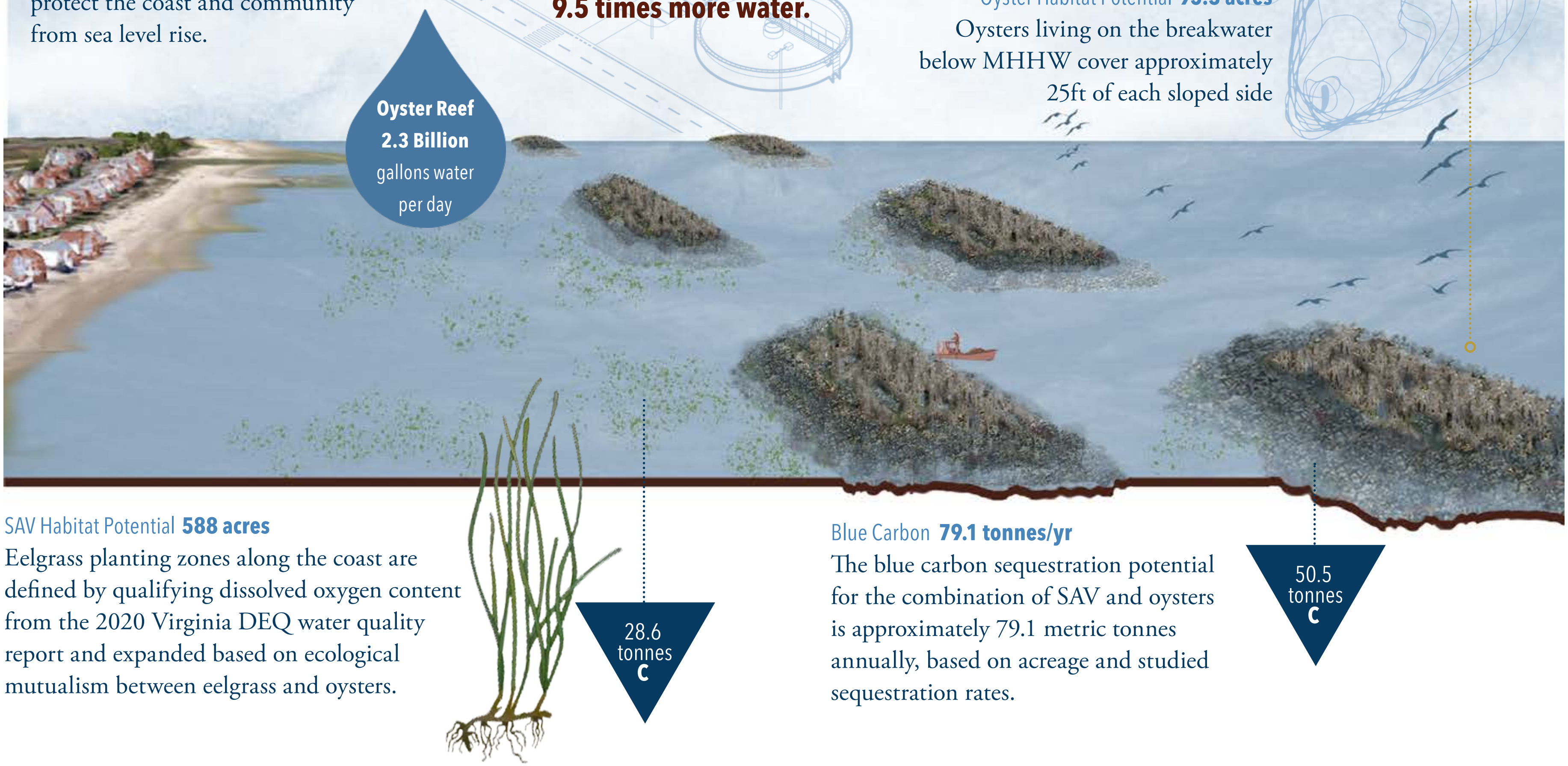
Productive Reuse Dredge Spoils
968, 657 Cubic Yards

Dredge spoils from the Army Corps shipping channel project can be used to fill the core of each breakwater. Approximately 1.1 million cubic yards are contracted to be dredged and pumped to **Craney Island only a few miles away**.

968,657 cubic yards Dredge Spoils Reuse

Oyster Habitat Potential **95.3 acres**

Oysters living on the breakwater below MHHW cover approximately 25ft of each sloped side



SAV Habitat Potential **588 acres**

Eelgrass planting zones along the coast are defined by qualifying dissolved oxygen content from the 2020 Virginia DEQ water quality report and expanded based on ecological mutualism between eelgrass and oysters.

Blue Carbon **79.1 tonnes/yr**

The blue carbon sequestration potential for the combination of SAV and oysters is approximately 79.1 metric tonnes annually, based on acreage and studied sequestration rates.

Carbon in the Tidewater

III. Ft. Monroe Wetland Restoration

The barrier island that has been home to Fort Monroe, protecting Phoebus for over 400 years, is at significant risk. Northern portions of the island will be inundated by sea level rise allowing wave energy from storms to breach the barrier island and enter Mill Creek. The fort itself appears to be at an elevation to withstand significant sea level rise but will be at risk during large storm events.

The naturally protective wetland system in Mill Creek has been slowly going under water and will be the first to be totally inundated at the lowest projected level of SLR by 2050. This area is of significant value to the residents of Phoebus ecologically and structurally.

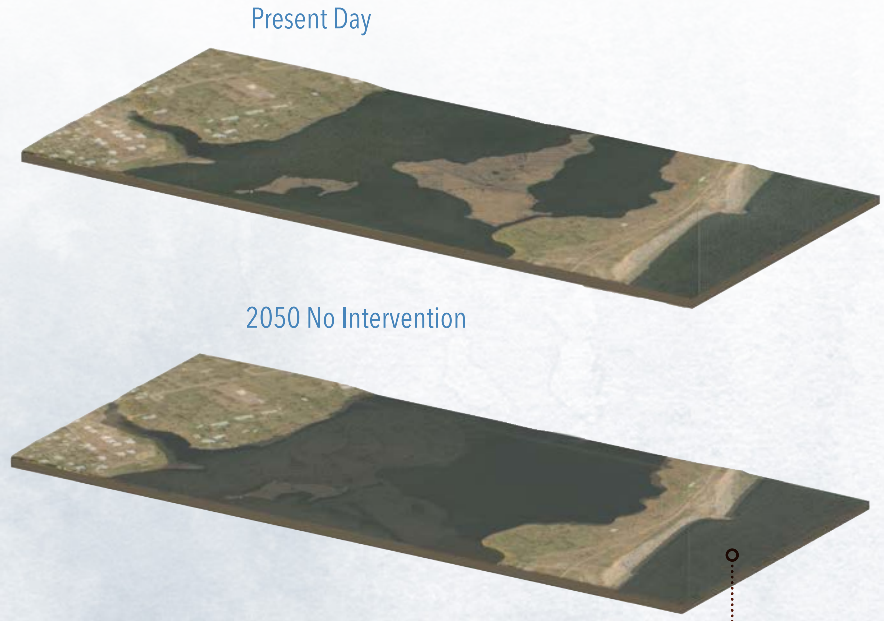
The team evaluated tidal flushing rates, the close proximity of dredge material, water quality, and Virginia environmental policy. The tidal flushing rate is adequate to support a wetland environment, the water inside Mill Creek passed the 30 day dissolved oxygen test required to support SAV but has insufficient benthics and water clarity of only 22%. In accordance with a 2020 change to title 28.2 of the Virginia Code, requiring the use of living shorelines, this design incorporates the use of biodegradable oyster mattresses as a living edge along the restored wetland to support its reconstruction and address SAV supportive water quality issues. To reconstruct the wetland, the close proximity of dredge spoils aligns with Virginia Code § 10.1-704 which prioritizes the use of dredged material for beach nourishment purposes and allows for those carbon emissions to be selected out of the GHG accounting for the Verra blue carbon project methodology.

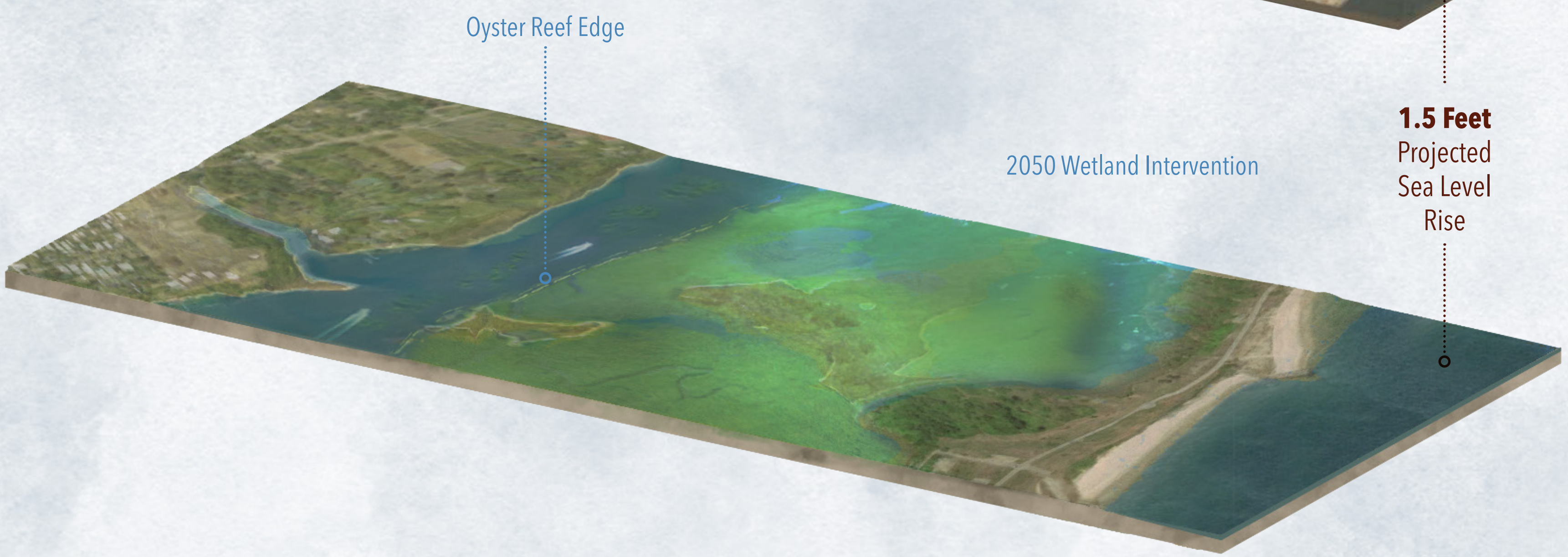
Ft. Monroe Wetland Restoration

Risk Mitigation

The wetland restoration rests between the Fort Monroe peninsula and the residential community of Phoebus in the area known as Mill Creek. Projected sea level rise in 2050 submerges the islands within the creek.

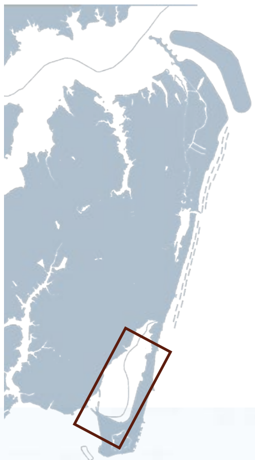
The creation of wetlands in this area rebuilds the historic conditions, supports better fishing, oysters, and water activities for residents and provides additional habitat for wildlife. Oyster reefs, designed to surround the wetland, protect from erosion occurring from storm events and boat week. The wetland is designed with channels that allow free flow of boat traffic to pass along the west side of the wetland and for small craft access throughout the area.





Ft. Monroe Wetland Restoration

Reclaimed Dredge, Oyster Habitat, SAV potential



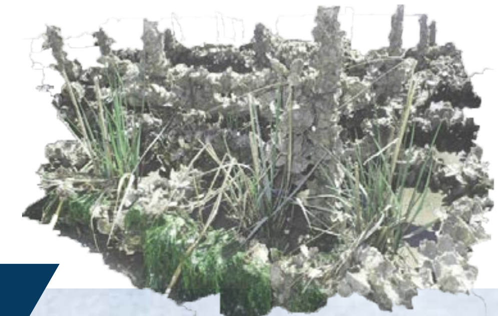
The fort side of Mill Creek becomes a restored wetland system, providing habitat for shore birds, oysters, and native plants, while also acting as a carbon sink.

The elevation above sea level needed to keep pace with sea level rise is jump-started by reclaimed hyperlocal dredged sediment from the shipping channel, with natural accretion taking over after initial plant establishment. If sea level rises faster than the wetland can accrete sediment, dredge spoils maintenance may be required.

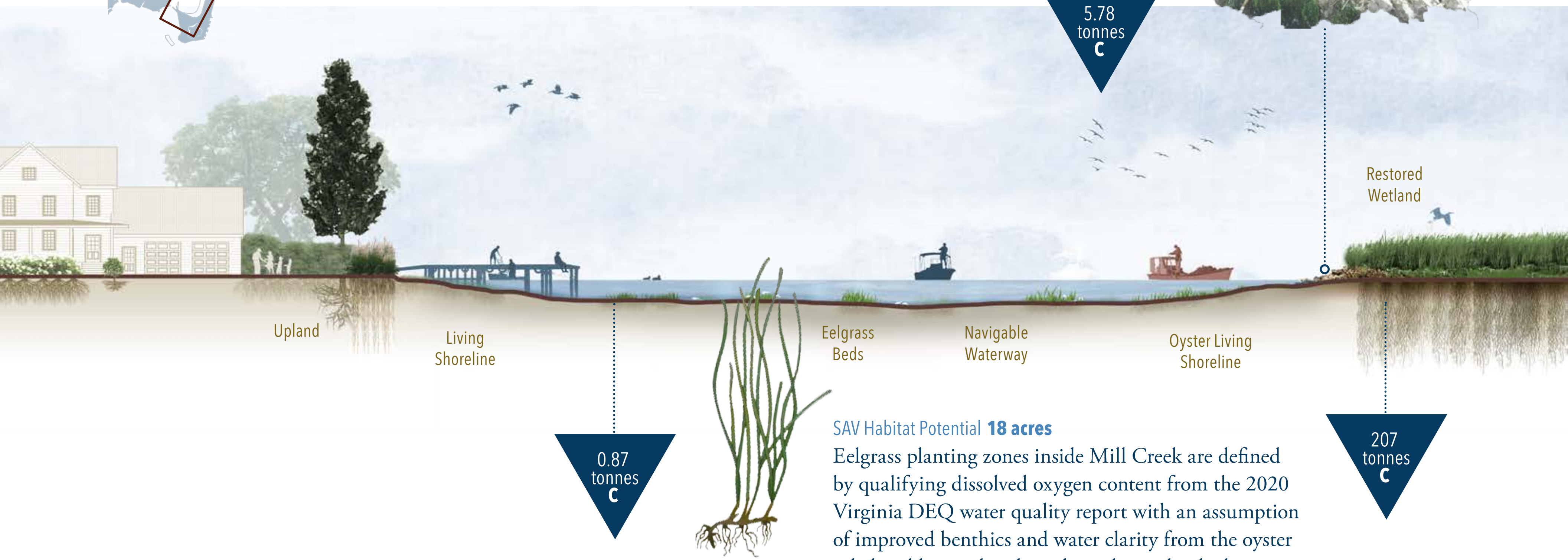
Oyster Reef
264 Million
gallons water
per day

Sandbar Oyster Co.. Biodegradable Oyster Substrate
Living Shoreline Edge
11 acres

These biodegradable, modular units with proven success in North Carolina are suggested in place of a traditional coir log edge surrounding the wetland.



5.78
tonnes
C

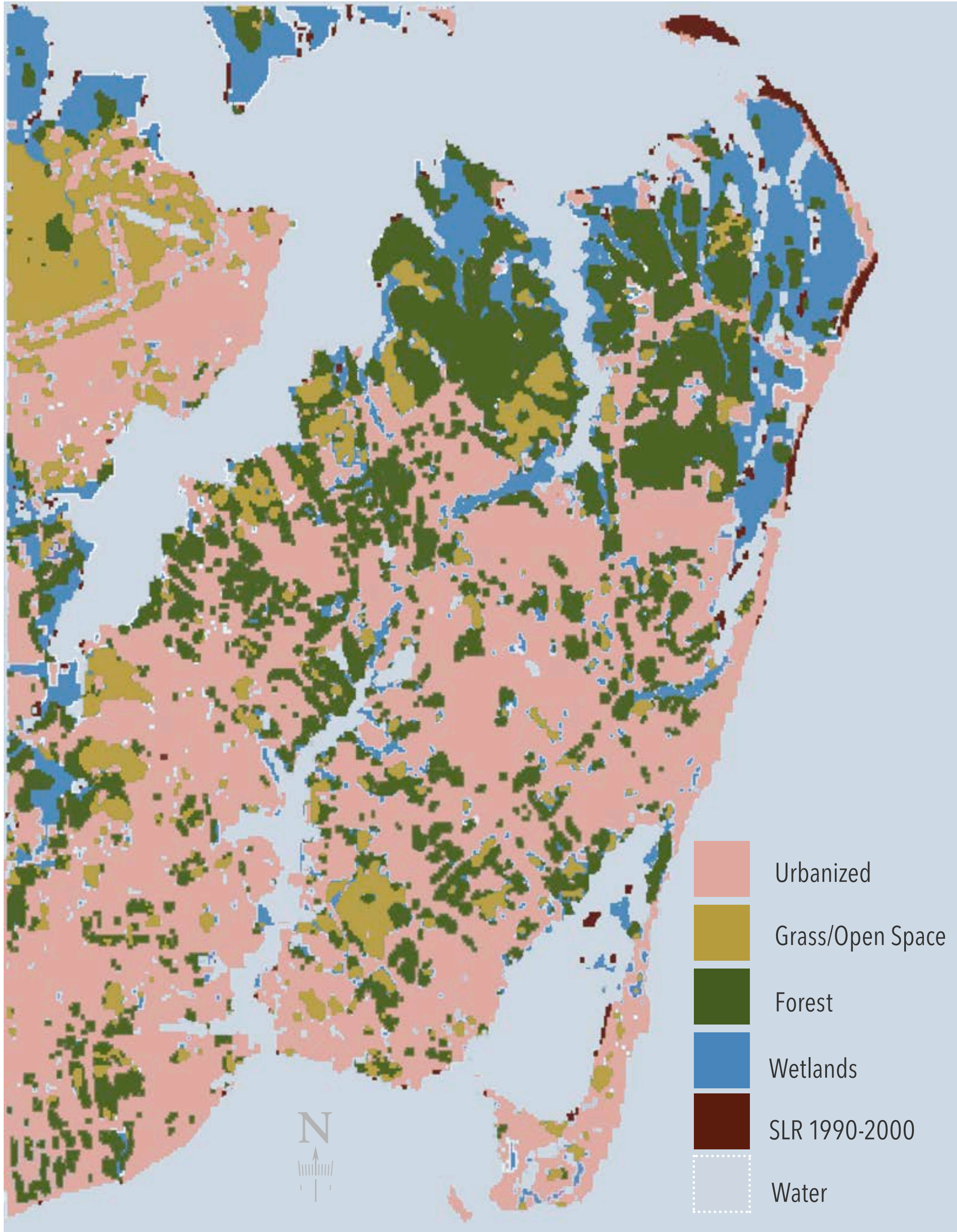


0.87
tonnes
C

207
tonnes
C

SAV Habitat Potential **18 acres**

Eelgrass planting zones inside Mill Creek are defined by qualifying dissolved oxygen content from the 2020 Virginia DEQ water quality report with an assumption of improved benthics and water clarity from the oyster inhabited living shoreline along the wetland edge.



Carbon in the Tidewater

IV. Chesapeake Carbon Gardens

Private land and community open space represents a valuable component of resilience planning. Motivations for homeowners to convert lawn to carbon gardens might include a feeling of community pride, a desire to help mitigate future climate change, and or financial incentives as a fraction of a carbon credit or stormwater fee savings.

In urban and suburban development, the classic green lawn is ubiquitous. By some estimates, 92% of plantable space in suburban areas is planted as turfgrass (Tallamy, 2021). An expansive lawn represents a monoculture - it is expensive to maintain, lacks biodiversity, and contributes little to combat a warming climate. Turfgrass neither reduces personal energy costs nor manages increased stormwater.

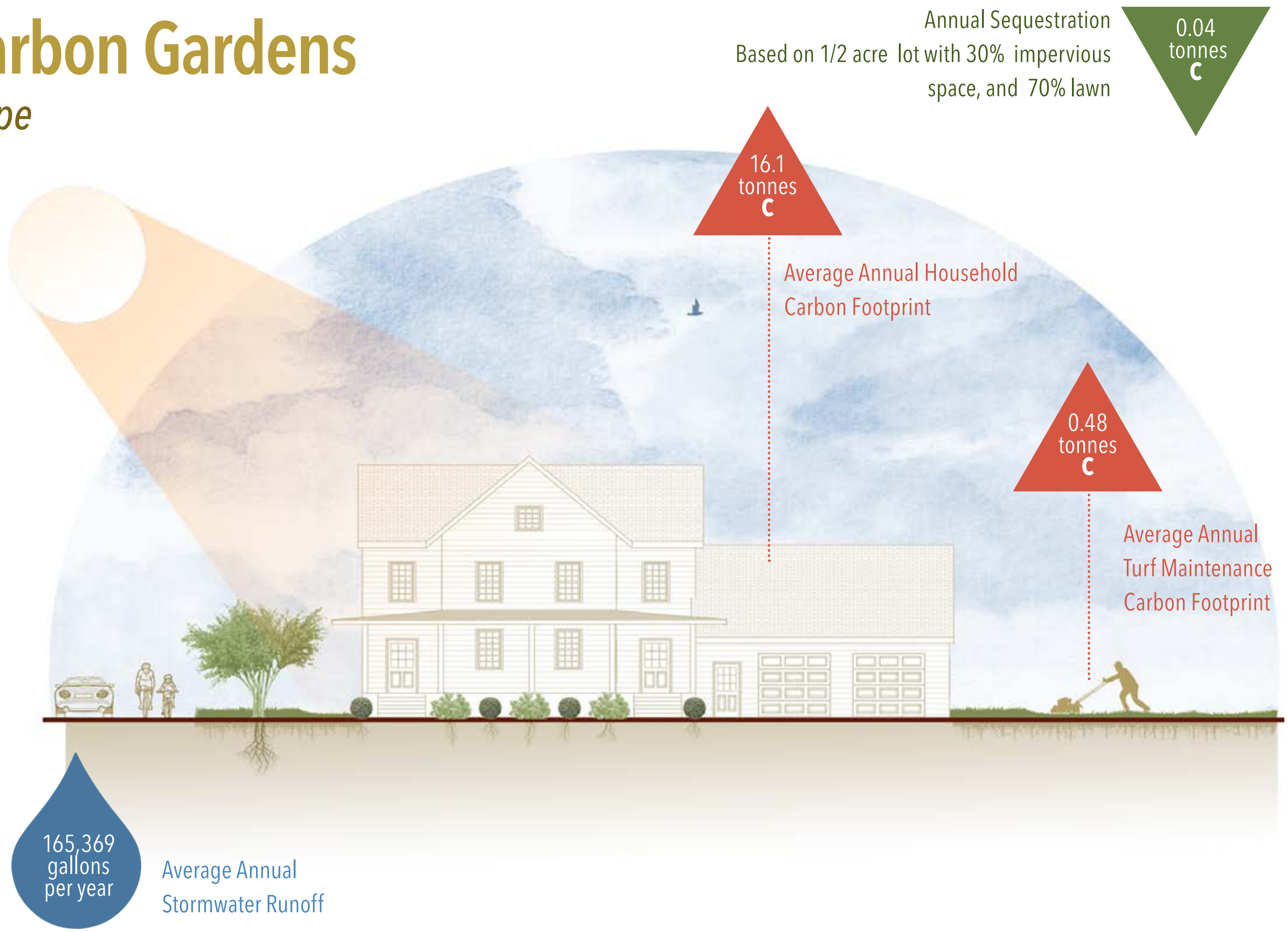
Our project analysis revealed the urban plantable space potential in the project area is **1,131 acres currently planted as turf grass**. Our conservative goal was to convert 10%, or **113 acres**, to Chesapeake Carbon Gardens.

By educating & empowering Hampton residents with attractive options and predefined planting palettes, citizens can contribute to a better carbon future by converting a portion of their lawn to a carbon garden.

Chesapeake Carbon Gardens

Lawn Dominant Landscape

The standard lawn approach consists of primarily turf grass. Foundation plants hug the base of the existing structures and small ornamental trees are frequently used as lawn ornaments. Weekly mowing during the growing season is required and is often performed using gas powered equipment. Turf grass poor infiltration rates result in additional runoff (EPA).



Ornamental tree

Evergreen shrub

Deciduous shrub

Turf grass

Sources: Epa.gov, NC State Carbon Footprint Calculator, Climate Positive Design Carbon Calculator

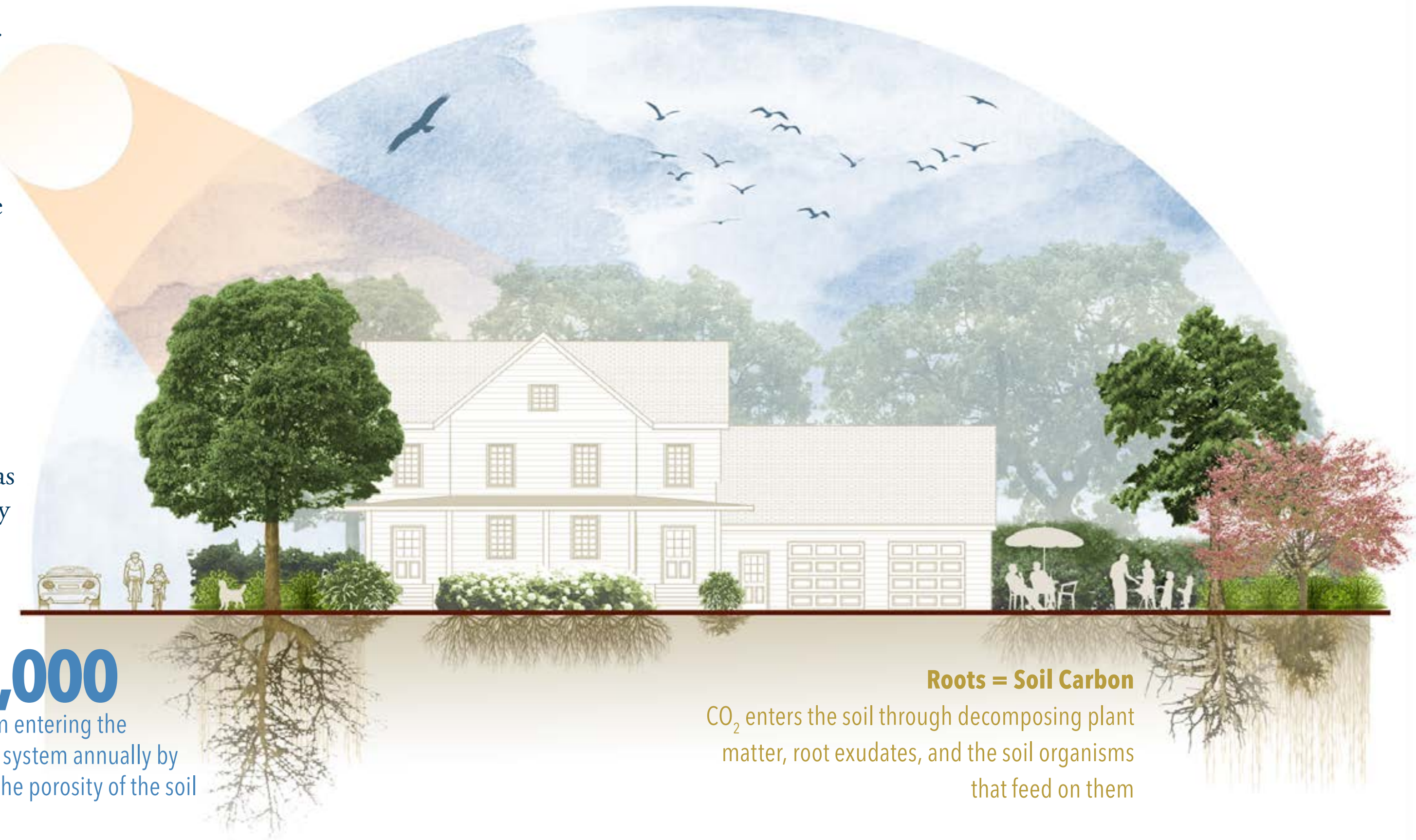
Chesapeake Carbon Gardens

Historic Tidewater Inspired Design

Increased Annual Sequestration
Based on 1/2 acre lot with 30% impervious space, 35% lawn, and 35% planted space

0.40 tonnes C

Inspired by the Virginia Tidewater regional design and architecture, this palette of carbon fixing plants will increase carbon sequestration, species biodiversity, soil porosity, stormwater infiltration, and reduce energy consumption. The pallet features a stately native deciduous tree that grows to shade the roof from summer sun and allow light to warm the structure in the winter reducing overall heating and cooling costs. Evergreen trees, flowering trees and shrubs as well as ornamental grasses provide a stately look to any residential yard.



reduced runoff

100,000
gallons from entering the stormwater system annually by increasing the porosity of the soil

Roots = Soil Carbon
CO_2 enters the soil through decomposing plant matter, root exudates, and the soil organisms that feed on them

Quercus phellos | *Pinus palustris* | *Cornus florida* | *Ilex glabra* | *Hydrangea arborescens* | *Itea virginica* | *Sporobolus heterolepis*

Sources: Epa.gov, NC State Carbon Footprint Calculator, Climate Positive Design Carbon Calculator

Chesapeake Carbon Gardens

Vernacular Tidal Inspired Design

Increased Annual Sequestration
Based on 1/2 acre lot with 30% impervious space, 35% lawn, and 35% planted space

0.41 tonnes C

Inspired by the colors and textures of the Chesapeake, this garden palette focuses on using high carbon sequestration trees, C4 carbon fixing grasses, provides an increased focus on plant biodiversity and visually communicates the stormwater capacity of a native grass palette.

Sources: Epa.gov, NC State Carbon Footprint Calculator, Climate Positive Design Carbon Calculator

Liriodendron tulipifera

Aesculus hippocastanum

Hamamelis virginiana

Ilex verticillata

Andropogon gerardii

Bouteloua gracilis

Eragrostis spectabilis

Muhlenbergia capillaris

Schizachyrium scoparium

Sorghastrum nutans

Carbon in the Tidewater

1395 tonnes C

Results: Water Quality and Carbon Sequestration Potential

Our proposal focuses on protecting the people, culture, and environment of coastal Hampton. We provided a feasible solution for coastal resilience, options for the citizens to participate through installations of carbon gardens, and a national model for economic sustainability through certification of green infrastructure projects through existing and future blue carbon market economies. The following information includes calculations and results of two metrics: carbon sequestration potential for carbon credits, and water quality improvement potential from implementation of the oyster reef breakwaters and projects at Mill Creek.

$$.43\ tC \bullet ha^{-1} \bullet yr^{-1} \times (588\ ac / 247)ha = 102.34\ tC \bullet yr^{-1}$$

Intervention	Sequestration Rate	Area (acres)	Total Carbon Sequestered
Oysters - Breakwaters	131 gC m^{-2} yr^{-1}	95	50.53 tC yr^{-1}
Oysters - Ft. Monroe	131 gC m^{-2} yr^{-1}	11	5.78 tC yr^{-1}
Eelgrass - Coastal	0.12 gC m^{-2} yr^{-1}	588	28.60 tC yr^{-1}
Eelgrass - Ft. Monroe	0.12 gC m^{-2} yr^{-1}	18	0.87 tC yr^{-1}
Wetland - Ft. Monroe	161.8 gC m^{-2} yr^{-1}	317	207.64 tC yr^{-1}
Wetland - Grandview	161.8 gC m^{-2} yr^{-1}	677	443.45 tC yr^{-1}
C4 Veg - Barrier Island	2.66 tC ha^{-1} yr^{-1}	390	419.82 tC yr^{-1}
Trees - Barrier Island	1.43 tC ha^{-1} yr^{-1}	210	121.53 tC yr^{-1}
C4 Veg - C Gardens	2.66 tC ha^{-1} yr^{-1}	73.45	79.07 tC yr^{-1}
C4 Veg - C Gardens	1.43 tC ha^{-1} yr^{-1}	39.55	22.89 tC yr^{-1}

Carbon Sequestration Calculations

Carbon sequestration totals were calculated per habitat type based on sequestration rates garnered from category specific peer reviewed articles. An example calculation is provided. The table includes total carbon sequestered for each treatment.

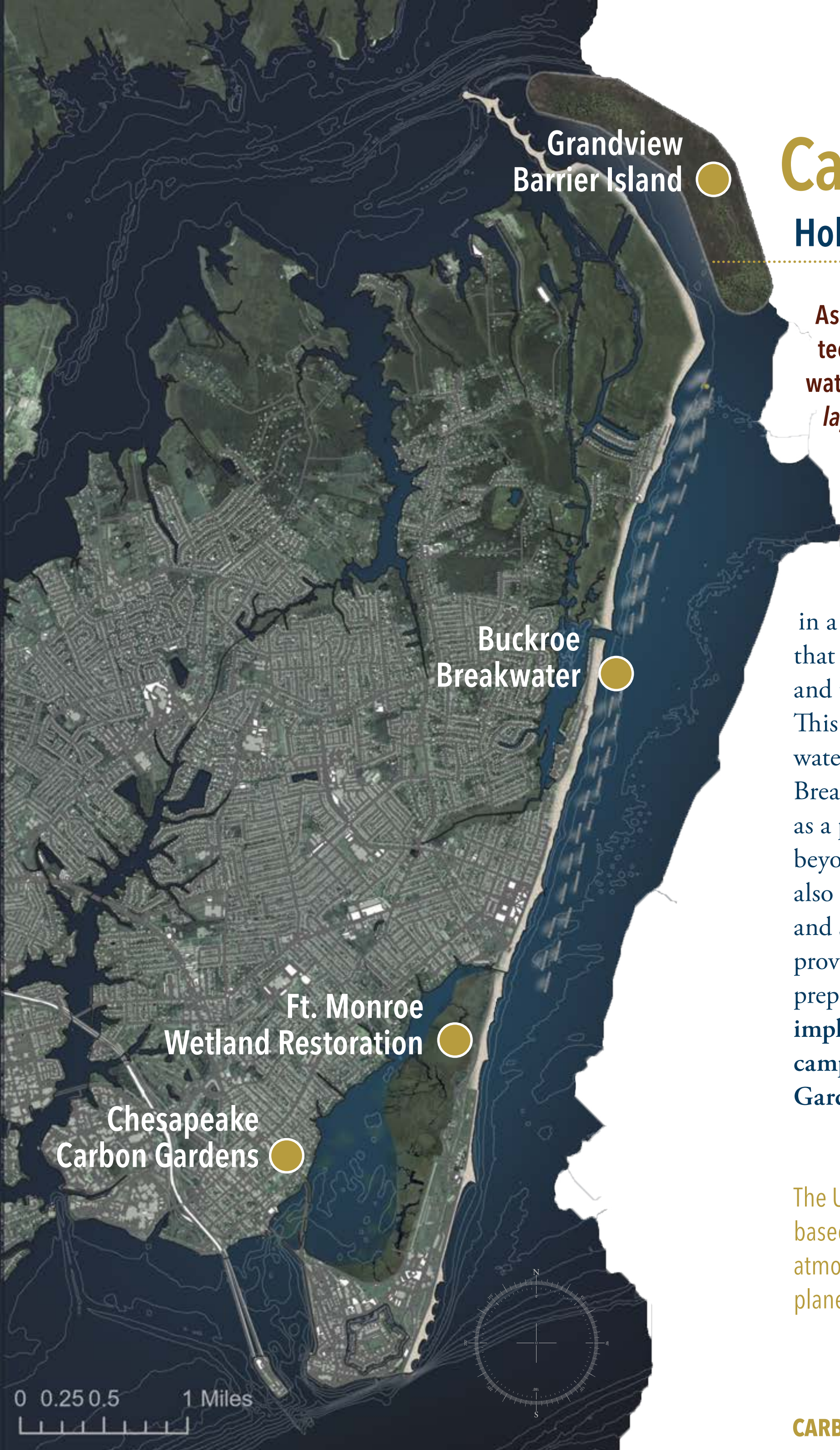
*Represents a 10% conversion of current turf

$$24{,}000{,}000\ gal \bullet ac^{-1} \bullet day^{-1} \times 106\ ac = 2{,}544{,}000{,}000\ gal \bullet day^{-1}$$

Project Zone	Area (acres)	Water Filtration Capacity	Total Water Filtration	
Breakwaters	95.00	24,000,000 gal ac^{-1} day^{-1}	2,280,000,000 gal/day	832,200,000,000 gal/year
Ft. Monroe	11.00	24,000,000 gal ac^{-1} day^{-1}	264,000,000 gal/day	93,360,000,000 gal/year

Water Filtration Calculations

https://www.nature.org/en-us/about-us/where-we-work/united-states/new-york/stories-in-new-york/billion-oyster-project-partnership/



Carbon in the Tidewater

Holistic Response: Resilient Self-Generative Infrastructure

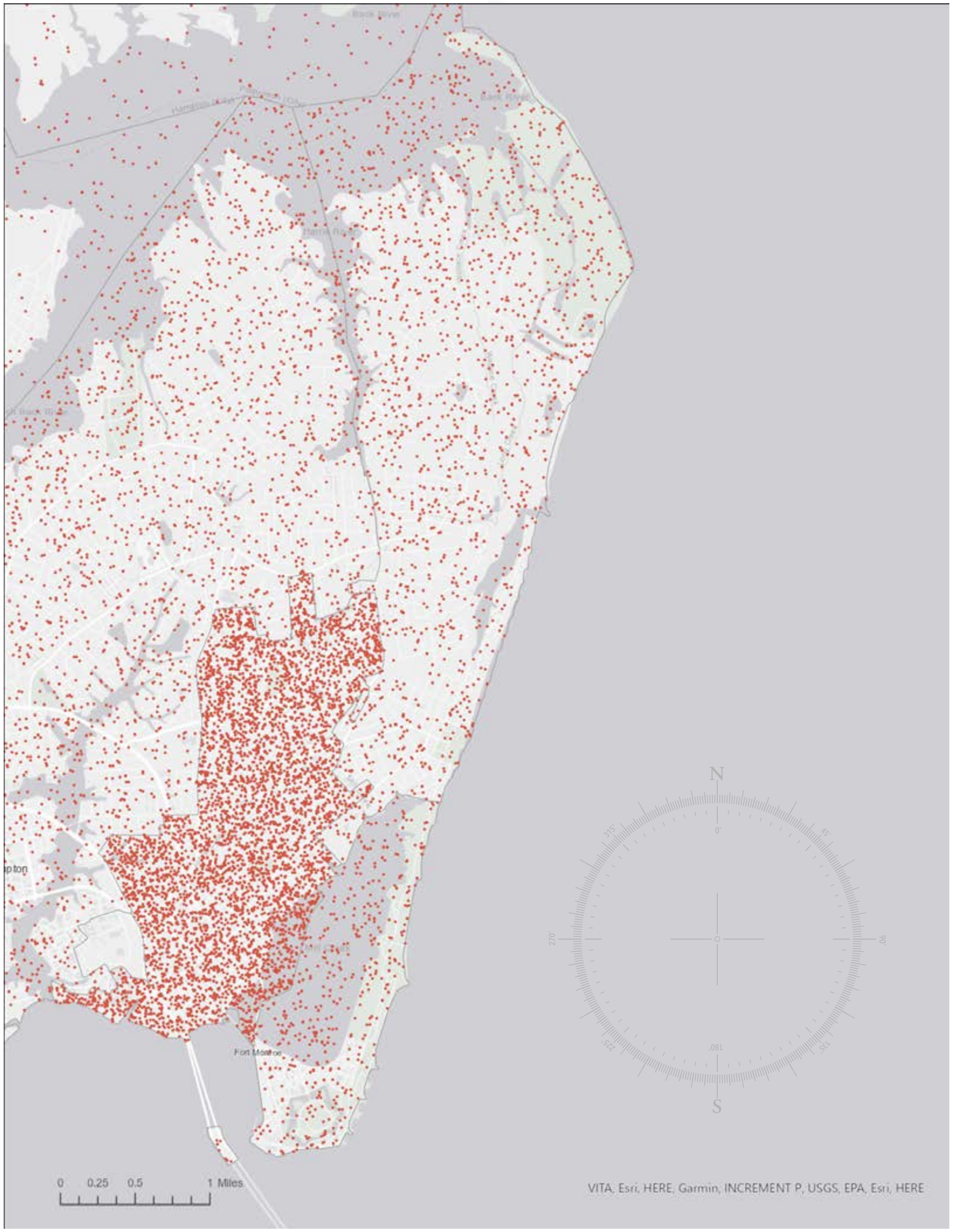
As the planet warms and waters rise, we have the opportunity to synthesize science, technology, engineering, and the resilient superpower of nature to capture carbon, clean water, and provide coastal protection. Resilient Self-Generative Infrastructure offers a *layered benefits* approach to coastal infrastructure by capitalizing on the carbon credit and emerging resilience credit markets, validating ecological systems as critical protective infrastructure, and re-framing current spending.

Located along the coast of Hampton, Virginia, this plan addresses the coastline issues in a holistic way. The team heard the problems identified by CERF and the community that includes concerns about rising water, property damage, economic loss from storms, and the loss of historic fishing and aquaculture industries from contaminated waterways. This plan considers the larger issues of sea level rise, increased wave energy, storm surge, and water quality. A large installation of Grandview Barrier Island, the addition of a Buckroe Breakwater living oyster reef system, the reestablishment of the full power of Fort Monroe as a protective buffer to Phoebus creates ecological systems that can regenerate and live beyond the needs of the next 80 years. On a smaller, yet remarkably effective scale, this plan also offers an accessible way for neighborhoods and individuals to impact climate change and stormwater through the addition of the Chesapeake Carbon Gardens. Lastly, we have provided access to climate monitoring and early warning systems for data confirmed storm preparedness. **The team recommends a series of feasibility studies as the first step toward implementation for the larger infrastructure elements and a community awareness campaign to kick start lawn conversions in public open space to Chesapeake Carbon Gardens.**

The University of Delaware **Coastal Resilience Design Studio** imagines a future with ecologically based infrastructure and development that continually contributes to drawing down carbon from the atmosphere as the *economic standard* to tackle the heart of the problem that threatens all life on the planet we call home.

Appendix A

MAPS



Demographics

Population Information

This map illustrates population density data collected the 2019 American Community survey and the City of Hampton. There is a clear urban core located in and around the historic city of Phoebus. The surrounding suburban areas developed over the last century.

The city of Hampton, Virginia has a population of 137,436 residents comprised of 53,283 households.

The community has a racial composition
49.6% African American
42.7% White
4.5% Hispanic/Latino
3.7% Identified as two or more
2.2% Asian
0.4% Native American
0.1% Native Hawaiian/Pacific Islander

The median household income is $49,815

The city of Hampton, and Phoebus in particular, is a diverse community both racially and economically.

● 1 Person

Fig. AA-1

Land Use

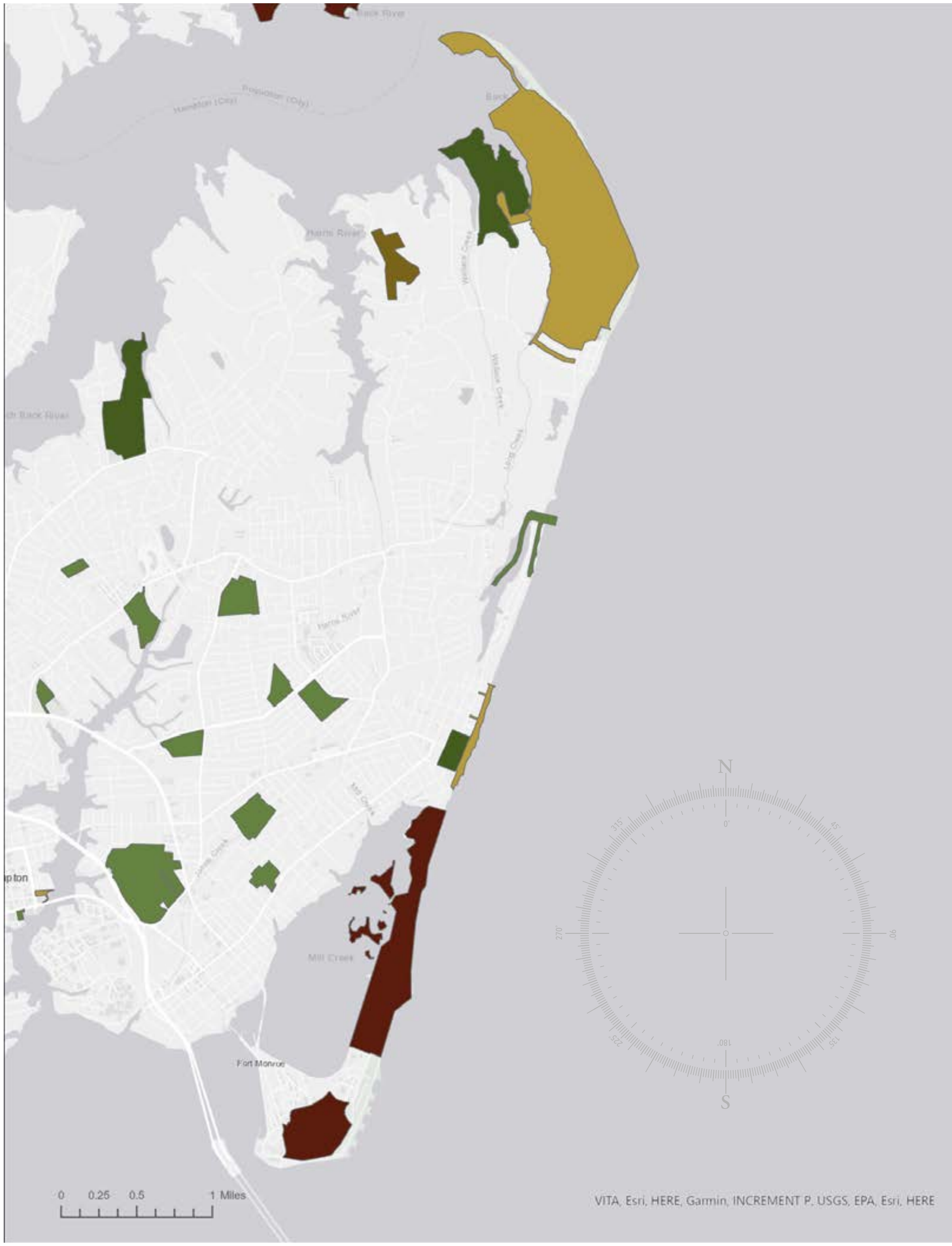
Future Major Land Use Planning

This map illustrates future land use data collected from the City of Hampton.

The study area is highly urbanized. The historic downtown is concentrated with mixed use property that extends over to Fort Monroe. The large institutional property in the south is Hampton University. To the west, the military zone is Langley Airforce Base.

- Military
- Institutional
- Residential
- Mixed Use
- Open Space
- Commercial

Fig. AA-2



Open Space

Parks and Protected Land

This map illustrates data collected from the city of Hampton showing parks and open space in the community.

The Grandview Nature Preserve on the north end of the city is locally owned by the city of Hampton. The Plum Tree Island Wildlife Refuge just north of the nature preserve is federally owned and protected.

To the south, Fort Monroe was decommissioned as a military fort and made a national monument and park in 2011. It serves as a vitally important place in American History and continues to serve the community as a national park, a charming downtown, and a park experience that is unique to Phoebus and Hampton.

The study area has approximately 10% public open space.

Local Park

National Park

Conservation/Open Space

Neighborhood Park

Fig. AA-3

Flood Zones

Population Density living in the 100 and 500 Year Floodplain

This map illustrates data collected from FEMA and the 2019 American Community survey to evaluate risk to the population living in the study area.

The data clearly shows the **highest population density (per square mile) is largely living in the 500 year floodplain**. However, there are still significant numbers of residents spread out in suburban neighborhoods, and many living along the coast in historic beach communities.

Additionally, the Hampton Roads area of Virginia is sinking approximately 1 inch every 10 years due to natural subsidence and the pumping of groundwater from deep underground, creating large voids. Small changes in subsidence combined with sea level rise, it is projected that by 2050, **100 year storms may be happening as regularly as every 10 years**.

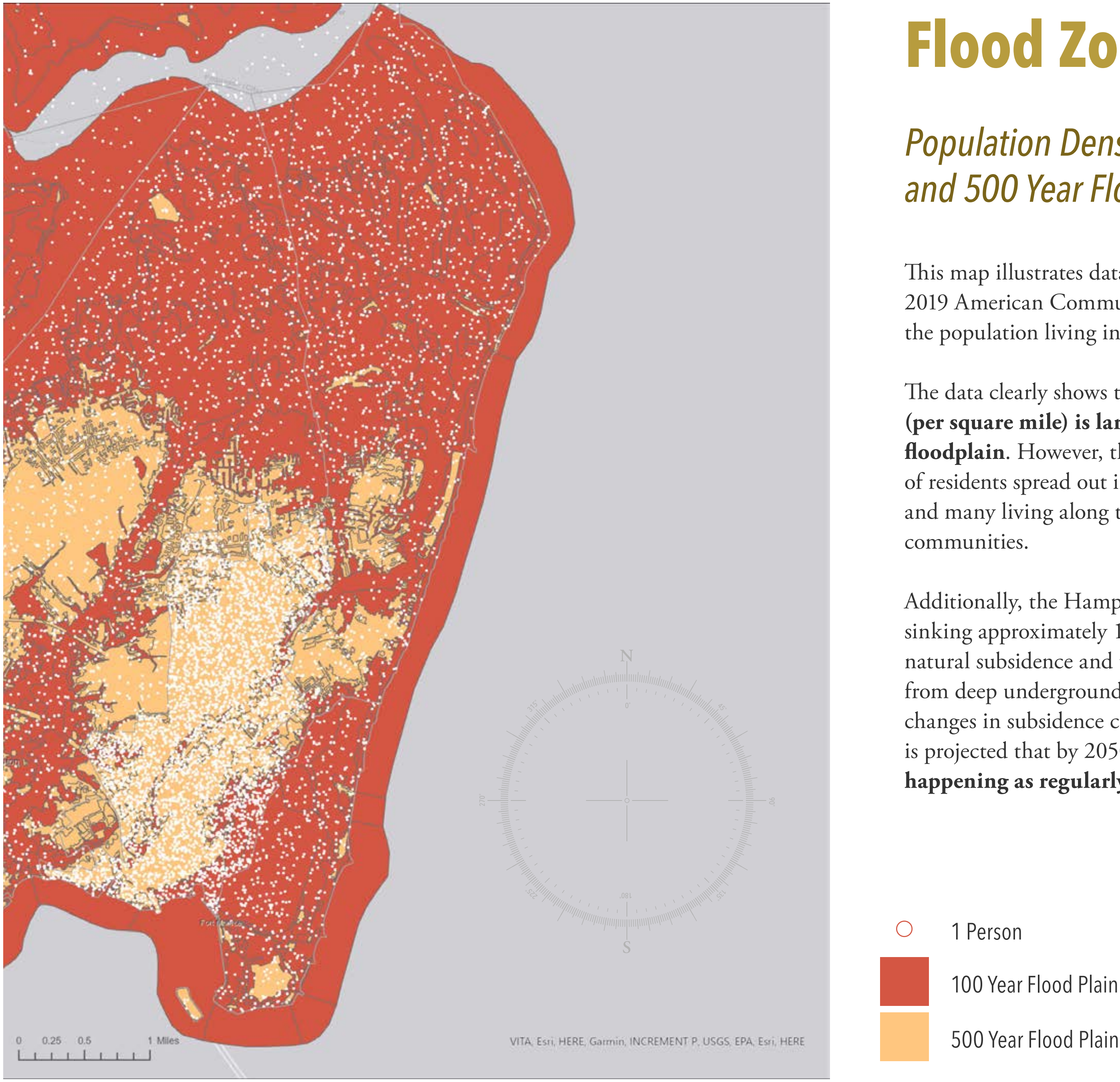
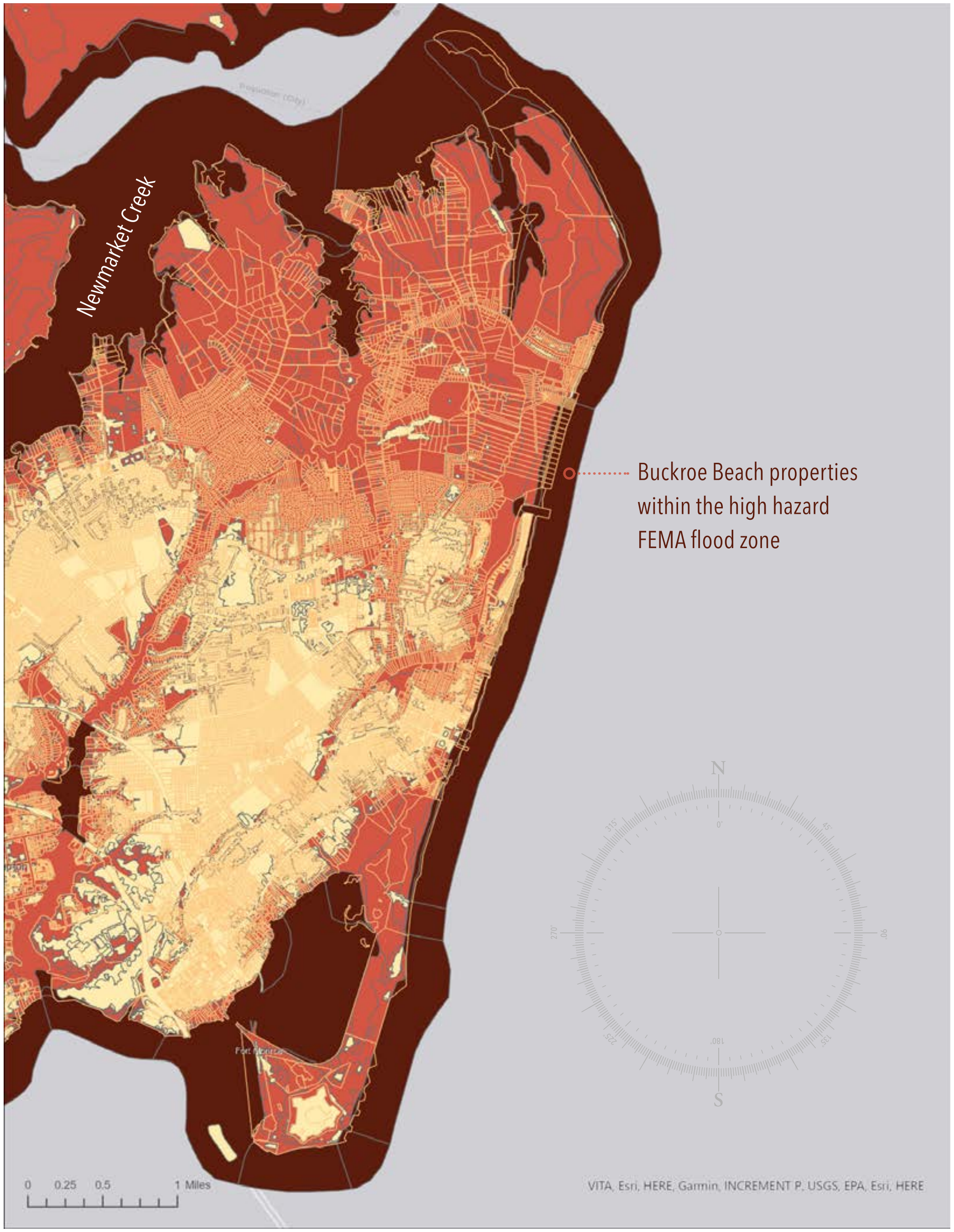


Fig. AA-4



High Hazard Zones

Properties within the FEMA designated high hazard flood zones

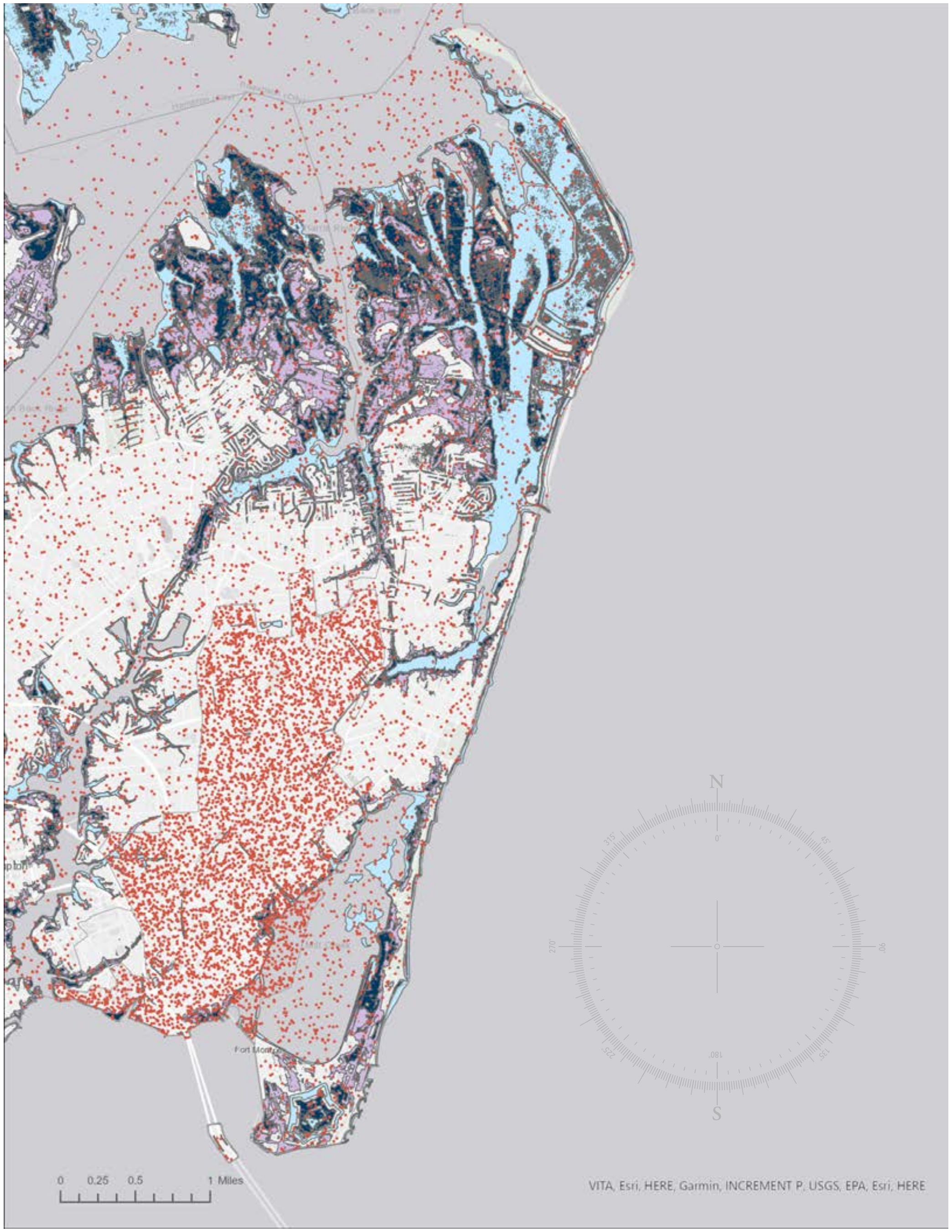
This map illustrates data collected from FEMA flood zone designations.

This map shows the areas that FEMA designates a high hazard zone. These areas are all coastal and river inlet areas, lying within the 100 year floodplain.

The nature based Resilient Hampton Newmarket Creek projects address in the inland flooding in the central business district and residential neighborhoods. The team chose to focus on the open coastal zones to complement the work being done inland. It is possible to see where the urban properties and wetland areas not only buffer the hazard zone, but some are fully within the zone in the Buckroe Beach area.

High Hazard Zone
100 Year Flood Plain
500 Year Flood Plain

Fig. AA-5



Sea Level Rise

Current Population Density Risk

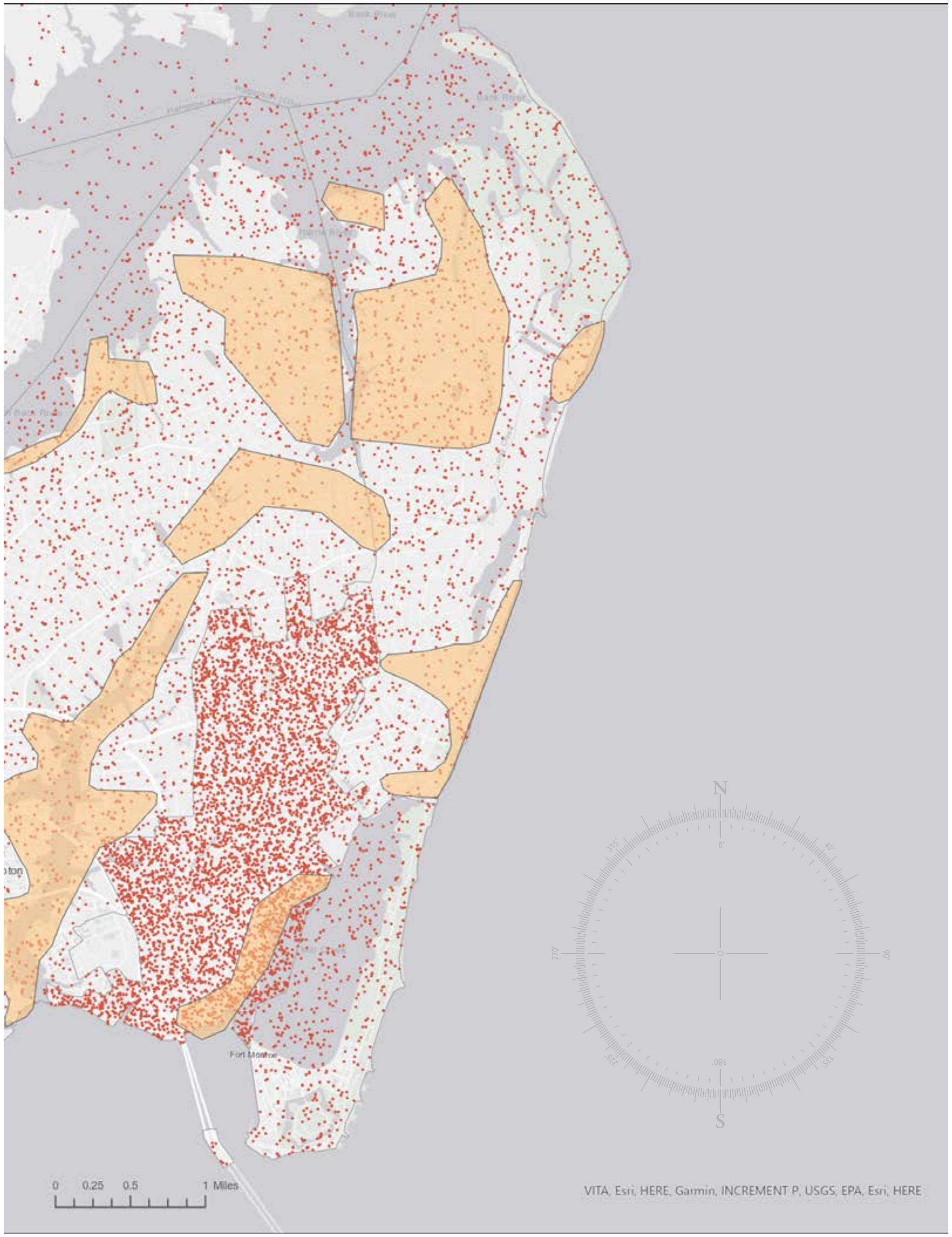
This map illustrates data collected from the city of Hampton and the US Census to evaluate risk to the population living in the study area.Population growth is projected to grow at a rate of .13% per year.

The data clearly shows the **highest population density (per square mile) is largely living outside the risk zone for sea level rise.** However, this map also indicates the most land lost will occur with the lowest rise in sea levels over the next 30 years (2020-2050) leaving the residents living in high risk zones vulnerable to significant property loss.

Additionally, with the loss of the protective ecosystems along the coast, specifically the Grandview Nature Preserve, residents living just outside the loss zones will be at high risk for storm damage and flooding.

- 1 Person
- 1.5 Ft above MHHW (2020-2050)
- 3 Ft above MHHW (2050-2080)
- 4.5 Ft above MHHW (2080-2100)

Fig. AA-6



Repetitive Loss

Clusters of Repetitive Loss & Insurance Claims

This map illustrates data provided by CERF indicating zones of repeated insurance claim loss.

These zones are largely coastal or connected to major waterways. Designing a more robust and healthy ecological protective system can help mitigate loss and damage to property.

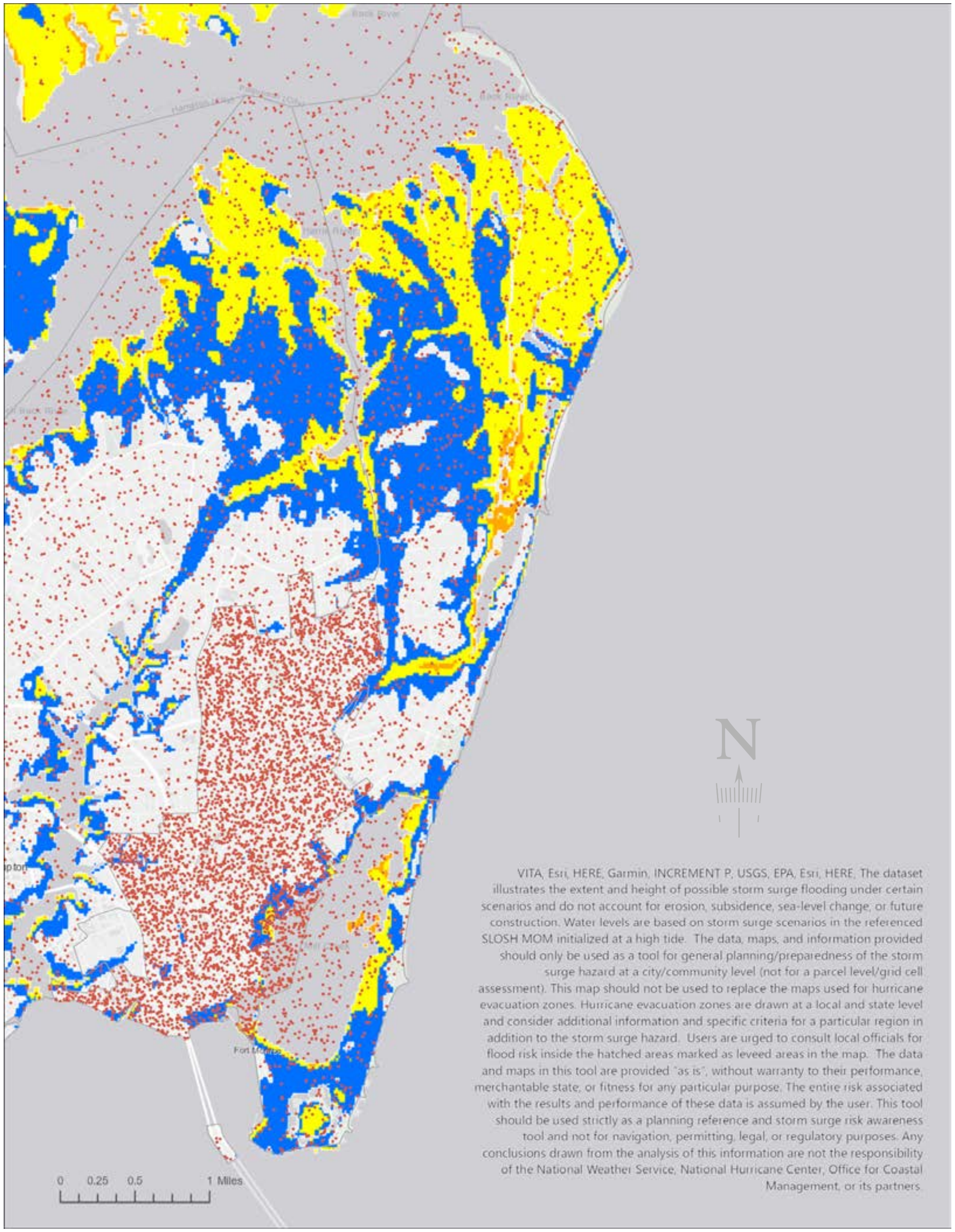
However, **the zones of repetitive loss are mostly in areas with lower relative population density**. The Phoebus coastline is the one area of exception.

If ecosystems like the Grandview Nature Preserve are not protected, the loss zones will continue to grow as climate change increases the amount of water coming into the affected suburban neighborhoods.

1 Person

Loss Zone

Fig. AA-7



Hurricane CAT 1

National Hurricane Center SLOSH inundation model for CAT 1 Storm

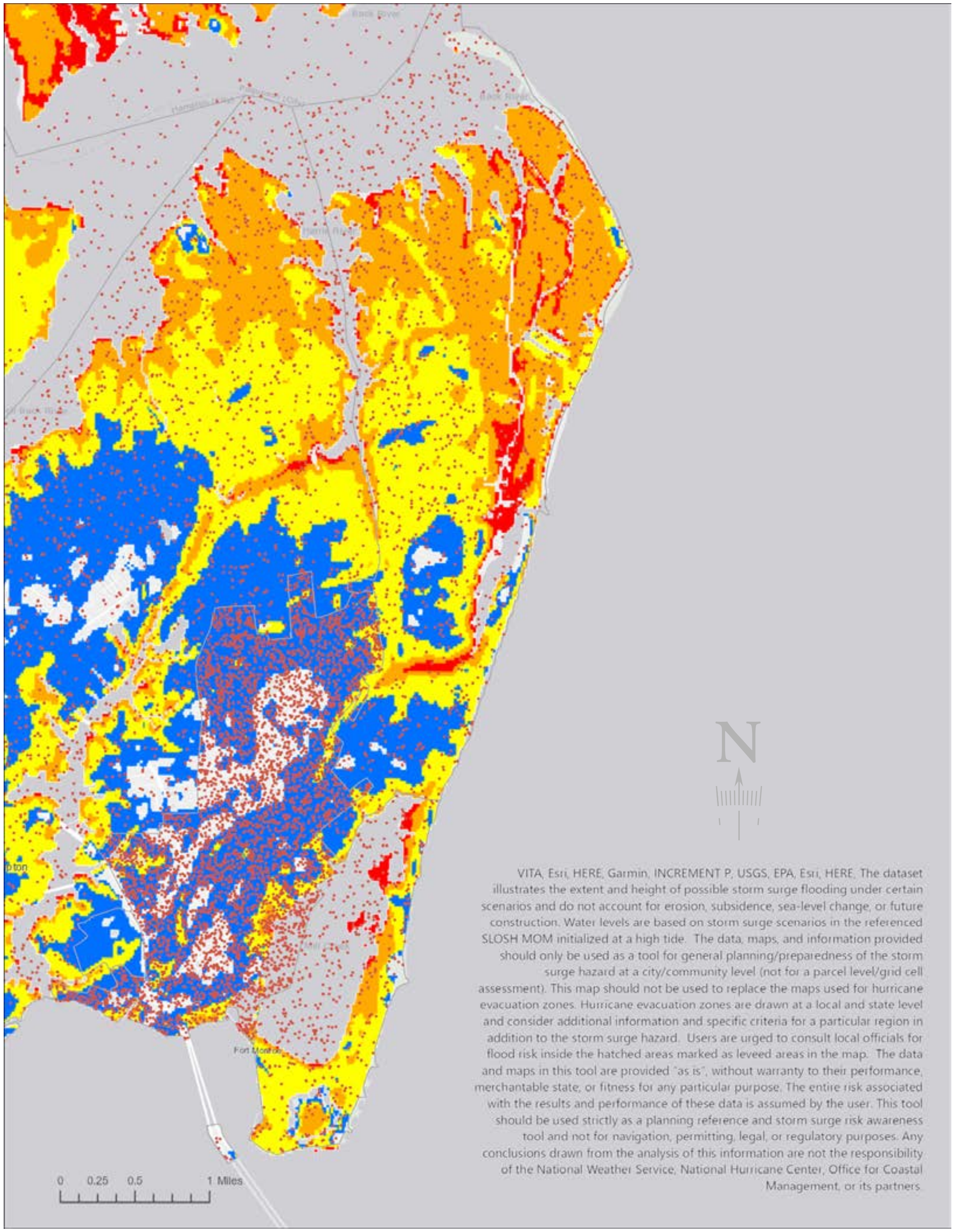
Data provided by the National Hurricane Center for the US Gulf and East Coast hurricane planning.

This model predicts worst case storm scenarios at high tide.. The predictions are based on computing the maximum storm surge from 100,000 hypothetical storms simulated through the SLOSH model grid of varying forward speed, radius of maximum wind, intensity, landfall locations, tide level, and storm direction.

The lowest lying areas are projected to be impacted the most with a minimum 3 ft storm surge.

- 1 Person
- Up to 3 ft above ground
- Greater than 3 ft above ground
- Greater than 6 ft above ground
- Greater than 9 ft above ground

Fig. AA-8



Hurricane CAT 2

National Hurricane Center SLOSH inundation model for CAT 2 Storm

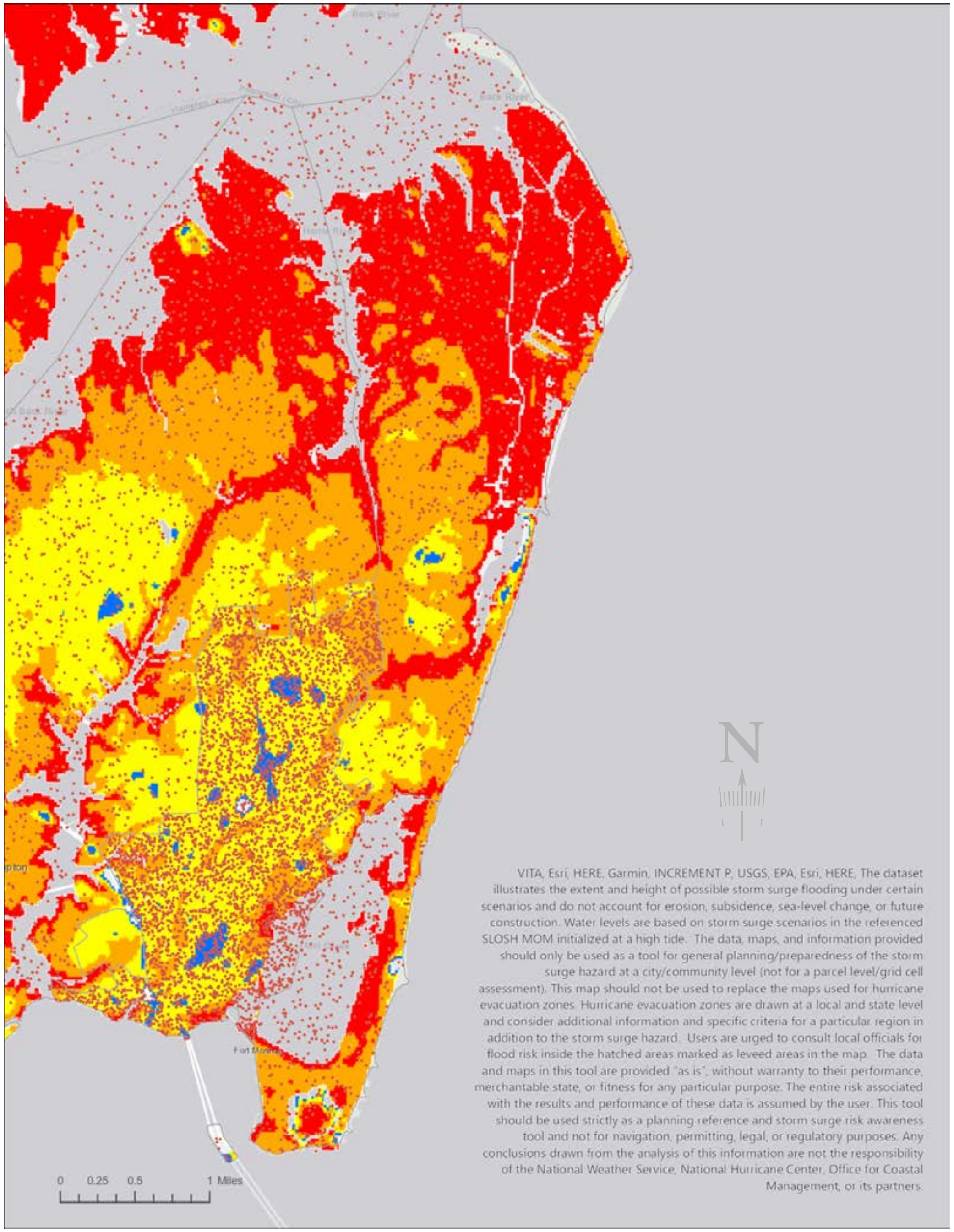
Data provided by the National Hurricane Center for the US Gulf and East Coast hurricane planning.

This model predicts worst case storm scenarios at high tide.. The predictions are based on computing the maximum storm surge from 100,000 hypothetical storms simulated through the SLOSH model grid of varying forward speed, radius of maximum wind, intensity, landfall locations, tide level, and storm direction.

The entire study area is projected to be impacted with a minimum 3ft storm surge and low lying areas to the north and south with a 3-6ft surge. The historic downtown and urban core could see significant damage from a poorly timed Category 2 hurricane.

- 1 Person
- Up to 3 ft above ground
- Greater than 3 ft above ground
- Greater than 6 ft above ground
- Greater than 9 ft above ground

Fig. AA-9



Hurricane CAT 3

National Hurricane Center SLOSH inundation model for CAT 3 Storm

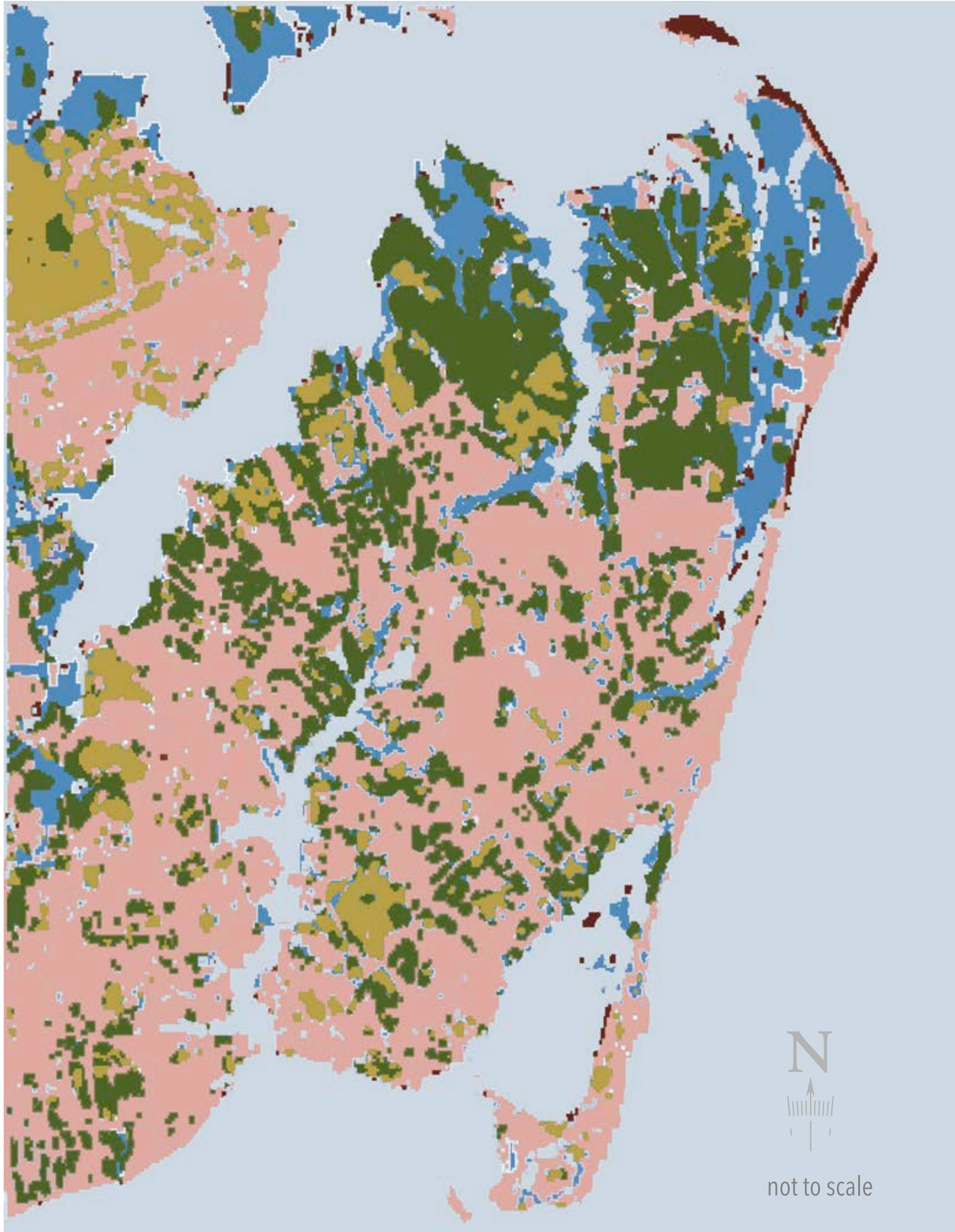
Data provided by the National Hurricane Center for the US Gulf and East Coast hurricane planning.

This model predicts worst case storm scenarios at high tide.. The predictions are based on computing the maximum storm surge from 100,000 hypothetical storms simulated through the SLOSH model grid of varying forward speed, radius of maximum wind, intensity, landfall locations, tide level, and storm direction.

The majority of the study area is predicted to experience a 6-9ft storm surge in the event of a Category 3 hurricane. Significant property damage and loss should be expected in this scenario.

- 1 Person
- Up to 3 ft above ground
- Greater than 3 ft above ground
- Greater than 6 ft above ground
- Greater than 9 ft above ground

Fig. AA-10



Shoreline Change

Land Lost to Sea Level Rise 1990-2020

This map illustrates sea level rise in the study area between 1990 and 2020 using remote sensing technology from Google Earth Engine.

Classification Data

The results showed that approximately 190.4 acres of total area was lost due to sea level rise during this time.

Estimates showed that 127.2 of those acres were from wetlands.

Within the study area, satellite imagery estimated that there were approximately 2,284.3 acres of wetlands lost and 63.2 acres of beach lost.

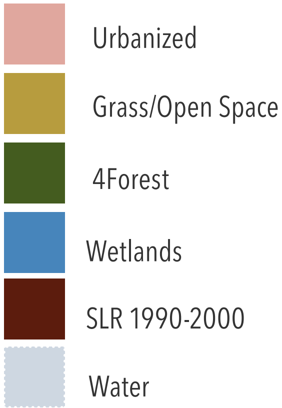
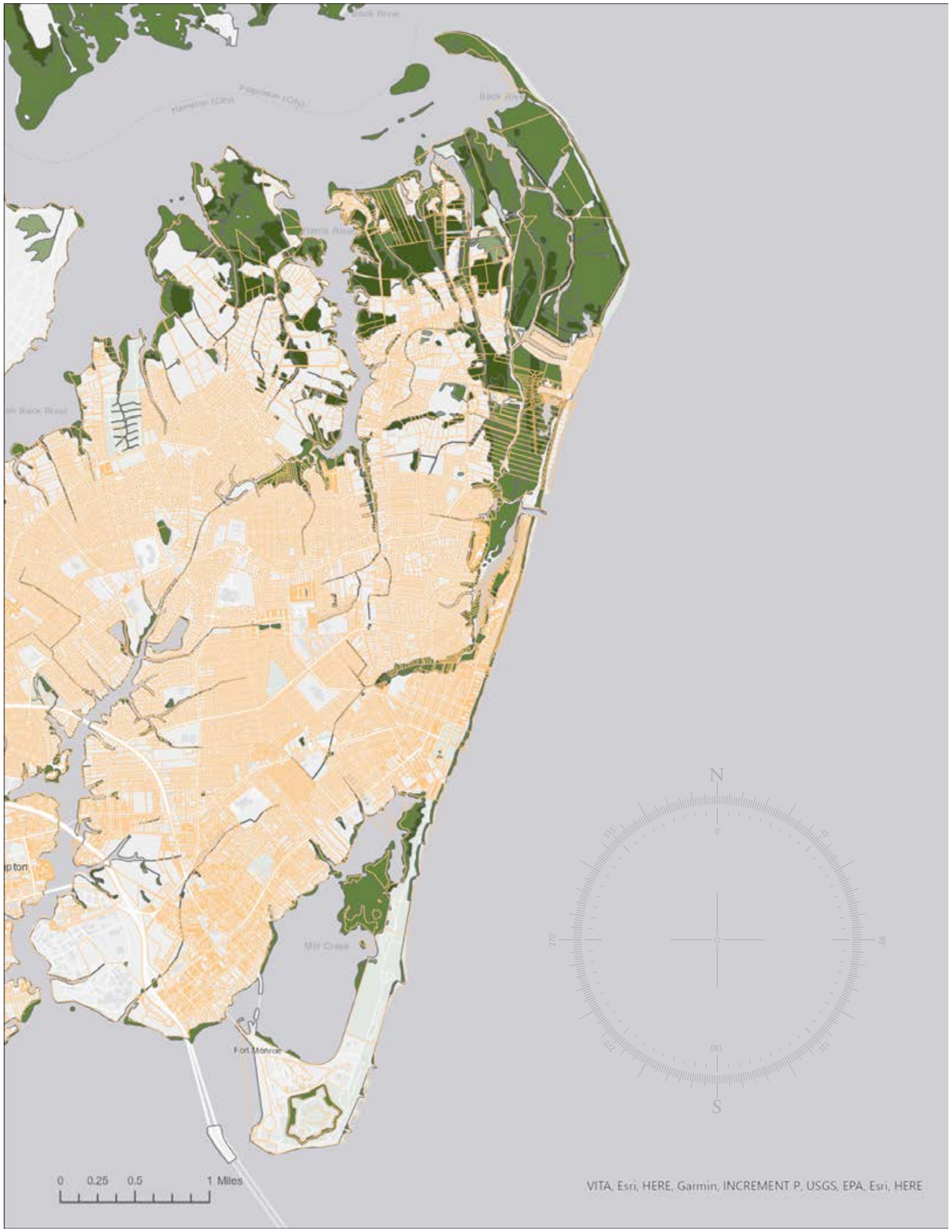


Fig. AA-11



Wetlands

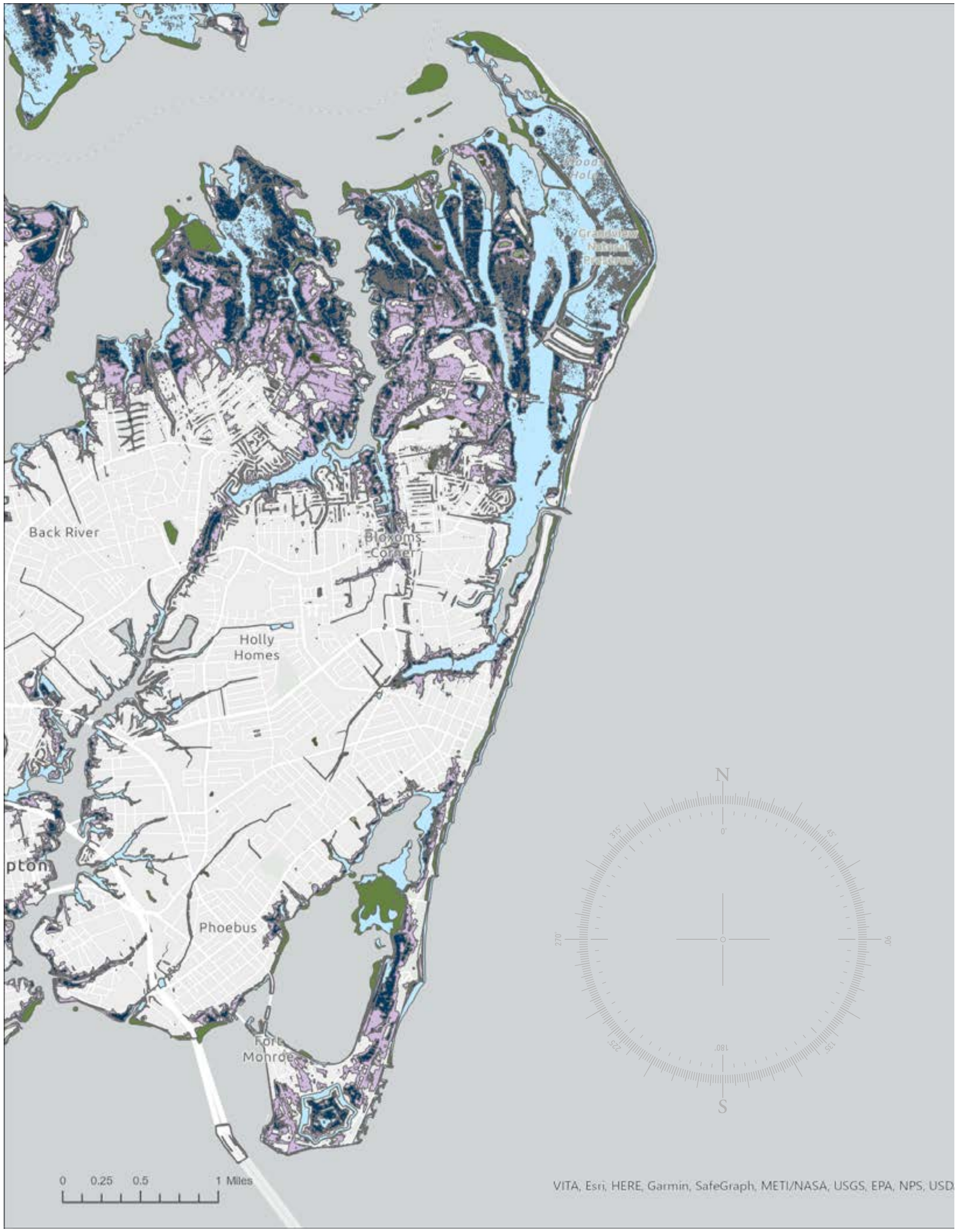
Urban Pressure on Existing Wetlands

This map illustrates wetland data collected from the National Wetlands Inventory and parcel data from the city of Hampton, Virginia.

The data shows the extent of urban pressure on existing wetlands in the study area. It is clear that as natural conditions change due to climate change, the **wetlands will be unable to migrate inland** due to urban sprawl.

- Urban Parcel Outlines
- Estuarine & Marine Wetland
- Forested Freshwater Shrub Wetland
- Freshwater Emergent Wetland

Fig. AA-12



Wetlands

Sea Level Rise Impacts on Existing Wetlands

This map illustrates wetland data collected from the National Wetlands Inventory and sea level rise planning data from the city of Hampton, Virginia.

This data shows the future loss of wetland areas due to sea level rise predictions. **The lowest level of predicted SLR results in the greatest loss of protective wetland buffer**.

1.5 Ft above MHHW (2020-2050)

3 Ft above MHHW (2050-2080)

4.5 Ft above MHHW (2080-2100)

Fig. AA-13

Wetlands

Future Loss of Mill Creek Wetland

This map illustrates wetland data collected from the National Wetlands Inventory and sea level rise planning data from the city of Hampton, Virginia.

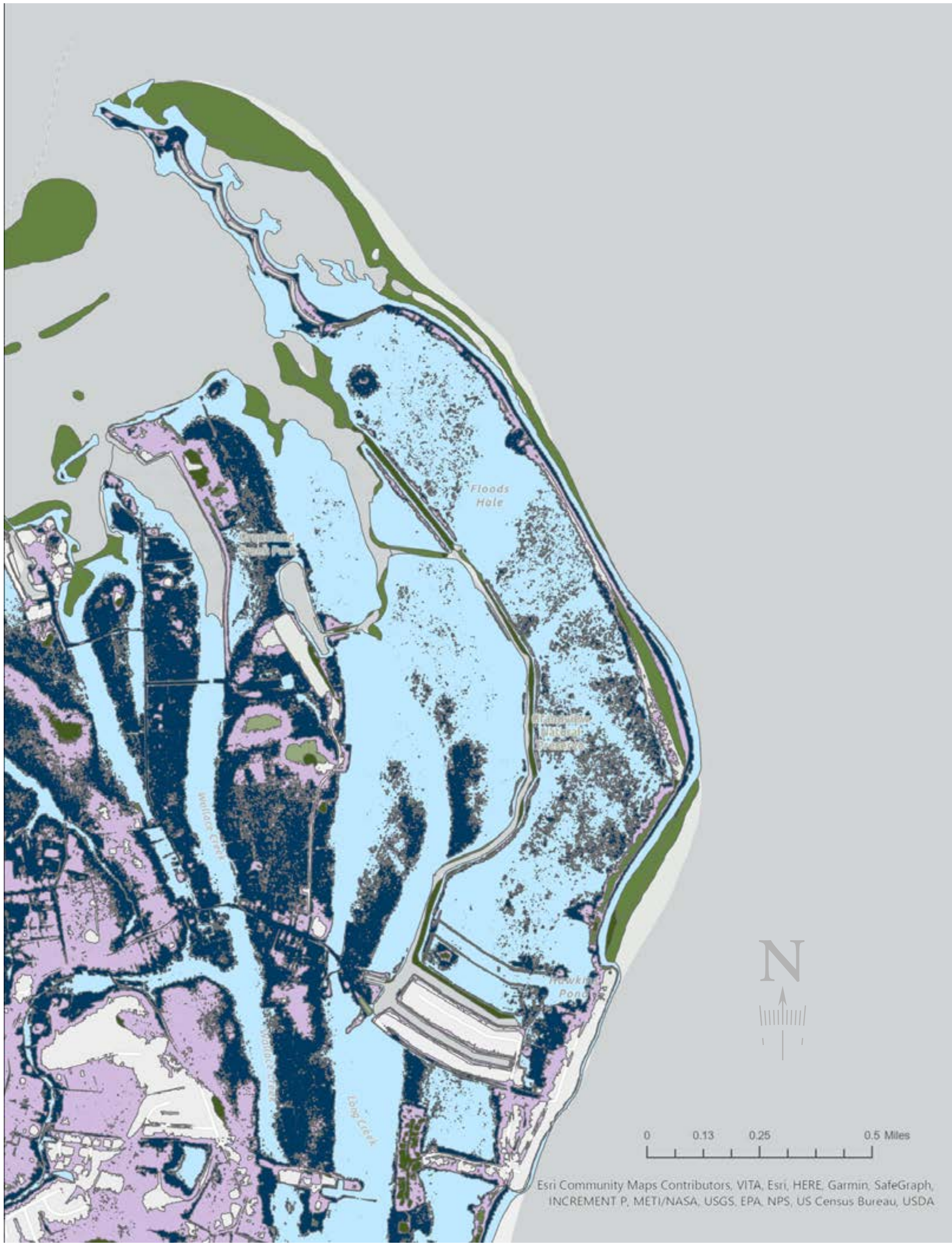
Currently, the Mill Creek wetland is less than 41 acres and disappearing quickly to water inundation.

1.5 Ft above MHHW (2020-2050)

3 Ft above MHHW (2050-2080)

4.5 Ft above MHHW (2080-2100)

Fig. AA-14



Wetlands

Future Loss of Grandview Nature Preserve

This map illustrates wetland data collected from the National Wetlands Inventory and sea level rise planning data from the city of Hampton, Virginia.

According to the EPA, wetlands can store 1-1.5million gallons of water per acre. Currently, **the Grandview Nature Preserve wetland area is approximately 1,576 acres, capable of storing up to 2,364,000,000 gallons of water**. The encroaching suburban environment does not have the storage capacity to manage that much water if the wetlands are lost.

1.5 Ft above MHHW (2020-2050)

3 Ft above MHHW (2050-2080)

4.5 Ft above MHHW (2080-2100)

Fig. AA-15

Wake Energy

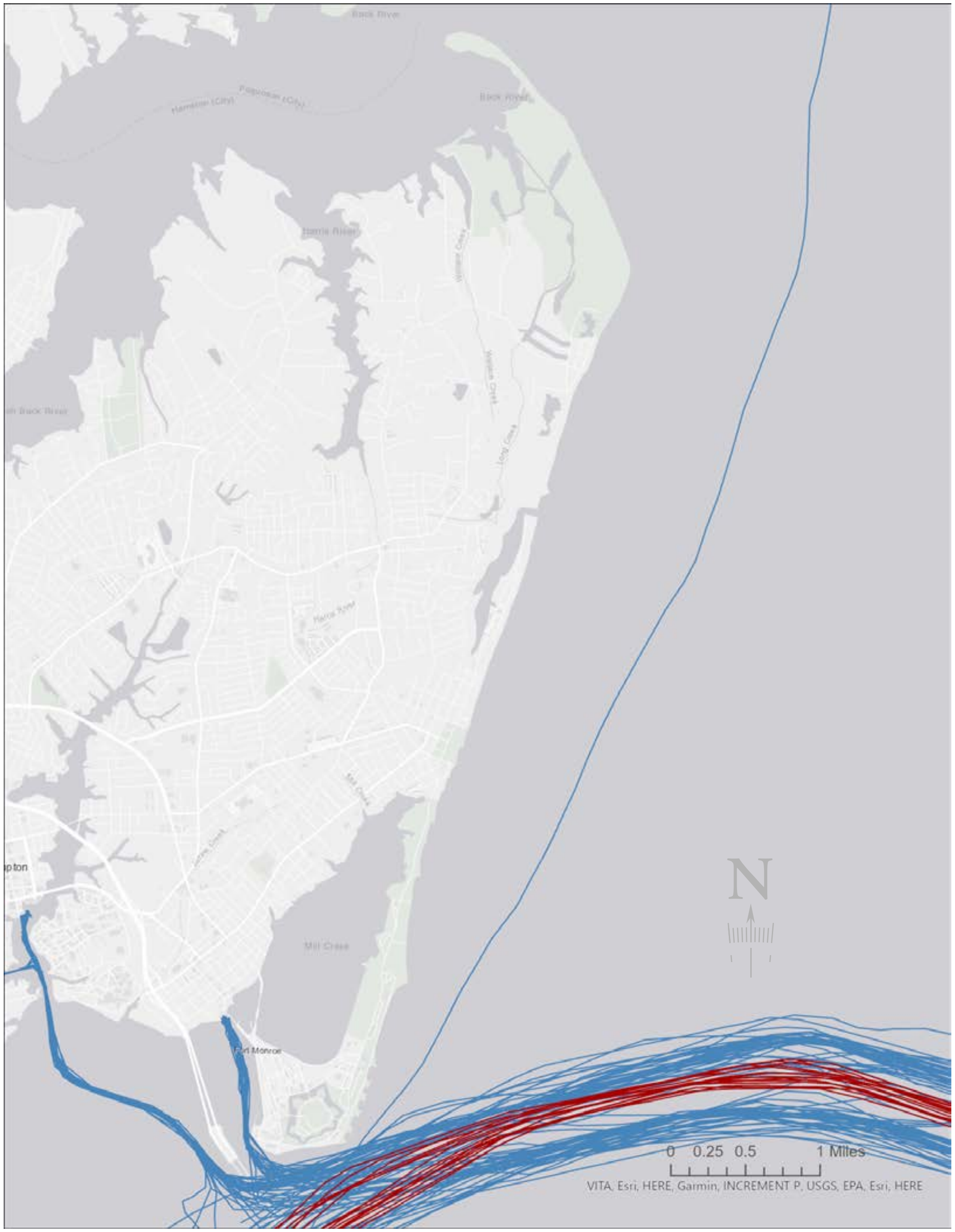
Commercial Fishing & Cargo Vessels

This map illustrates data collected from the movements of registered commercial fishing and shipping boats.

Over a one month period, in June 2017,

1,441 commercial fishing boats and 28 cargo vessels passed through the dredged shipping channel just south of Fort Monroe. This is a substantial amount of ship wake affecting the coastline of Hampton, Virginia. Perpendicular jettys installed on the southeast edge of Fort Monroe appear to be helping restore some shoreline and beach loss.

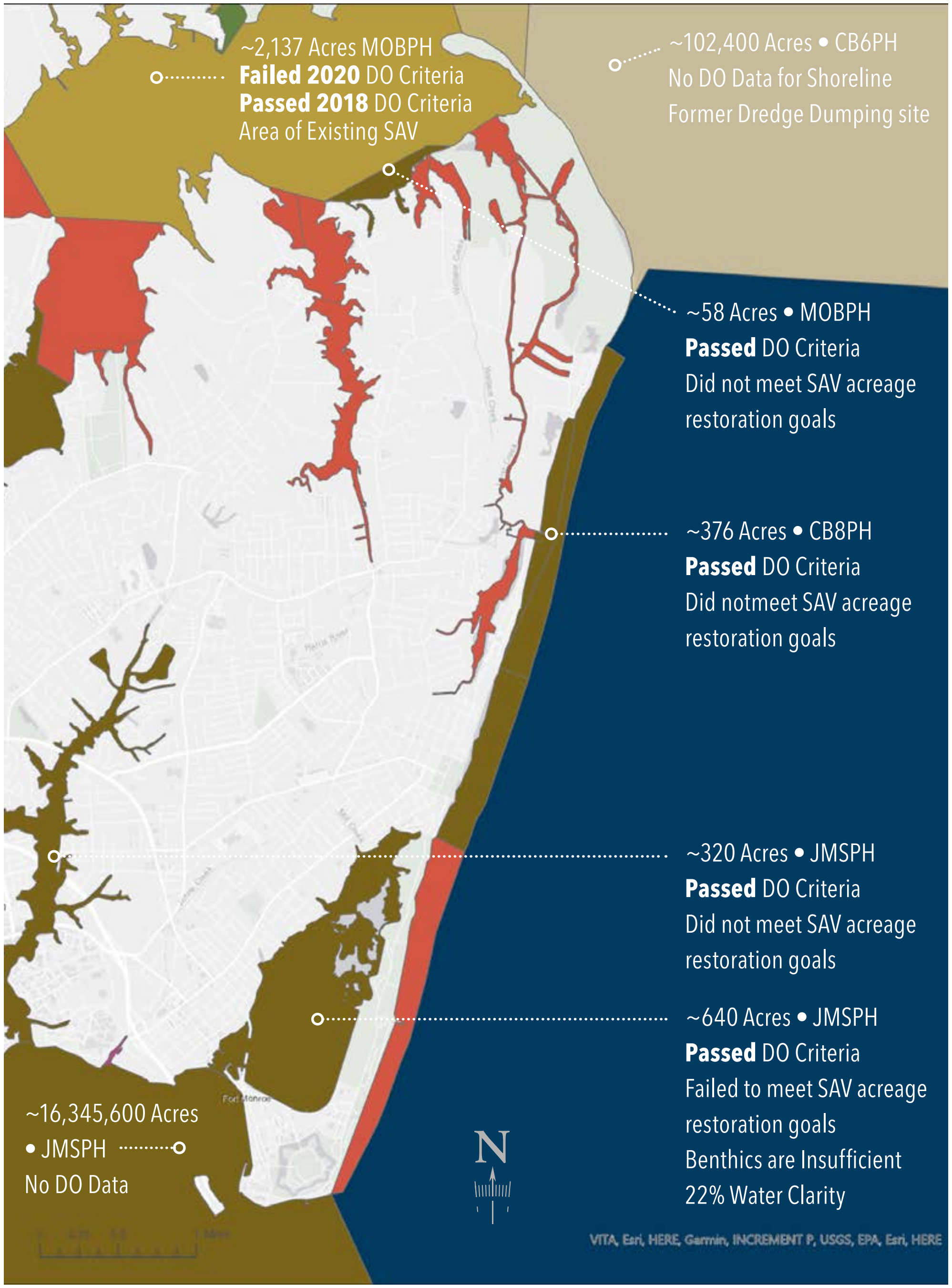
To maintain the growth and health of protective ecosystems, ship wake on this scale must be considered in any design solution.



Commercial Fishing Boats

Cargo Ships

Fig. AA-16



SAV Potential

2020 Water Quality Analysis for SAV

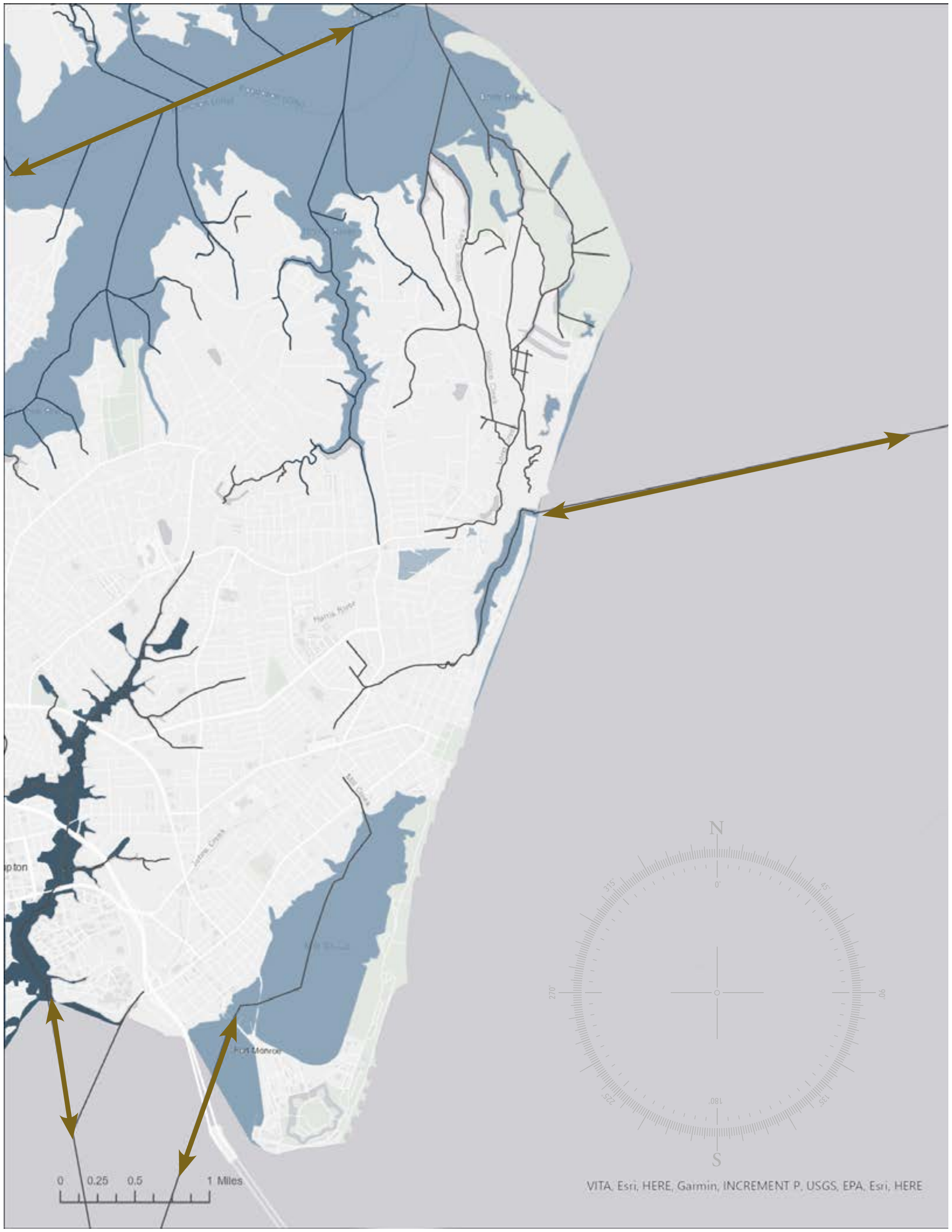
This map illustrates data collected by the Virginia Department of Environmental Quality as part of the 2020 Water Quality Assessment Integrated Water Quality Report 305(b)/303(d).

The areas highlighted in dark brown passed the 30 day dissolved oxygen criteria to support submerged aquatic vegetation. However, none of those zones met the SAV acreage restoration goals established in 2003, which could indicate another toxin affecting water quality in those areas. Areas in gold previously passed the DO test but failed the 2020 test, **indicating a decline in water quality**. The areas surrounding Grandview Nature Preserve are noted in DEQ reports to have high nitrogen levels, sanitary sewer overflows, and marina/boating vessel discharges impacting water quality.

Additional data needs to be collected to satisfy additional enabling SAV conditions. Water temperatures at or below 74 degrees, adequate light attenuation for photosynthesis, low to moderate wave energy, and stable sediment to avoid over-suspension.

- Passed 2020 SAV 30 Day Dissolved Oxygen Criteria
- Passed 2018 but Failed 2020 SAV 30 Day Dissolved Oxygen Criteria
- No Dissolved Oxygen data, recommended study area
- Failed 2020 30 Day Dissolved Oxygen Criteria

Fig. AA-17



Tidal Datums

Tidal Flow Patterns

This map illustrates tidal flow and flushing rate data from the Virginia Department of Environmental Quality.

Tide Data

NOAA Local Tide Data:
Sewell's Point, Virginia 8638610
Datum: NAVD88

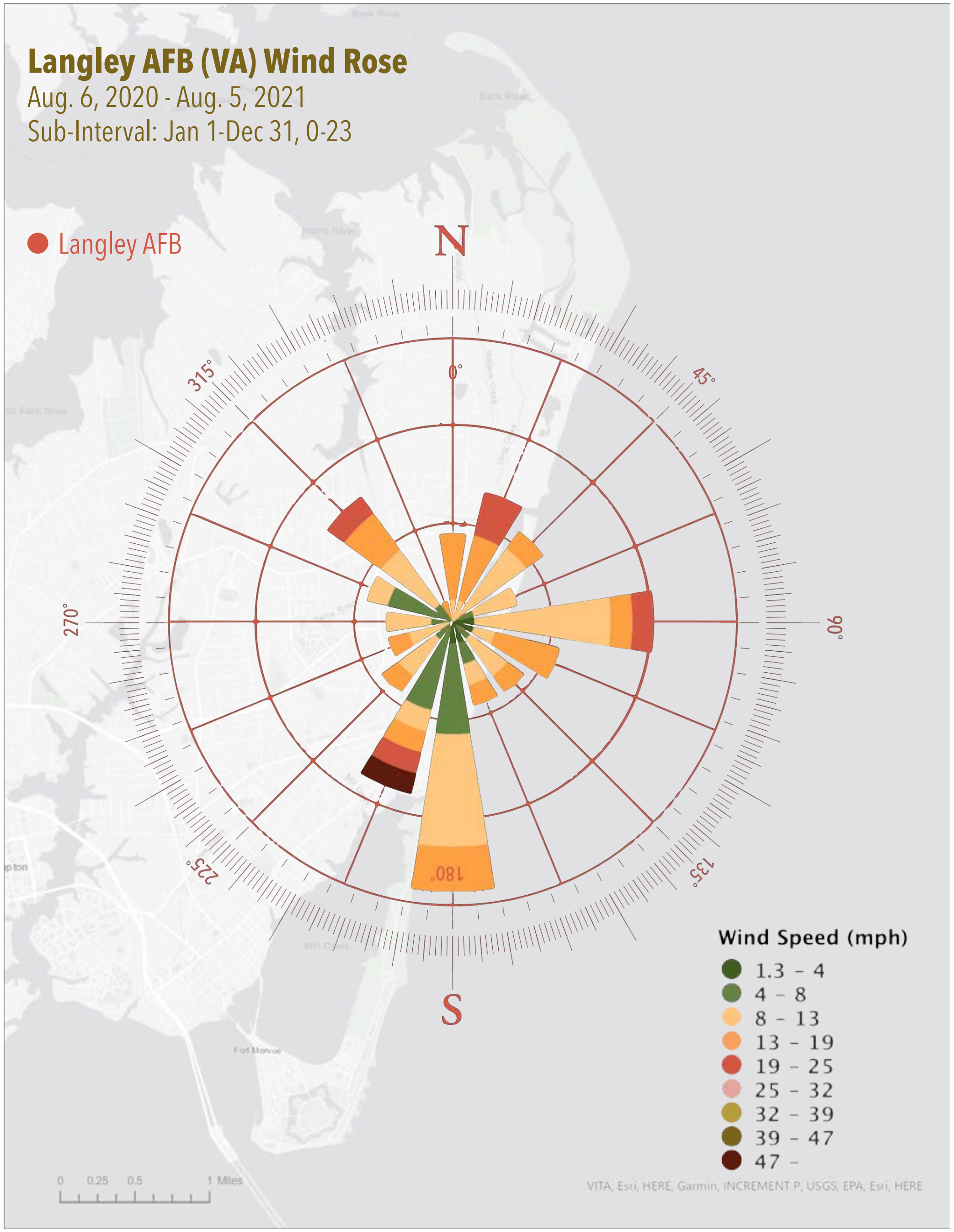
MHHW: 1.15ft
MHW: .95ft
MLLW: -1.61ft
MLW: -1.48ft

Mean Sea Level: -.25ft
Tidal Range: 2.76ft

Highest Astronomical Tide: 2.02ft
Lowest Astronomical Tide: -2.33ft

Tidal Flow Path
Intermediate Tidal Flushing
Quick Tidal Flushing

Fig. AA-18



Wind & Waves

Fetch & Significant Wave Height

This data generated by the cli-MATE calculator from the Midwestern Regional Climate Center shows the longest fetch from the E over the Atlantic Ocean and the strongest average winds **affecting the coast** from the NNE over the Chesapeake Bay. The average wind speed from the S to SE is between 8.6 and 9.5 mph. The average wind speed from the NNE is 16.3 mph. There is an outlier of stronger wind from the SSW however that wind travels over land and does not impact coastal wave energy.

Using the average wind speeds affecting the coast, significant wave height was calculated using the USGS Fetch and Depth Limited Waves module.

Significant wave heights were calculated at 9.5ft and confirmed by FEMA's 2016 Flood Insurance Study.

Fig. AA-19

Bathymetry

Digital Elevation Model

This data was generated using a Digital Elevation Model (DEM) created by USGS. It was rasterized and converted to a topographical map using GIS. Only major contour lines are represented for this project. The majority of the coastline interventions are sited on or close to the -10' elevation.

Fig. AA-20

Appendix B
CALCULATIONS & RESEARCH

Breakwater Calculations

The table illustrates the results of calculated breakwater crest elevation, breakwater slope width, and total breakwater width. These calculations were based off of information from the Federal Emergency Management Agency's Flood Insurance Study for Hampton City and the city of Hampton's projected sea level rise estimates. All calculations are provided per FIS Transect and for design purposes, the greatest calculated height was used as the standard for all breakwaters.

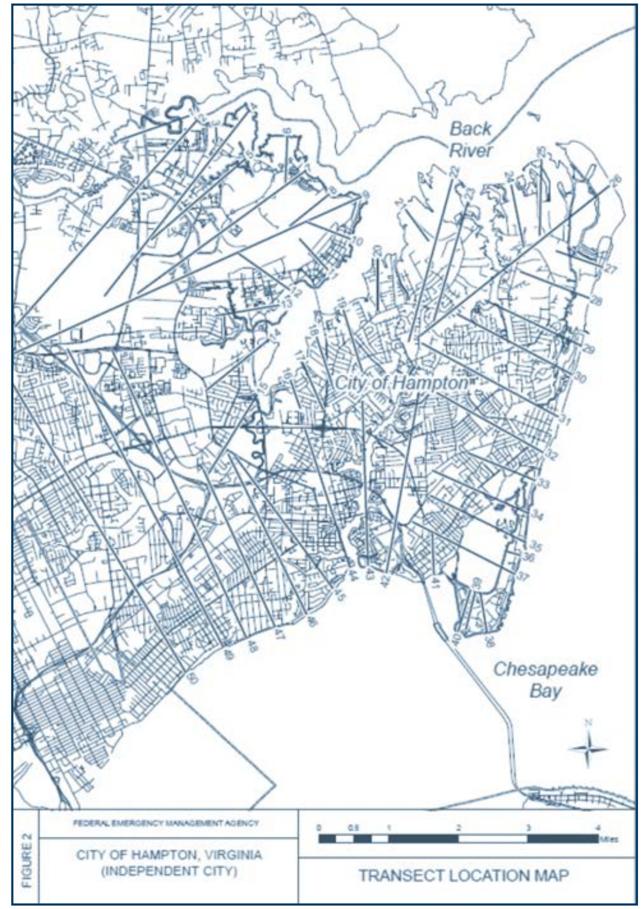


Fig. AB-1 2016 FEMA Flood Insurance Transect Map

Flood Source	Transect	Significant Wave Height (ft)	Peak Wave Period (sec)	Starting Stillwater Elevation (feet NAVD 88)				Sea Level Rise			Minimum Breakwater Crest Elevation (Non-overtopping)						Slope Width	Crest Width	Total Width
				10% Annual Chance	2% Annual Chance	1% Annual Chance	0.2% Annual Chance	30-year	60-year	80-year	Current - 10 yr	Current - 100 yr	30 yrs - 10 yr	30 yrs - 100 yr	80 yrs - 10 yr	80 yrs - 100 yr			
Back River	25	2.7	2.6	5.0	6.4	7.0	8.4	1.5	3.0	4.5	7.7	9.7	9.2	11.2	12.2	14.2	48.4	30.0	126.8
Chesapeake Bay	26	8.9	7.3	4.7	6.0	6.6	7.7	1.5	3.0	4.5	13.6	15.5	15.1	17.0	18.1	20.0	60.0	30.0	150.0
Chesapeake Bay	27	9.1	7.4	4.8	6.2	6.7	7.8	1.5	3.0	4.5	13.9	15.8	15.4	17.3	18.4	20.3	60.6	30.0	151.2
Chesapeake Bay	28	8.1	7.5	5.0	6.3	6.8	8.1	1.5	3.0	4.5	13.1	14.9	14.6	16.4	17.6	19.4	58.8	30.0	147.6
Chesapeake Bay	29	9.4	7.5	5.0	6.3	6.9	8.1	1.5	3.0	4.5	14.4	16.3	15.9	17.8	18.9	20.8	61.6	30.0	153.2
Chesapeake Bay	30	9.8	7.4	5.0	6.4	6.9	8.2	1.5	3.0	4.5	**14.8**	**16.7**	**16.3**	**18.2**	**19.3**	**21.2**	62.4	30.0	154.8
Chesapeake Bay	31	9.8	7.5	5.0	6.4	6.9	8.2	1.5	3.0	4.5	**14.8**	**16.7**	**16.3**	**18.2**	**19.3**	**21.2**	62.4	30.0	154.8
Chesapeake Bay	32	9.7	7.6	5.0	6.5	7.0	8.2	1.5	3.0	4.5	14.7	16.7	16.2	18.2	19.2	21.2	62.4	30.0	154.8
Chesapeake Bay	33	9.6	7.5	5.0	6.5	7.0	8.3	1.5	3.0	4.5	14.6	16.6	16.1	18.1	19.1	21.1	62.2	30.0	154.4
Chesapeake Bay	34	9.2	7.4	5.1	6.5	7.1	8.4	1.5	3.0	4.5	14.3	16.3	15.8	17.8	18.8	20.8	61.6	30.0	153.2
Chesapeake Bay	35	9.0	7.4	5.0	6.5	7.1	8.3	1.5	3.0	4.5	14.0	16.1	15.5	17.6	18.5	20.6	61.2	30.0	152.4
Chesapeake Bay	36	2.1	2.6	5.0	6.5	7.1	8.5	1.5	3.0	4.5	7.1	9.2	8.6	10.7	11.6	13.7	47.4	30.0	124.8
Chesapeake Bay	37	8.8	7.3	5.1	6.6	7.1	8.4	1.5	3.0	4.5	13.9	15.9	15.4	17.4	18.4	20.4	60.8	30.0	151.6
Hampton Roads	38	7.7	6.7	5.1	6.5	7.1	8.3	1.5	3.0	4.5	12.8	14.8	14.3	16.3	17.3	19.3	58.6	30.0	147.2
Hampton Roads	39	2.1	2.7	5.1	6.7	7.4	8.8	1.5	3.0	4.5	7.2	9.5	8.7	11.0	11.7	14.0	48.0	30.0	126.0
Hampton Roads	40	5.2	6.6	5.1	6.5	7.1	8.4	1.5	3.0	4.5	10.3	12.3	11.8	13.8	14.8	16.8	53.6	30.0	137.2
Hampton Roads	41	2.9	2.8	5.1	6.5	7.0	8.3	1.5	3.0	4.5	8.0	9.9	9.5	11.4	12.5	14.4	48.8	30.0	127.6

Remote Sensing

Grandview Nature Preserve

Grandview currently exists as a headland and the northern section is highly susceptible to north and northeast storm activity. In addition to continued erosion, breaches have occurred subjecting Hawkins Pond to periodic influxes of seawater. VIMS (2005) suggests that the Grandview shoreline has been eroding at a rate of -0.6 ft/yr between 1994 and 2002.

Fig. AB-2 Shoreline 1994

Fig. AB-3 Shoreline 2002

Grandview Nature Preserve South

The average rate of erosion from 1937 to 1997 has been -5.5 ft/yr. This section of shoreline is exposed to the northern storms and does not benefit from the addition of littoral sediment. There is a reversal in the net littoral direction around Lighthouse Point. Therefore, new sand is rarely supplied naturally to the beaches at the Nature Preserve. The eroded material from Grandview Nature Preserve does tend to migrate to the south, however, since the Grandview seawall serves as a headland, much of this material is diverted offshore. In its current state, the shoreline along the Grandview Nature Preserve will continue to erode. Rates of erosion should diminish, however, since the south side of Lighthouse Point is no longer a prominent headland. VIMS (2005) suggests that the southern end of the Nature Preserve has been eroding at a rate of -0.6 ft/yr between 1994 and 2002.

Grandview Nature Preserve North

The average rate of shoreline change for the first half-mile segment immediately north of Lighthouse Point has been in the range of +0.5 ft/yr since 1937. The spit, however, has historically continued to migrate to the southwest at an average rate of -15 ft/yr. A headland exists between the spit and the segment adjacent to Lighthouse Point. This headland has also historically migrated to the southwest, but the rate has been significantly less than that of the spit. VIMS (2005) estimates that between 1994 and 2002, the northern end of the Grandview Nature Preserve has eroded at an estimated rate of -3.5 ft/yr. 28 The headland and the spit at Factory Point were extremely low lying with average dune crest elevations less than about 5.5 ft MLLW. As a result, this section of the shoreline was frequently overtopped. During the fall of 1997 the throat of the spit was completely breached creating an island at Factory Point. The breach widened during the following thirteen years. In 2010, more than 140,000 CY of sand was pumped from the nearshore shoal to reattach the island at Factory Point with the mainland at the Grandview Nature Preserve. In addition, five breakwater structures were constructed to help stabilize the restoration project.

Remote Sensing

Shoreline Changes 1990-2020

Google Earth Engine allowed the team to analyze shoreline change over time to see how loss has occurred historically.

(1990 – 2020)
Loss due to Sea Level Rise 190.4 acres = 0.63%

Area Total (Study Site)   30,435.2 acres 100.00%
Urbanized Land 8,700.9 acres = 28.60%
Undeveloped Land/Forest 5,401.8 acres = 17.75%
Water 13,857.8 acres = 45.53%
Wetlands 2,284.3 acres = 7.51%

Conversion Calculations:
514632.94958496094 sq meters (wetlands loss) = 127.2 Acres
255811.39373779297 sq meters (beach loss) = 63.2 Acres
Total = 190.4 acres

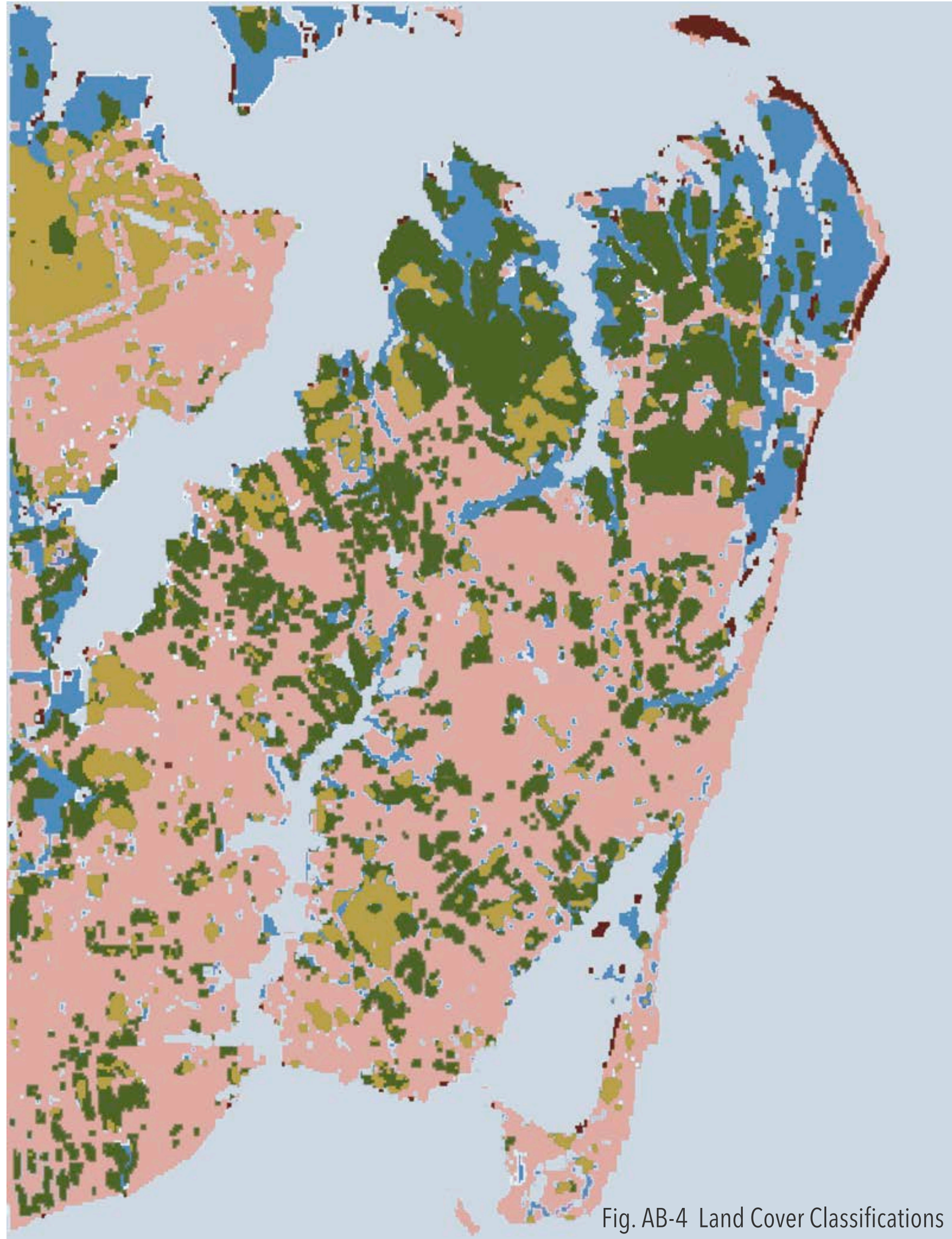


Fig. AB-4 Land Cover Classifications

Environmental Policy

Riparian Rights

In the state of Virginia, waterfront property owners receive riparian rights, which allow them to use and enjoy the benefits of the water on their land. There are numerous benefits of riparian rights, including the right to enjoy the natural advantages conferred upon the land by its adjacency to the water, rights of access to the water, and rights to build a pier out to the navigable part of the water. They also include the right for the size of your property to expand through a natural process called "accretion," and the right to make a reasonable use of the water as it flows past or washes up on the land. Riparian property rights apply within a defined "riparian area" which is unique to each waterfront property. It is formed by the shore of the waterfront property on one side and by the line of navigation on the other side.

Establishing a riparian area requires assistance from a riparian property rights attorney and a hydrographic surveyor working under the attorney's supervision. One important thing to note is that riparian rights can be withheld by a prior property owner. Ownership of the bottomland, or the land submerged under the water however varies, dependent upon the body of water in which it lies. The commonwealth of Virginia typically owns the bottomland of bays, rivers, creeks, and seashores within the state. The bottomland on non-navigable rivers and creeks; however, is privately owned, and property lines will extend out into the water to the center of the waterbody. Waterfront property owners on a bay or the seashore will never qualify for this non-navigability exception because these waterbodies are subject to the ebb and flow of the tide and are therefore deemed navigable.

Dredge Material

The code of Virginia consists of the general and permanent laws of the Commonwealth of Virginia that have been passed by the state's General Assembly and signed into law by the governor. Code of Virginia, § 10.1-704 prioritizes the use of dredged material for beach nourishment purposes. The secretary of Natural and Historic Resources shall possess the responsibility to determine whether the dredged material obtained is suitable for beach nourishment. Code of Virginia, § 10.1-709 also establishes a public beach maintenance and development fund to provide grants to local governments that cover up to one-half of the costs of erosion reducing efforts.

Environmental Policy

Living Shorelines

Development projects that affect shorelines in Virginia will soon need to plan for the use of living shorelines as the preferred method for shoreline management in their development plans.
During the 2020 Legislative Session, the Virginia General Assembly amended Title 28.2 of the Virginia Code to strengthen Virginia Marine Resources Commission's (VMRC) mandate to protect sensitive shorelines and wetlands. Where the law previously encouraged the use of living shorelines, the law now requires it by requiring VMRC to permit "only living shoreline approaches to shoreline management unless the best available science shows that such approaches are not suitable." Further, even if the best available science shows a living shoreline is not suitable, the VMRC must still require applicants to incorporate elements of living shorelines into the permitted project "to the maximum extent possible." The amendments require VMRC to develop new minimum standards for shoreline and coastal habitat protection that account for sea-level rise, and minimum standards for the protection and conservation of wetlands. Once created, the VMRC must consider these new standards when reviewing permit applications for activities that impact shorelines and wetlands.

The General Assembly incorporated these amendments into the statutory wetlands zoning ordinance used by Virginia municipalities. City, county, and town wetlands boards will be required to consider VMRC's minimum wetlands protection standards, once promulgated, during adjudication of permit applications. The amendments also require that applications to municipal wetlands boards contain a statement indicating whether the use of a living shoreline is not suitable, including reasons for the determination.

These changes will make it more difficult for project planners to use traditional defensive structures, such as seawalls or bulkheads, on some or all portions of a shoreline. This is particularly true in areas that are good candidates for living shorelines, such as inshore areas that experience less wave or vessel-wake action. In addition, project planners may need to consider the potential increased costs associated with the establishment of a living shoreline, particularly if the property currently experiences shoreline management problems. This includes properties that have older, failing defensive structures, or properties that are suffering from significant shoreline erosion and may require installation of breakwaters or other structures to help rebuild the shoreline. Alternatively, planners will have to consider the additional costs needed to prepare a detailed justification explaining why a living shoreline is not feasible as part of the application. These costs, however, may be offset by a more simplified or expedited permitting process. In addition, owners may benefit from favorable property tax treatment that exempts living shorelines from taxation. Owners may see a decrease in long-term shoreline management costs if a healthy living shoreline can be established, as opposed to a defensive structure that requires maintenance, repair, and eventual replacement.

Chesapeake Dredge Activities

United States Dredging Activity

The United States Maritime Transportation System, which is supported by 900 federal channel projects, spans about 25,000 miles of navigable channels. Channel projects are separated into two categories: deep (greater than 12 feet deep) and shallow (less than 12 feet deep). During maintenance of these channels, approximately 200-300 million cubic yards of material are dredged annually by the United States Army Corps of Engineers (USACE). However, only 20-30% of this material is reused for beneficial purposes. Beneficial purposes include placement of material for habitat development, fishery enhancement, recreational facility creation, and shoreline construction. The EPA's National Dredging Team (NDT) published an action plan entitled, "Dredged Material Management: Action Agenda of the Next Decade" in 2003 in part to guide the USACE in the expansion of beneficial use of dredge material.

Dredging in Hampton Roads

Located at the confluence of shipping lanes and military facilities, Hampton Roads', the 33rd largest metropolitan statistical area in the U.S., shipping channels must remain accessible to large ships to sustain vital commerce. To keep shipping lanes and military routes open, Norfolk Harbor Channel, roughly 40 feet deep, is continually dredged just south of Fort Monroe. After a planned depth increase contracted in August 2019, the channel will reach 52 feet below the mean lower low water depth. The USACE and Cottrell Contracting signed a $10.4 million contract in August 2019 to dredge 1.1 million cubic yards of the federal channel. The dredged sediment will be transported by pipeline to Craney Island Dredged Material Management Area (CIDMMA) in Portsmouth, VA., which was constructed as a consequence of the River and Harbor Act of 1946. Completed in 1957, Craney Island encompasses about 2,500 acres and is surrounded by perimeter dikes. Storing sediment at CIDMMA costs $1.38 per cubic yard of sediment directly pumped to the placement area, or $6.81 per cubic yard of mud, silt, clay, sand, shell, marl, etc. stored temporarily in the Rehandling Basin. All private interest groups, municipalities, and government agencies must use the CIDMMA to dispose of dredged sediments that support navigation in Norfolk Harbor and adjacent waters. In order to maintain depth, maintenance dredging at intervals of 12 to 15 months is required in the Norfolk Harbor Channel.

Cost of Hampton Roads Dredging

In 2019, 1.1 million cubic yards of material were dredged from the Norfolk Harbor Channel and transported to CIDMMA. Based on storage cost rates that same year,it cost a minimum of $1.5 million to store materials. Additional costs are incurred each step of the dredging process, adding to overall costs. The process, and associated costs, are incurred annually.

Construction of Dredge Spoil Islands

Dredge spoil islands are generally constructed by expanding existing islets.The process starts with remediation of the seabed to hasten natural processes such as settlement. Where natural settlement may take decades, remediation efforts can complete the process in about a year. Next, a seawall is put in place to reduce the effects of erosion by the waves and currents impacting the perimeter of the site. Finally, to complete island construction, the reclamation area is filled with a mixture of sand, gravel, and rock.

Appendix C

CASE STUDIES & REFERENCES

Collecting Eelgrass seeds
Photo: https://www.sciencenews.org/article/seagrass-restoration-project-virginia-ecosystem-rapid-recovery

Bay scallop in an eelgrass bed
Photo by Jay Fleming

Virginia Eelgrass: Blue Carbon Project

The largest and most successful eelgrass restoration project on the planet is now growing in an area, where for 50 years, eelgrass had been rooted up and destroyed by disease and successive hurricanes. Located on the Atlantic side of Virginia's Eastern Shore in what is known as the South Bay, project partners and volunteers have grown this resource from zero acres to 9,000 acres in 18 years.

Process: The Virginia Institute of Marine Science invented a new approach for harvesting and distributing eelgrass seeds. The team located prime areas for scattering seeds, and in a relatively short time began seeing great results. The VIMS team work has shown that using eelgrass seeds can be much more effective than transplanting adult plants for large-scale restoration in the mid-Atlantic.

Habitat: VIMS is working to reestablish the bay scallop that used to thrive in eelgrass beds but hasn't been seen in any large number in over a century.

Resilience: Under normal conditions, seagrass meadows are able to slow down water currents and reduce wave energy, reducing the impact of wave action on adjacent shorelines. Additionally, seagrass beds are capable of stabilizing the sea floor with their extensive root systems, keeping sediments from moving and trapping suspended sediment to maintain the integrity of the local shoreline.

The effectiveness of seagrass is substantially reduced in major storm events as the larger waves overwhelm the grasses. However, seagrass meadows provide the most effective protection when paired with other coastal protection features like mangroves, coral reefs, oyster reefs, and coastal marshes.

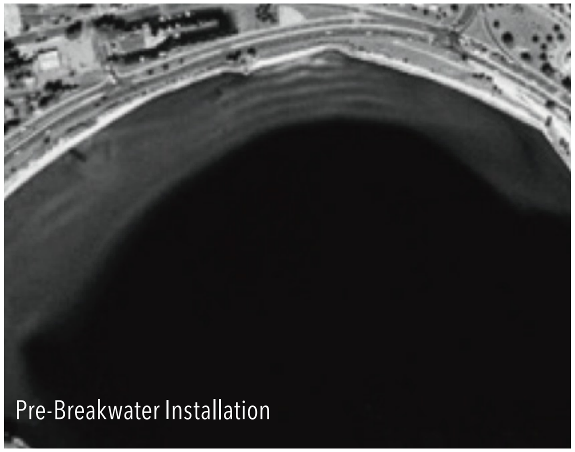
Lessons: Improving water quality is key to restoring seagrass coverage. Seagrass thrives in shallow, clear water without excessive nutrient or sediment deposits. Upland water quality must be evaluated as part of the site feasibility. However, it looks promising that as the meadow expands, the water quality improves and the grasses expand their footprint. Seagrass is also sensitive to changing water temperatures and sea level rise. These factors must be considered when determining if an area is suitable for a restoration project.

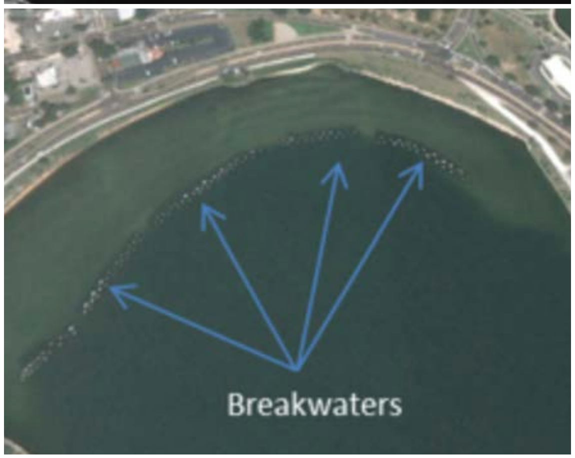
Carbon: The eelgrass meadow has removed 9,600 metric tons of CO2 over the past 15 years and continues to remove nearly 1 ton per 5 acres, annually from the atmosphere. At the current market rate of $10 per carbon unit, selling the carbon credits will offset approximately 10% of the project cost.

https://coast.noaa.gov/states/stories/worlds-most-successful-eelgrass-restoration-project.html

https://www.vims.edu/research/units/programs/sav1/restoration/index.php

Oreska, M.P.J., McGlathery, K.J., Aoki, L.R. et al. The greenhouse gas offset potential from seagrass restoration.





Project Greenshores: Resilient Breakwater

In 2000, the City of Pensacola began a project to re-establish lost marsh habitat along its downtown shoreline. While the primary objective of "Project Greenshores" was not to protect its residents from storms, the unintended benefits from the project include increased protection from storm-related surges and rising sea levels, making this an accidental example of natural infrastructure improving a community's resiliency.

Process: The first phase was the construction of a breakwater. The structure sits on the bay floor and extends above the surface. The breakwaters used 14,000 tons of limestone, 6,000 tons of recycled concrete, and 40 preformed concrete blocks and 35,000 cubic yards of sand were formed into a series of five islands, just inside the breakwater. Approximately 41,000 Spartina Alterniflora plants were planted to produce eight acres of marsh habitat.

In 2007, Project Greenshores began construction at Site 2 that featured a similar, but smaller-scale design. Here, citizens requested the breakwaters be completely submerged underwater to improve the site's aesthetics. The breakwaters were constructed from 25,000 cubic yards of recycled concrete. Three islands were created from 16,000 cubic yardsof dredge spoil.

Habitat: Project Greenshores is a habitat restoration success. Bird species are now so abundant that the Audubon Society added it to the Great Florida Birding Trail. Oysters have grown on the breakwaters and crab fishermen have benefited from increased numbers of blue crabs, which were scarce in the bay before the project.

Resilience: In 2004 Pensacola took a direct hit from Hurricane Ivan, a Category 3 hurricane when it made landfall. The storm surge reached 15 feet and washed out most of a major roadway that runs parallel to the bay's shoreline. The damage closed the majority of the road for months. The section of Bayfront Parkway directly behind Project Greenshores experienced less damage—only the eastbound lanes were closed here. Also, the shoreline at the project sites did not experience heavy erosion.

The following year Pensacola was hit by Hurricane Dennis, also a Category 3 hurricane, and the benefits of the project were again observed, as the breakwaters and marsh islands helped protect the shore from storm surge.

Lessons: The submerged breakwater at site two has not done as well at protecting the marsh islands. Oysters have inhabited the breakwater even though the design was not specifically catered to them. Two of the zones have experienced erosion an lost vertical height. However, the performance of the breakwaters during two hurricanes proved its utilization in coastal resiliency.

http://nrcsolutions.org/pensacola-florida/

Eelgrass in optimal conditions
www.seagrant.noaa.gov

A healthy eelgrass bed
https://www.pewtrusts.org

Eelgrass: Supporting Conditions & Productivity

Creating and restoring suitable habitat for thriving eelgrass (Zostera marina) populations in the 21st century requires an understanding of our changing climate. Temperature, water column depth, sediment composition and more must all be considered.

Process

To find the most productive habitat conditions for Z. marina, researchers gathered data on the variability of temperature. light exposure, and water depth across several eelgrass beds ranging from .9 to 6.2 meters deep off the Atlantic coast of Nova Scotia, Canada. Data was collected for roughly one year, beginning April 2017 and ending in May 2018. Temperature variability was collected every 10 minutes within all eelgrass beds, and these measurements were used to find an average temperature. Total days above 74 degrees Fahrenheit, the maximum temperature for eelgrass growth, was quantified as well. Biological metrics were collected, including chlorophyll concentration, number of leaves per plant, sheath length, vegetative shoot density, and canopy height. Finally, data was collected on "resilience metrics", characteristics which show an attempt to mitigate stress. These metrics include phenolic acid and rhizome water soluble carbohydrate concentrations, leaf nitrogen content, reproductive shoot density, above to below ground biomass ratio, and eelgrass patch size and density.

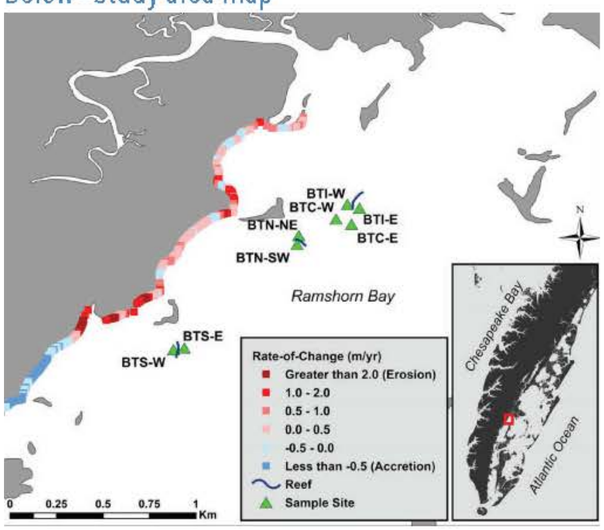
Results

The study shows "strong interacting roles of temperature, light, water movement, and sediment characteristics in shaping metrics of eelgrass productivity and resilience across a broad range of biological scales." Z. marina beds at the warmest sites in the study showed signs of temperature and light stress, which led to declines in photosynthetic efficiency and resilience. Also at warm sites, Z. marina increased resilience to low light by producing longer sheaths, leaves, and canopy heights relative to sites with more light, which increases photsynthetic capability. Plants at warmer sites also experienced heat-induced damage. Plants at deeper, cooler sites, however, were able to maintain high productivity and resilience under lower light conditions. Together, these results suggest that plants at the warmest sites in the study were stressed leading to declines in photosynthetic efficiency and overall resilience relative to cooler sites.

Lessons

Eelgrass projects should be situated at deep, cool sites in anticipation of warmer water temperatures caused by climate change and the increasing threat of marine heatwaves. While warmer, lower light conditions produced greater carbon uptake, the overall resilience of the plant decreased, making deeper, cooler sites (roughly 3-6m deep and 55-60 degrees Fahrenheit) the safest option for long term productivity and bed density.

BTS - crushed oyster shell, BTN - oyster shell and oyster castles, BTI - oyster castles, and MBE - oyster castles
Below - Study area map



Wave Reduction by Oyster Reefs

Previous studies conducted recognized the decrease in erosion in result to oyster reef restoration in collecting sedimentation but not wave reduction. This study was conducted to determine the effects of oyster reefs on wave attenuation. The study site focussed in Ramshorn Bay, VA where the coast and marsh land meet.

Process:

The waves were measured at a distance of 10 feet from each side of the four existing constructed oyster reefs of several types: crushed shell, oyster castles, and combination of shell and oyster castles in addition to a control site (no reef). The reefs ranged from depths between 0.5 to 1.5 m, while the crests ranged from 0.3 to 0.5 m beneath the sea level.

Habitat:

Though the study focused on wave attenuation rather than oyster restoration, the breakwaters successfully promoted oyster growth. Oysters covered all reefs.

Resilience:

Oyster reefs notably reduce wave heights by an average 30–50% at depths ranging from 0.5 to 1.0 m, 0 to 20% at depths ranging from 1.0 to 1.5 m, and less than 10% at 1.5 m or more. In addition, the different type of reefs performed similarly.

Lessons:

Conditions are critical for breakwater success in oyster reefs. Oyster reefs have the ability to reduce wave size in shallower conditions: 0.5 to 1.0 meters. In addition shorelines with larger edge scarps (higher wave energy) require more aggressive strategies to protect shorelines.

http://www.a-npdc.org/wp-content/uploads/2018/12/Wiberg2018E_C_WaveAttenuationByOysterReefs.pdf

Aerials of Island Restoration
Photo: https://earthobservatory.nasa.gov/images/78415/a-disappearing-island-restored

Dumping of Dredge Material
Photo: https://www.baltimoresun.com/business/bs-bz-harbor-dredging-20170201-story.html

Poplar Island: Beneficial Reuse of Dredge Material

In less than 150 years, thousands of acres of land on Poplar Island had been lost to erosion and sea level rise. In 1998, The U.S. Army Corps of Engineers and the Maryland Department of Transportation Maryland Port Administration teamed up to create a dredged material ecosystem restoration project. The state of Maryland then began the Environmental Impact Statement process by which dredge material was hoped to be the answer to building the island back to its 1847 footprint.

Process: Dredged navigation channels in the northern Chesapeake Bay result in large quantities of sediment that need disposal. With considerable marsh degradation along the Chesapeake and acreage of wetlands being cited as a performance metric for ecological restoration, restorative efforts became a priority. To tackle the problem of excess dredge material and loss of wetlands, soil sampling began in 1998 to see if one problem could have the potential to help the other. The samples taken were tested and analyzed for moisture content, grain size, and dissolved concentrations of Carbon, Ammonium, and more.

The dredge material was then dried to a specific level to be pumped into the wetland cells depending on tidal conditions. These cells were continually monitored as the dredge was placed and seasoned within the first two years.

Habitat: Poplar Island is a tidal marsh restoration success. Despite the ammonium losses during the dredge dewatering process, the iron-associated labile phosphorous and ammonium concentrations resulted in high nutrient concentrations specifically beneficial to plant growth. Beyond the successful support of vegetative growth, Poplar island is now home to over 224 species of bird that have been identified on site as well.

Resilience: Poplar Island has been a project that has successfully restored almost 300 acres of wetlands to date. This island not only provides a habitat solutions, but also protection against storm surges and more.

Lessons: Wetland restoration by use of dredge materials can be a successful project if specific conditions are met. For a project similar to Poplar Island to become a success, fine-grained dredge material free of contaminants must be used for the creation of tidal wetlands. With proper sediment testing, moisture levels, soil types, pH, and more, it is feasible to restore a tidal wetland by use of dredge material.

https://link.springer.com/content/pdf/10.1007/s13157-020-01294-5.pdf

http://www.poplarislandrestoration.com/

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