*November 2023*

Middle Peninsula Planning District Commission

# NEXT GENERATION MODERATE ENERGY SHORELINE PLAN DEVELOPMENT FINAL REPORT

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*The views expressed herein are those of the authors and do not necessarily reflect the views of the U.S. Department of Commerce, NOAA, or any of its subagencies.*

## Executive Summary

Coastal regions must evolve shoreline planning and designs based on ever changing public need driven by Federal, state, and local governmental priorities, socio-economic need, and environmental protection. Regarding Federal priorities, the Middle Peninsula (specifically the York-Piankatank-Mobjack Bay system) has been identified by the U.S. Army Corps of Engineers (USACE) and the National Oceanic and Atmospheric Administration (NOAA) as an area of special interest for the restoration of coastal resources that support resilient shorelines. USACE and the Commonwealth of Virginia have stated in the Chesapeake Bay Watershed Comprehensive Plan that the York-Piankatank-Mobjack Bay system is a "priority sub-watershed" for coastal habitat restoration. In addition, NOAA has designated this location as a Habitat Focus Area with an emphasis on supporting climate resilient nearshore habitat demonstration projects and oyster restoration. From a state level, recent changes to the Code of Virginia to establish living shorelines as the default rather than the preferred alternative for shoreline protection (see Sidebar to right) has also shifted the policy focus toward promoting resiliency through nature-based solutions. Accordingly, Virginia shoreline planning must evolve to find a new balance between water quality, habitat enhancement, and resiliency protection.

Over time, living shorelines have become the preferred shoreline management strategy for scientists and management professionals and are now the required best management strategy for shore protection in Virginia. The first element of this project was a literature review which was intended to determine best practices for their design and installation. Many technological advances in the field of shoreline management are presently occurring in many areas including remote sensing and modeling, as well as the development of innovative technologies. Living shorelines are being designed to maximize in equal parts both their shoreline protection capabilities and their enhancement of the local ecosystem.

The second element of the project was to develop a next generation shoreline management plan for a moderate energy setting which is intended to serve as a template for other shorelines with similar wave energy regimes. In part, the plan focused on how to balance cost-effective shore protection and habitat goals that recognized the priorities and preferences of the property owner. Finally, with the passing of HB 1322, the plan utilized and incorporated the new modified definition for "other structures and organic materials" within living shorelines permit process. Simultaneously, MPPDC staff contracted with Consociate Media to document the story and lessons learned, as the third and final element of the project.

### Living Shoreline Legislative Changes in Virginia

During the 2022 General Assembly session, HB 1322 was passed which modifies the definition of "other structural and organic materials" in §28.2-104.1. Living shorelines; development of general permit; guidance. The bill modifies the definition to read, *"Other structural and organic materials" means materials or features that provide added protection or stability for the natural shoreline habitat components of a living shoreline that attenuate wave energy and do not interfere with natural coastal processes or the natural continuity of the land-water interface. "Other structural and organic materials" may be composed of a variety of natural or man-made materials, including rock, concrete, wood fiber, oyster shells, and geotextiles; however, structural features shall be free from contaminants and shall be adequately secured to prevent full or partial dislodging or detachment due to wave action or other natural forces.* This definition modification will be used and considered in the development of a shoreline plan and design for a moderate energy shoreline. As this broadens the definition, it simultaneously boards the scope and spectrum of management options.

# Introduction

With funding through NOAA and the Virginia Coastal Zone Management Program (Virginia CZM), a next generation shoreline management planning process was developed and piloted for one public project.This effort consisted of an expanded research and literature review whitepaper, the development of a shoreline management plan design for a publicly owned property with a moderate to low wave energy setting, and project documentation and educational materials summarizing the effort. This report will touch on these three products of this project.

# Product #1: Next Generation Moderate Energy Shoreline Plan Whitepaper

MPPDC staff contracted with the Virginia Institute of Marine Science (VIMS)'s Shoreline Studies Program (SSP) to apply the lessons learned from the white paper developed in Year 1 of the project (FY21), update the whitepaper with information relevant to a medium or moderate energy setting, and expand on key factors involved in the planning process such as cost, affordability, and property rights. The whitepaper is included as **Appendix A**.

The whitepaper consisted of a literature review of historic and recent research for shorelines in the Chesapeake Bay. The purpose of the literature review was to survey the use of technology, modeling, alternative materials, novel and proprietary products, and innovative nature-based mitigation in the planning process for engineered shoreline protection with ecological benefits on high and medium energy shorelines. It examined the ideas, tools, and materials that are being used successfully in developing resilient shoreline management planning with a specific focus on 1) physical performance of shoreline protection, stabilization, and erosion control, 2) innovation, ease/efficiency of construction and implementation, and cost 3) innovative and/or improved monitoring methods using both emerging technology and traditional approaches, and 4) the future of living shorelines and the shift to putting them in the forefront of coastal resiliency.

The goal was to determine the best practices for proven shore protection that balances habitat restoration, shoreline protection, cost, and coastal resiliency in Chesapeake Bay and to map the future of living shorelines and their use as the emerging preferred strategy for coastal resiliency. In addition to traditional and current practices, innovative nature-based mitigation measures were also examined in the literature. The thrust of this project was hybrid structural living shorelines, so low energy/non-structural shore protection methods generally were not examined except on a case-by-case basis. Peer-reviewed scientific articles and grey literature, with an emphasis on research from the last five years, was reviewed and summarized for this comprehensive report.

This is the summary of literature reviewed over the course of this two-year project. For the first year, strict boundaries were created for determining what papers would be reviewed. This eased into the initial search for information due to the overwhelming amount of literature in the field. Additional literature types and topics have built upon this information in the second year of the project, particularly with regards to physical performance and materials.

## Product #2: Next Generation Shoreline Design

MPPDC contracted with VIMS's SSP to develop a next generation shoreline design of a moderate energy setting using the shoreline "plate" that VIMS created in Year 1 of the project but for a moderate to low energy site. Staff MPPDC staff selected and Virginia CZM staff approved a recently acquired ~100-acre waterfront property owned by the Middle Peninsula Chesapeake Bay Public Access Authority (MPCBPAA). The property is an addition to the MPCBPAA-owned Captain Sinclairs Public Recreational Area in Gloucester County on the Severn River. VIMS SSP staff completed a remote site assessment of the property including compiling of existing data, studies, etc. and conducted field work including aerial photography and LiDAR elevation surveys. All remote and field assessments were compiled, and a series of shoreline and habitat management alternatives were presented to MPPDC staff (who serve as staff for the MPCBPAA) for consideration. MPPDC/MPCBPAA staff selected to have VIMS design for a phased shoreline protection approach, prioritizing the moderate energy shoreline locations first before later protecting the lower energy shorelines as well as thin-spraying dredged sediment into the interior of the tidal marsh complex at the site. The final designs and draft Joint Permit Application were finalized and are included in **Appendix B**.

## Product #3: Project Documentation and Promotion

MPPDC staff contracted with Consociate Media to develop a presentation and video summarizing the next generation shoreline management process. The materials will be incorporated in the MPPDC Fight the Flood (FTF) website (www.FightTheFloodVA.com) and utilized in local, state, and regional meetings to highlight the outcomes and importance of the process with the intent to educate local contractors, property owners, and potential future funders of this work and what a project like this entails. Furthermore, it is anticipated that these materials can also help with the local transfer of knowledge as well as transferability to other coastal communities. The presentation is included as **Appendix C** and the video may be viewed here. Additionally, VIMS SSP staff developed a presentation for a regional conference summarizing their efforts in the project. This presentation is included as **Appendix D**.

# Appendix A: Living Shorelines and Shoreline Management in Chesapeake Bay Research Literature Review: 2018-Present

# Living Shorelines and Shoreline Management in Chesapeake Bay Research Literature Review: 2018-Present

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**September 2023**

# Table of Contents

# 1 Introduction

The purpose of this literature review is to survey the use of technology, modeling, alternative materials, novel and proprietary products, and innovative nature-based mitigation in the planning process for engineered shoreline protection with ecological benefits on high and medium energy shorelines in Chesapeake Bay. It examines the ideas, tools, and materials that are being used successfully in developing resilient shoreline management planning with a specific focus on 1) physical performance of shoreline protection, stabilization, and erosion control, 2) innovation, ease/efficiency of construction and implementation, and cost 3) innovative and/or improved monitoring methods using both emerging technology and traditional approaches, and 4) the future of living shorelines and the shift to putting them in the forefront of coastal resiliency.

The goal is to determine the best practices for proven shore protection that balances habitat restoration, shoreline protection, cost, and coastal resiliency in Chesapeake Bay and to map the future of living shorelines and their use as the emerging preferred strategy for coastal resiliency. In addition to traditional and current practices, innovative nature-based mitigation measures will be examined in the literature. The thrust of this project is hybrid structural living shorelines, so low energy/non-structural shore protection methods generally will not be examined except on a case-by-case basis. Peer-reviewed scientific articles and grey literature, with an emphasis on research from the last five years, was reviewed and summarized for this comprehensive report.

Over time, living shorelines have become the preferred shoreline management strategy for scientists and management professionals and are now the required best management strategy for shore protection in Virginia. This literature review is intended to determine best practices for their design and installation. Many technological advances in the field of shoreline management are presently occurring in many areas including remote sensing and modeling, as well as the development of innovative technologies. Living shorelines are being designed to maximize in equal parts both their shoreline protection capabilities and their enhancement of the local ecosystem.

This is the summary of literature reviewed over the course of this two-year project. For the first year, strict boundaries were created for determining what papers would be reviewed. This eased into the initial search for information due to the overwhelming amount of literature in the field. Additional literature types and topics have built upon this information in the second year of the project, particularly with regards to physical performance and materials.

# 2 Methods

Hundreds of peer-reviewed scientific articles and grey literature, almost entirely from 2018 to present, were reviewed to determine if the data they contained were within the guidelines for this literature review. For those that passed the initial review, a deeper dive into the relevancy of the data occurred. Those that passed the second review were summarized and annotated (Appendix A) for information regarding emerging and proven strategies, technology, designs, and general knowledge regarding nature-based shoreline management. The performance of these strategies as compared to traditional methods was investigated, as well as their benefits to both humans and the ecosystem and their successes and problems, both documented and theorized. The literature was grouped based upon general categories and analyzed for keywords and study location. A total of 125 pieces of literature were analyzed for this literature review, where the three most prolific categories were Marsh Habitats (17.8%), Designing Living Shorelines (9.3%), and Shoreline Planning (7.6%) (Figure 1). Of the associated keywords in this study, the three most common were “erosion” (53.3%), “vegetation” (40%), and “saltmarsh” (40%). All of the keywords analyzed in the study are located in Figure 2. The three most common locations of papers analyzed in this study were Chesapeake Bay (33.1%), US Southeast Atlantic (18.6%), and Unknown/Unspecified (15.3%) (Figure 3).

Several common trends have appeared during this literature review. The most prominent is that research focused on assessing the physical performance of living shorelines on shoreline protection primarily measures wave attenuation, as reducing the energy impacting the shoreline from waves is one of the most effective forms of protection. Similarly, much of the research measuring wave attenuation also measures sediment retention, as the two are linked in terms of creating a resilient coastal management system. Another common trend is that hybrid structural living shorelines are the most common form of living shoreline being studied for physical performance, and oyster structures are by far the most common structure being researched, though their materials and designs vary widely. Finally, during the process of this literature review, it became apparent that the environmental and ecological effects of living shorelines are the primary focus of living shoreline research, as there are far less papers focused on their physical performance.

This literature analysis began by creating an outline of topics, keywords, and general categories to research. This outline was used to create an online Google Form which served as a database to store and categorize the literature researched. Research was conducted largely on primary, peer-reviewed journal articles (82.5%) along with some gray literature (17.5%) sources. These sources were found by searching specific topics and keywords across several online literature databases, and sources were largely limited to a date range of 2018 to present. Once a potential source was found, the abstract was read to determine if it was useful for this analysis. If the source was deemed of interest, it was read in its entirety, after which it was formatted as a reference into a Microsoft Word document along with a one to two paragraph summary of its contents. Afterwards, an entry in Google Forms was completed wherein the source’s reference and summary were entered, along with standardized categorical data such as its general topic and study location.

Once the gathering of sources was completed, the Google Forms database was analyzed for the statistics mentioned above, and the Word document was entered into an analysis software called dedoose (https://dedoose.com/), a collaborative, inexpensive web-based application for qualitative researchers. This software allows researchers to code keywords and topics so that sources could be easily recalled to aid in creating this report. The sources were grouped into general topics that serve as the section headings below, where they were reviewed for patterns and consensuses in order to create the summary of next generation living shoreline research that is this report.

Structure names and system types varied significantly throughout the literature. This report groups the structures researched in this literature review into, generally, two types of systems:

Hybrid living shorelines which consist of sand and plants with structures in front to provide wave attenuation, typically made from rock, that protect the placed sand and planted marsh. These systems are generally called marsh sills in low to medium energy areas and attached headland breakwaters in medium to high energy areas. They are considered hybrid gray/green structures (Figure 4). They create, restore, and protect marsh habitat, and the structures provide additional hard surface for shellfish establishment and intertidal pore space for small fauna. Generally, the headland breakwaters were not a focus of this study, as much of the living shoreline research utilized was geared toward rocks sills with marsh rather than higher energy beaches.

Intertidal oyster reef sill which consists of some type of structural unit placed along the shoreline as sills (Figure 4), generally in the intertidal zone, that is designed to attenuate waves and create oyster habitat. The units placed varied greatly from smaller oyster bag sills that were placed by hand to larger concrete units that require machinery for installation. This made it very difficult to compare systems. Some systems also included sand and plants.

As noted, the actual systems built and monitored varied greatly. The authors did their best to ensure comparisons were of like systems.

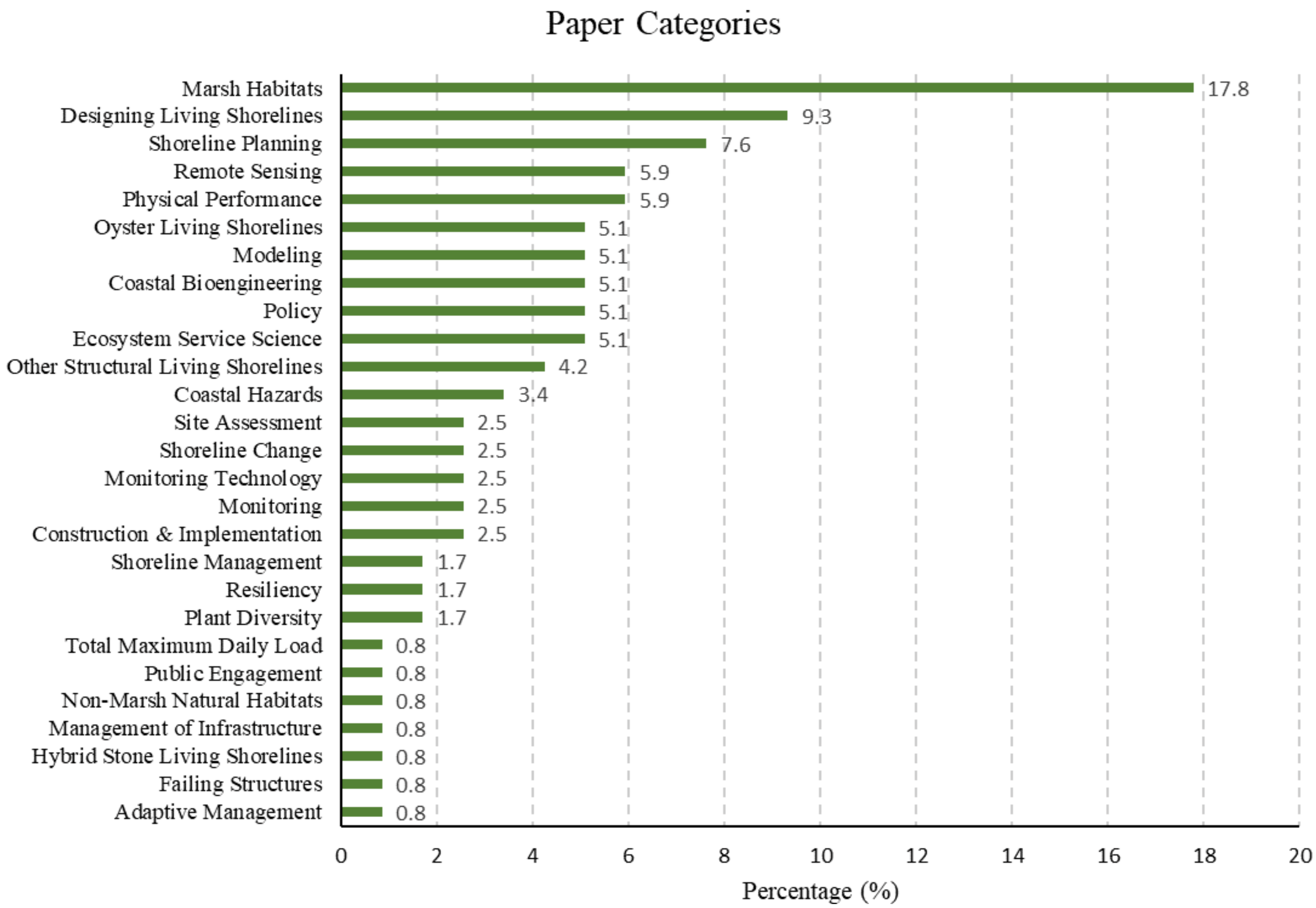


*Figure 1. The percentage of papers analyzed under each category.*

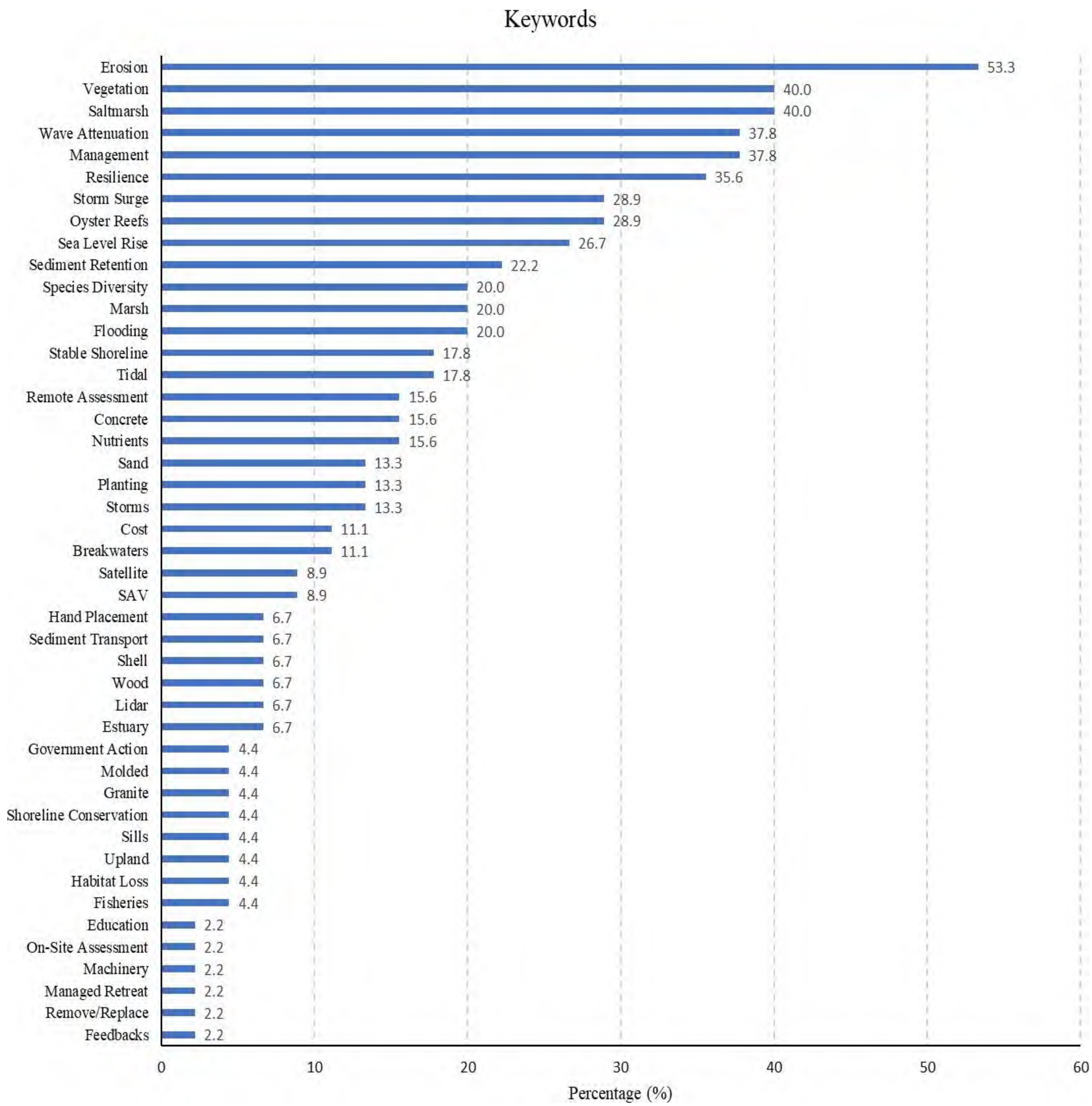


*Figure 2. The percentage of papers that contained each keyword. (Note: percentages do not total 100%, as they are based on the percentage of papers that contain the keyword, and many papers contain multiple keywords.)*

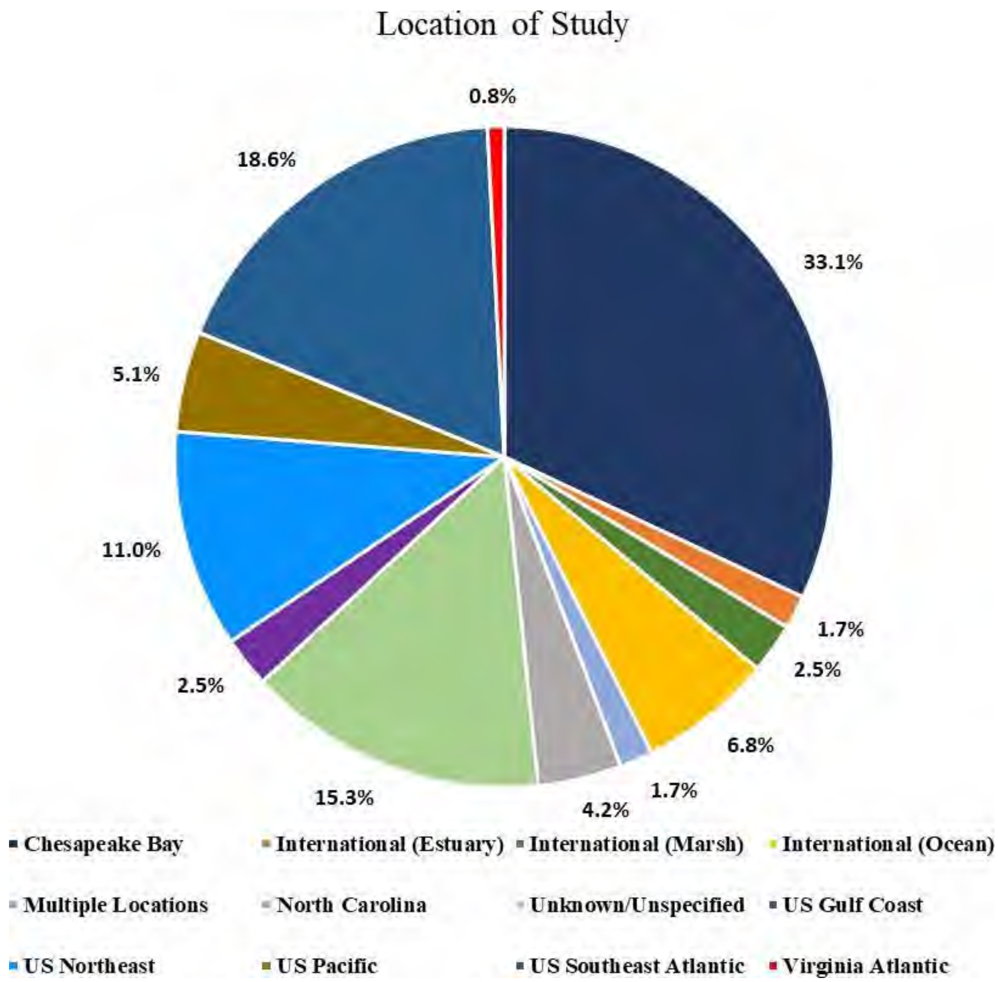


*Figure 3. The percentage of papers who research was conducted in each location.*


*Figure 4. Coastal Shoreline Continuum and Typical Living Shorelines Treatments. From https://www.fisheries.noaa.gov/insight/understanding-living-shorelines*

# 3 Results

## 3.1 Coastal Resiliency

Sea level rise remains the biggest threat to shorelines and coastal communities and infrastructure. It is becoming increasingly clear that sea level rise trends are likely to exceed previous predictions, though the extent of by how much still remains unclear. It is predicted in the coming decades that sea level rise and climate change will cause more frequent and extreme coastal flooding, as well as more frequent and extreme storm surges, which, combined with greater coastal tidal inundation, pose a serious threat to coastal resilience that existing infrastructure is not equipped to handle (Kyzar et al., 2021; Shen et al., 2022).

Based on multiple studies of current shoreline protective structures, especially in the Chesapeake Bay, the majority of existing structures are “hard” structures like bulkheads, riprap, etc. Landowners who are proponents of these methods do so due to their lower cost and familiarity, as multiple studies showed that private landowners are most likely to choose the same type of structures as their neighbors or community (Stafford & Guthrie, 2020). However, the choice of using living shorelines has become more popular in recent years (Smith et al., 2020), and the same tendency for neighbors to choose similar structures applies to them as well (Stafford & Guthrie, 2020). Similar studies on public lands show that tax payers tend to choose the most “natural” and “physically appealing” strategies as their preferred method of shoreline stabilization and management, with one studying finding that a 3/4ths majority said they would be willing to pay additional taxes for the use of these stabilization methods on public beaches (Charbonneau et al., 2019). That being said, shoreline hardening structures are still the most commonly chosen form of coastal protection, especially by private landowners in the Chesapeake Bay region (Stafford & Guthrie, 2020).

Many studies discuss their findings that hybrid living shoreline systems perform better at shoreline stabilization than hardening structures, as well as provide benefits to the surrounding ecosystem. Hardening structures, especially bulkheads, often cause more erosion to the nearshore in front of the structure through wave reflection. This not only disrupts the benthic ecosystem (Prosser et al., 2017), but also causes the eventual failure of the structure due to instability of the sediment beneath it, as well as water infiltration behind it (Takahashi et al., 2022). Oppositely, living shoreline systems provide shoreline stability (Polk et al., 2018; Safak et al., 2020a), as well as increase the health of the ecosystem; primarily by providing invertebrate and marsh habitat to be the base of a coastal food chain (Davenport et al., 2018), and allowing for more unrestricted access to the marsh surface for marine fauna (Guthrie et al., 2022).

## 3.2 Habitats

While living shoreline systems have been used in a variety of habitats such as cobble beaches (Komar & Allan, 2010; Winters et al., 2020; Bayle et al., 2021) and mangroves (Spiering et al., 2021), the vast majority are constructed as saltmarshes. As such, much research has been done on the ability of hybrid living shorelines to function as a natural marsh system. In terms of ecosystem functions and effects on local fauna, the consensus among the literature is that hybrid living shorelines function similarly to natural marshes once they have become established, which can take anywhere from 1 to 10 years (Spiering et al., 2021). For example, established living shoreline system soils contain similar nutrient contents and carbon storage to those of natural marshes (Chambers et al., 2021); however, and most likely due to the sand used to create them (Bilkovic et al., 2021), hybrid living shoreline marshes tend to have lower soil organic content (Chambers et al., 2021; Isdell et al., 2021), which some research suggests can have an effect on benthic organisms (Bilkovic et al., 2021). Established living shoreline vegetation also functions similarly to that of natural shorelines in terms of wave attenuation (Cohn et al., 2021) and can even function better if it is fronted by a structure such as a sill or oyster reef (Hogan & Reidenbach, 2022). Established living shoreline marshes also have statistically similar amounts of biodiversity and species density to natural marshes in terms of marine and coastal fauna (Smith et al., 2021; Guthrie et al., 2022). Finally, established living shoreline marshes function similarly to natural marshes in terms of sediment retention and erosion control (Polk et al., 2018) and may even perform better if they are fronted by a structure (Safak et al., 2020a).

One threat to living shoreline marshes, especially before they become established, is the erosion of sediment from the marsh surface before the planted vegetation establishes an extensive root mat (Spiering et al., 2021). Another is herbivory of the vegetation by fauna, especially crabs, which are not deterred by the goose fencing normally used to protect newly-planted vegetation. Multiple studies showed that crab herbivory of marsh grasses can cause huge die-offs of vegetation, which in turn leads to significant amounts of erosion, even among established and natural marsh habitats (Holdredge et al., 2009; Beheshti et al., 2021). Further research into the control of herbivory is needed.

The literature is largely in agreement on the ecological benefits of living shorelines. They perform significantly better in terms of providing habitat and increasing ecosystem health than traditional hardening structures, and, given enough time, perform just as well as natural marshes (Guthrie et al., 2022). There is also the question of how living shoreline marshes will perform into the future as sea level rises. Though many consider living shorelines as a relatively new management strategy, with researchers looking back no more than 10-15 years (Chambers et al., 2021), older sites do exist in Chesapeake Bay and have shown the efficacy of these systems over longer time frames (Hardaway et al., 2018; Hardaway et al., 2019; Milligan et al., 2021).

## 3.3 Site Assessment and Monitoring/Emerging Technology

On-site monitoring and surveying are still common, but substantial research is being done regarding the use of remote sensing and modeling for site assessment and monitoring. Several computer programs have been developed and are currently being tested to use aerial and satellite imagery to automatically detect, map, and track shorelines and shoreline change. These programs have not yet been used extensively, but they are showing promising results such as being able to determine waterlines faster and more accurately than conventional aerial photo analyzations (Awad & El-Sayed, 2021), calculating pixel-based tide heights of imagery (Bishop-Taylor et al. 2021), identifying existing structures (Nunez et al., 2022), and automatic, large-scale shoreline mapping and end point rate calculations (Almeida et al., 2021). Some of these programs can even be used with free software such as Google Earth Engine. There are even programs in development that automatically calculate marsh vegetation coverage from photos (Welch et al., 2021).

Research is also being done into modeling, primarily risk assessment and predicting future coastal hazards. For risk assessment, the models take a variety of factors into consideration, such as socio-economic factors, land use, historical and current flooding, and existing shoreline infrastructure to determine which areas are of highest importance in regards to shoreline protection strategies (Rangel-Buitrago et al., 2020). The coastal hazards models use previous flooding and storm surge trends (Smith & Scyphers, 2019) in combination with different sea level rise predictions (Mitchell et al., 2021) to determine the areas and severity of future flooding, as well as potential conditions of and future impacts to marshes and beaches (Andrews, 2020).

The emerging remote sensing and modeling technology is promising and has produced significant results in testing. However, little, if any, of it has been used in real-world applications for designing real management plans and protective infrastructure yet, as most projects are still in testing phases. That being said, there have been significant recent developments in technology for shoreline assessment, monitoring, and hazard predictions. Most of these developments allow for fast and automated results via computer programs, and they have been extremely accurate in testing. They may provide the tools for faster, more accurate, and more efficient shoreline management and protection plans, as well as help to prepare for future hazards.

Additional novel methods of remote monitoring and modeling were found during this literature review. Several articles outlined the use of unmanned aerial vehicles (UAV), or drones, to take aerial photography of shorelines in order to create extensive and detailed digital elevation models (DEM), digital terrain models (DTM), digital surface models (DSM), and orthoimagery (Winters et al. 2020; Young et al., 2021). Young et al. (2021) even used the construction of a living shoreline to test the accuracy of determining shore change via drone imagery, finding that the estimates using drone imagery were within 3% of the actual known fill material amount. Continual research is occurring regarding the use of computer modeling to more easily and more accurately determine things like shoreline change rates, habitat coverage, coastal vulnerability, and potential living shoreline sites. One study found that using satellite imagery from the US Geological Survey and the digital shoreline analysis system (DSAS) tool in ArcGIS could accurately determine the net change of small-scale living shoreline sites in $m^2$/year (McClenachen et al., 2020), while another conducted tests in DSAS using a variety of statistical methods to determine that using the weighted linear regression rate (WLR) provided the most accurate method of predicting shoreline change (Ciritci & Turk, 2020).

Meanwhile, other researchers are creating programs to aid in shoreline management. The researchers in Nunez et al. (2022) created a modeling system called the Shoreline Management Model that runs as an ArcGIS tool and uses inputs such as habitat type, bank elevation, nearshore bathymetry, and fetch to determine the best management practice, which was found to agree with on-site assessments 82.5% of the time. One set of researchers developed a model that determines whether areas of shorelines are acceptable candidates for non-structural or hybrid living shorelines (Young et al., 2023), while another discovered they could use ArcMap and modified least-cost analyses to use elevation data to predict the most-likely pathways of floodwaters in order to determine high-risk areas most in need of conservation, restoration, or construction of natural wetlands or living shoreline systems (Hendricks et al., 2023).

## 3.4 Design

There are many different designs for living shoreline protection systems that have been tested in the literature for a variety of habitats. On the west coast, where cobble beaches are common, some researchers have designed and implemented living shorelines consisting of constructed cobble berms fronted by sand dunes and filled in behind by vegetated sand dunes in a variety of energy environments to mixed results (Komar & Allan, 2010; Winters et al., 2020; Bayle et al., 2021). In some marsh areas of the US and Europe, designs utilizing walls or fences made of stacked wood debris and branches have been used, resulting in some success at wave attenuation, but poor results in longevity of the structures before needing to be rebuilt (Safak et al., 2020a).

The most common and researched living shoreline designs, especially in the Chesapeake Bay and the western Atlantic as a whole, consist of a sand-fill marsh surface planted with native vegetation and fronted with either stone or otherwise hardened material sill or breakwater (hybrid gray/green systems), or oyster reef sill structures placed in the intertidal zone. In terms of wave attenuation, sediment retention, and erosion control, hybrid living shoreline systems that utilize sill or breakwater structures in conjunction with sand and vegetative plantings tend to perform well in a variety of wave energies and tide ranges and can function just as well as, if not better than, traditional hardening structures (Smith et al., 2018), though research directly comparing the performance of living shorelines to traditional structures is lacking (Smith et al., 2020). Additionally, some preliminary studies show that living shorelines provide better shoreline stabilization in the face of extreme storm events than natural marshes and traditional hardened shorelines (Hardaway et al., 2005; Smith et al., 2018).

Intertidal oyster reef living shorelines are a much more complex issue, however. This is largely due to the fact that there is no standard construction of oyster reefs in living shoreline systems or in general, and, as such, there are many different designs, substrates, and strategies that have a wide range of success and effectiveness (Morris et al., 2021). Some of the reef structures are proprietary units and may not be widely used beyond a certain local area. Many studies have been done in order to determine which designs are the most effective at both establishing oyster reefs and shoreline protection. Studies show that a variety of substrates are capable at growing significantly-sized reefs, such as oyster bags (Milligan et al., 2018), concrete (Lipcius & Burke, 2018, Goelz et al., 2020), limestone (Goelz et al., 2020), and recycled crab traps (Johnson et al., 2019). In terms of shore protection, large and sturdy structures like concrete and rock provide better immediate results, especially in larger fetch areas, but are often placed outside of suitable oyster habitat and become less effective over time due to structural degradation and lack of natural reef. Conversely, reefs that are designed for optimal oyster settlement and development do not initially provide satisfactory shore protection, but over time may provide steadily-increasing protection as the reef develops (Morris et al., 2019). However, it does not eliminate erosion, only mitigate it. Therefore, it is less practical to develop a “standard” design for oyster reefs. However, standardizing the design process for reef systems to best fit the specific environment they will be placed in to maximize oyster settlement and growth will create the best long-term solution (Morris et al., 2019; Chowdhury et al., 2021).

Many living shoreline designs that have been researched produced mixed results as to their effectiveness at shoreline protection and resilience. Hybrid designs consisting of planted marsh and beach vegetation fronted by structures provide the best and most predictable shoreline protection, but some systems may be lacking in their initial ecological benefits, though studies have shown they tend to mimic natural systems as they mature. Living shorelines utilizing intertidal oyster reefs can also provide ecological benefits, but their designs vary widely and their effectiveness even more so, making it difficult to quantify. Many researchers agree that some standard designs are needed, but they are not in agreement as to what those designs should be. Additionally, research shows that the most effective long-term solution for shore protection and oyster recruitment is not a standard design (Vien, 2020), but instead site-specific designs optimized for wave and bank conditions. This is especially important for oyster settlement and growth, as local conditions can vary such that spat are not available to settle on structures. In general, understanding specific site conditions is essential to the shore protection design process overall, and will ensure longevity and ecological function of the system (Hardaway et al., 2021).

Based upon the available literature, living shoreline design innovation is flourishing, but only in lower-energy environments. The majority of novel designs and materials are being tested and implemented in low-to-moderate energy environments, as they tend to be at best ineffective, and at worst structurally fail, in higher-energy environments (Safak et al., 2020a; Baldauf, 2021). Some novel designs currently being researched include modular designs such as the "SEAHIVE" sea wall; modular hollow, porous concrete structures that can be round, rectangular, or hexangular with varying sizes and numbers of perforations. The structures are made of low alkalinity, fiber reinforced concrete (FRC) and non-corrosive rebar to avoid both structural degradation and environmental pollution. The structures can be topped with or front a sand fill and vegetation living shoreline. The structures are being tested in a wave tank system at the University of Miami under conditions similar to those found in locations around Florida, as well as storm conditions ranging from tropical storm to category 5 hurricane. Research is currently ongoing in order to develop maximum efficiency designs for a variety of wave energy environments (Ghiassian et al., 2019). Other novel modular designs include 3D printed or molded concrete structures, biodegradable substrates, and shaped wire structures. One type of unit being field tested in a high-energy environment are 3D printed Natrx modules at Hog Island in the York River, Virginia. Each module weighs about 1 ton and are stacked two on the bottom and one on top. Monitoring is ongoing to see how they perform in terms of shore protection and habitat restoration. It should be noted, however, that "SEAHIVE," Natrx, and the majority of the other novel products have yet to be used in a wide scale and only have recent installations.

## 3.5 Physical Assessment of Living Shoreline Designs and Materials

The most commonly researched topic of living shoreline physical performance is wave attenuation, or how well they are able to dissipate wave energy and reduce its impact on shorelines. The most commonly researched type of living shoreline, in terms of both wave attenuation and in general, is the constructed intertidal oyster reef living shoreline. However, even though this living shoreline form is the most researched, it does not appear to be the most effective at wave attenuation. When comparing the rates of wave energy reduction between different forms of hybrid living shorelines, hybrid gray/green systems performed the best and most consistently (Kerr et al., 2020; Leone & Tahvildari, 2022), with rates averaging around 40% to 50%. Intertidal oyster reef living shorelines can also perform well in reducing wave energy, with attenuation rates comparable to and even exceeding those of hybrid gray/green systems (Spiering, 2019; Spiering et al., 2021), but performance varies widely among them, primarily due to inundation levels and height of the structures. Oyster structures that are built to extend above the water line perform better at reducing wave energy; however, these structures are not conducive to facilitating oyster growth (Salatin et al., 2022). One study found that the minimum amount of inundation time experienced by oyster reefs that could still be considered suitable oyster habitat was 50%, but that amount of inundation time did not significantly attenuate waves (Morris et al., 2021). A number of studies even found that if oyster reefs are inundated a majority of the time, not only are they not effective at wave attenuation, but they can actually increase wave energy impacting the shoreline (Zhu et al., 2020a; Spiering et al., 2021; Bredes et al., 2022). Another study found that oyster reefs placed closer to the shoreline in the intertidal zone performed better at wave attenuation, but worse at sediment retention than reefs placed further from the shore in deeper water, though this was a microtidal environment (Vien, 2020). In general, intertidal oyster reef living shorelines can be an effective strategy, but they seem to work best in lower-energy environments with small tidal ranges.

Some novel hybrid living shoreline designs are being researched as well. These designs primarily consist of using either wood and branches or coir logs to create breakwalls and sill structures. The wood and branch breakwalls experienced widely-varying rates of wave attenuation based on porosity and inundation. In one study, a stacked branch breakwall system with a low porosity achieved a wave attenuation rate of up to 47%, but overall rates varied widely with water levels. Increasing the porosity greatly reduced variations, but also greatly reduced attenuation rates (Safak et al., 2020b). In another study, stacked branch breakwalls were placed in front of constructed oyster reefs, but were ultimately deemed too porous to be effective. The researchers determined the ideal porosity to maximize sediment retention and wave attenuation was 0.25, but also noted this would essentially be considered a hardened system similar to a bulkhead, and therefore experience problems such as toe scouring (Herbert et al., 2018). Another study used two novel strategies; the first being coir logs filled with oyster shells and stacked to act as sills, with the idea being that, as the coir logs broke down, the oyster shells would begin forming a reef, and the second being stacked branch breakwalls fronting traditional coir logs to form a “T” shape. The oyster and coir log sills performed similarly to traditional coir log sills, but the “T” shape designs were broken by waves almost immediately (Baldauf, 2021). Finally, one study focused on using aquaculture methods as living shoreline systems. They tested both a cantilever-beam model to represent kelp-growing aquaculture systems, and a floating buoy and anchor system to represent mussel aquaculture systems. The kelp-inspired system was limited by fluctuating water levels and storm events, but the mussel-inspired system moved with water levels and performed far better at wave attenuation, leading the researchers to consider it as a possible viable living shoreline design (Zhu et al., 2020b).

Overall, living shoreline systems in general provide some form of shore protection, and many systems have been shown to significantly slow or even reverse erosion. In one study by Polk et al. (2018), 12 of 17 living shoreline systems spanning a variety of habitats showed significant reductions of erosion, and 6 had even started accreting sediments. Other research showed that even in the face of severe weather such as a hurricane, living shoreline systems not only survived, but all sites included in the study significantly reduced erosion during the storm event when compared to neighboring control sites (Hardaway et al., 2005; Polk, et al. 2021). Based on this literature review, hybrid living shoreline systems, especially hybrid gray/green systems, provide the best protection and stabilization of shorelines, especially in higher-energy environments. When considering a design for a living shoreline system, a variety of factors such as wave energy and water levels should be considered, but perhaps most importantly, a living shoreline system should be built to mimic and enhance the natural processes of the environment to have the best chance of providing a resilient shoreline protection system well into the future (Mitchell & Bilkovic, 2019).

## 3.6 Construction and Implementation: Materials, Methods, and Cost

The general design for a living shoreline consists of sand fill and planted vegetation. Usually, some form of structure is added either directly in front of the plantings (hybrid gray/green systems) or in the intertidal zone (oyster reefs) to help reduce wave energy impacting the shoreline. The typical process of constructing a living shoreline involves constructing and placing the structures, if applicable, either by hand or with machinery, filling and grading the area with sand, and planting native vegetation (Hardaway et al., 2021). It is recommended to fertilize each individual planting with a high nitrogen content, slow-releasing fertilizer to both ensure healthy vegetation and increase vegetation density for improved shoreline protection, as the sand fill used in living shorelines usually lacks the essential nutrients to facilitate plant growth (Priest, III, 2017; Currin, 2019).

When compared to traditional hardening methods for shoreline protection, living shorelines can be a significantly cheaper option, especially when longevity is considered. Traditional methods are expensive due to a variety of factors such as cost of materials and fabrication, cost of installation, and recurring repair costs. The cost of living shorelines has a larger range, as they can vary from relatively cheap options such as hand-placed coir logs and oyster castles to more expensive designs like granite hybrid gray/green systems. As such, cost of materials and installation can be cheaper than, or similar to, traditional methods on a per-unit basis, but when compared on a project-sized scale, living shorelines are a clearly cheaper option, and can cost a fraction of what traditional hardening structures would. In addition, the average lifespan of a traditional hardening structure such as a bulkhead is estimated to be approximately 25 years, whereas, though currently indeterminate, structural living shoreline systems such as oyster reef and hybrid gray/green systems are estimated to be much longer (Brown, 2018; Sicango et al., 2021). Hardaway et al. (2021) showed that some systems have been functioning with minimal maintenance for 40 years in Chesapeake Bay. Similarly, traditional hardening systems are extremely vulnerable to sea level rise, as they are fixed and must be either modified or altogether replaced to adapt to rising water levels, whereas the dynamic marshes of living shoreline systems are more responsive and adaptable to sea level rise, and are capable of shifting and migrating upland with rising water levels (Sudol et al., 2020).

Finally, when repair costs are considered, living shorelines become even less expensive than their traditional counterparts. One study found the yearly maintenance of a traditional bulkhead was $31 per meter, compared to an oyster castle and planted marsh grass living shoreline that, if constructed correctly, should require little to no future maintenance. They calculated that over a 60-year period, the oyster castle and marsh grass living shoreline would save approximately $85,000 compared to a bulkhead of the same size, and that the living shoreline could have an initial cost of up to 3.25 times that of the bulkhead and still be cheaper over the 60-year time period; meaning that, even if more materials and heavy equipment are required for installation, such as in a hybrid gray/green living shoreline, the cost should still be cheaper than that of a traditional hardening structure (Sicango et al., 2021).

## 3.7 Policy

Because Virginia law requires the use of living shorelines whenever possible, much of the literature regarding policymaking to champion living shorelines over other shoreline protection methods is not pertinent to the Virginia portion of Chesapeake Bay. However, some research and suggestions into living shoreline policy may be beneficial for Virginia's consideration. These considerations may not reflect the authors' views, and are merely presented as research found during the literature review process.

For example, one article mentions the utilization of a policy where requiring existing armored shoreline areas to be flanked by living shorelines provided the ecological benefits of living shorelines to the area while reinforcing the existing structure and surrounding shoreline (Jones & Pippin, 2022). As mentioned before, even though living shorelines are becoming more popular and are now required in Virginia, the majority of protective structures are hard structures. Additionally, under current Virginia law per a 1984 Attorney General's opinion, when current hardened shoreline structures fail, generally, they can be replaced with a similar hardening system (Virginia, 1985). Jones & Pippin (2022) suggest that it would be beneficial to require these armored shorelines to be replaced with living shorelines when they begin to fail, instead of being repaired or replaced with new hardening structures.

The current policy regarding SAV set forth by the Virginia Marine Resource Commission (VMRC, 2017) states that "it shall be the Commission's policy to avoid authorization of any new structure, including aquaculture structures on unleased bottoms, and any new activity, or leasing oyster planting grounds on any SAV bed annually mapped by VIMS during at least 1 of the previous 5 years. Proposed encroachments or activities in SAV beds may be authorized by permit, if deemed acceptable, however, all mitigation measures to reduce impacts to SAV must be considered and compensation of SAV losses may be required." This means that coastal structures, including living shorelines, cannot be built in areas where they would impact SAV unless otherwise approved by the VMRC.

Research by Palinkas et al. (2017 and 2023) found that, while the construction of living shorelines did change the sediment composition in the immediate vicinity of the sites, it had no observable impact on SAV in Chesapeake Bay. Furthermore, it was found that the construction of the living shorelines actually enhanced nutrient and sediment burial due to the introduction of marsh vegetation, increasing water clarity in the coastal zone while also benefitting the benthic community. In the 2023 study, the authors even go so far as to suggest that "discouraging living shoreline installation in areas with SAV may miss an opportunity to enhance nutrient burial in the coastal zone," (Palinkas et al., 2023).

Public education, outreach, and discussion regarding shoreline management and threats to coastal communities is vital to establishing more effective policies, and has been shown to be both well-received by the public and beneficial to the process of choosing more natural solutions to shore protection (Charbonneau et al., 2019). Additionally, traditional ecological knowledge (TEK) is an important, but often overlooked, resource in the shoreline management decision-making process. One study shows how engaging with community residents provides a better understanding of an area's ecological processes, as well as specific target areas that should take priority. They tested a system to allow residents of the Pamunkey Indian Reservation to log and share areas of concern that should be included in shoreline protection efforts to reduce impacts from coastal flooding and storm events. This information can then be used alongside typical methods of shoreline management planning. The authors collected TEK data by having the residents recount hazard and socio-economic experiences, as well as identify areas of concern when presented with sea level rise maps predicting the next 60 years. These data were recorded in GIS and put into a resilience matrix. Using the information from the TEK, the management plan results focused on structural solutions to protect residences, heritage sites, and access points (Hutton & Allen, 2020).

The property rights framework may be an issue that will affect coastal managers as sea levels rise, and Virginia's public/private property line at mean low water (MLW) continues to shift. Deeds and easements based on previous shorelines will need to be addressed. One such case has been through the court system. The 2015 case of *Marble Techs., Inc. v. Mallon* considered a deed from 1936 regarding an easement in Hampton which established the property line "along present mean high water." That original line was obviously underwater by 2015, and the question of where the property line should be located was asked. The Virginia Supreme Court decided that, per the literal language of the original deed, the property line should remain at its original location of the 1936 mean high water line, despite that location now being inaccessible (Messer, 2018). As sea level continues to rise and governments work to protect the shoreline through mitigation and adaptation projects, these projects that straddle both state-owned bottomlands and privately-owned waterfront property could lead to property rights issues ending up in court.

A study conducted by interviewing members of six Virginia wetlands boards found that all 12 participants mentioned that the Shoreline Management Handbook and recommendations/guidelines from government agencies (Virginia Institute of Marine Science, Virginia Marine Resource Commission, U.S. Army Corps of Engineers, etc.) are important to their decision-making process. They also noted that the most important factors in accepting a project were confirming that detrimental erosion is occurring, no habitat destruction will occur, and there is no net loss of wetlands.

In terms of living shorelines, 5 of the 6 board chairs confirmed that living shorelines were a typical project, but some interviewees noted that landowners prefer hardening structures over living shorelines. While all interviewees responded that technical guidelines and data were important in their decision-making process, a majority also responded that compromising and avoiding conflict with property owners played an important role as well. Some interviewees also responded that previous projects and decisions factored into their decision-making process. While most interviewees admitted that social factors (compromise, avoiding conflict) affected their decisions, all responded that they believed their permit decisions were balanced between technical/environmental factors and social factors (Rawat et al., 2021).

Some issues with current shoreline management policy in the United States brought up in the literature is that much of it uses current or historical flooding, storm surge, and water level data to design management plans and structures, rather than taking future predictions into consideration, which means that these management plans will likely have to be modified or replaced in the future. One article in particular uses the fact that American political cycles occur on a 2-to-4-year basis, and that most of our policies tend to be reactive in nature as opposed to preventative, such that implementing long-term management and predictive protection policies is unattractive to government officials (Andrews, 2020) as contentious policy change can result in ongoing stresses (Brown et al., 2023).

Building upon these ideas, a paper by Brown et al. (2023) addresses the concerns of citizens and property owners regarding changes to existing coastal management policy. The authors state that updating policies and shoreline management strategies to account for future environmental conditions and shifting to more realistic goals based upon those predictions may be interpreted by concerned parties as policy makers abandoning coastal areas and infrastructure, leading to conflict and resistance from both citizens and policy makers. The authors suggest that coastal management policy should integrate publicly-available, easily-accessible information regarding current and future environmental factors that will affect a given area, a multi-scale plan for how changes to current policies will account for those factors, and outline diverse sources of funding that can be used to achieve the goals of the new policies while also remaining easily-accessible to all concerned parties in order to minimize contention when introducing policy changes (Brown et al., 2023).

# 4 Conclusions

The goals of this project were to examine the ideas, tools, and materials that are being used successfully in developing resilient shoreline management planning and to determine the best practices for proven shore protection that provide for resiliency and habitat restoration in Chesapeake Bay, as well as practices that are being researched now. Living shorelines and shoreline science as a whole currently have a great deal of new research being published. While most of the emerging new technology pertains to remote sensing and using computer programs and satellites to map, track, and analyze shorelines, innovative ideas for living shoreline designs are being developed. New research into how coastal habitats are dealing with climate change and sea level rise, and how coastal areas will be affected by rising sea level and increased precipitation and storm surges, are being researched. Scientists and managers are trying to determine what should be prioritized in terms of shoreline protection decision making, and, most importantly, how this research can be used to improve shoreline management and coastal resiliency.

The overall takeaways from this research are:

1) Different structure names for similar systems (often proprietary) and varying site-specific conditions make comparisons difficult – some standardization is needed;
2) Natural and developed coastal areas face elevated threats from climate change and sea level rise;
3) Particularly in areas where conflicts arise between users and managers;
4) Emerging technology is making it easier and more accurate to analyze shorelines to determine where problems lie and what needs to be done about them;
5) That scientists and managers can use this knowledge and technology, along with continuing research, to enhance and optimize living shoreline designs;
6) Living shorelines can be extremely effective at enhancing both coastal resiliency and ecology;
7) However, designs, materials, and strategies vary widely, as does their effectiveness;
8) With regards to the site’s energy environment, the more structural-based designs for hybrid living shorelines provide better shore protection in higher-energy environments;
9) Living shorelines work best when designed using site-specific parameters;
10) Costs generally are not published, making comparisons extremely difficult, especially for intertidal oyster reefs due to the varying systems, which are often proprietary, and differences in how the systems are installed;
11) Virginia has already made great strides in their living shoreline policy, but can continue to improve it through public involvement and possible policy considerations for implementing long-term management and predictive protection; and
12) The current laws determining coastal/riparian property ownership open up potential conflicts in the maintenance and construction of living shorelines, especially in the face of rising sea levels.

# 5 Limitations and Future Work

Research into shoreline management and, particularly, living shorelines, has grown significantly in the last few years. Living shorelines have been installed in Chesapeake Bay since the 1980s. With the Burke et al. (2005) assessment of hybrid shore erosion control projects in Maryland's Chesapeake Bay and the Living Shoreline Summit in 2006, living shoreline research has continued to grow nearly exponentially. Even with the limitations placed on the review (generally limited to research concerning Chesapeake Bay and similar environments published since 2018), it was impossible to review all the pertinent peer-reviewed, grey, and website/story map literature/case studies that are being produced. In addition, the peer-review articles tended to skew toward the biologic components of living shorelines rather than the engineering side or monitoring for shore protection. As this review is aimed at determining the efficacy of living shorelines for shore protection and coastal resiliency along generally medium and high-energy shorelines, the engineering design considerations are significant, but not highly published.

Many websites had cases studies of newer, proprietary products, but many have only recently been installed. As these systems age, more data will become available on their efficacy and best design practices. To further increase the understanding of some of these topics, more grey literature may need to be examined. However, grey literature typically is longer and takes significant resources to review, especially theses, dissertations, and project reports. As such, the number reviewed had to be limited for this paper. Another issue that needs to be addressed is that names can vary for similar types of systems. Not only do the types of oyster restoration systems vary greatly, but what they are called in the literature can be different, as many systems are proprietary and only available through one company and in one location. This means that across the board comparisons on systems were difficult to make.

In addition, scientists are increasingly diversifying the way in which their studies are communicated to the wider public and policy-makers. More online resources are becoming available as the web of knowledge becomes more complex and diverse than it was in the earliest research (Teodoro & Nairn, 2020). Though this may present a challenge to identify legitimate and useful sources of science-based information, some online information was included where appropriate, but much more information is available for further review.

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Zhu, L., Huguenard, K., Zou, Q.P., Fredriksson, D.W., Xie, D. (2020b). Aquaculture farms as nature-based coastal protection: Random wave attenuation by suspended and submerged canopies. *Coastal Engineering, 160,* 103737. doi: https://doi.org/10.1016/j.coastaleng.2020.103737

# Appendix A

Year 1 and 2 Annotated Bibliographies for Literature Reviewed

The documents are not in alphabetical order; use the find tool to locate a specific document.

## Year 1

Jones, S.C. and Pippin, J.S. (2022). Towards principles and policy levers for advancing living shorelines. *Journal of Environmental Management, 311*, 114695. doi: 10.1016/j.jenvman.2022.114695

- Using policy levers and innovation to develop optimal shoreline management strategies. Virginia requires living shorelines, so some factors are irrelevant, but the ones that still apply are building living shoreline systems in areas where a minimum percentage (10-25%) of the shoreline is already armored by seawalls, bulkheads, etc., and failing/damaged hard armor structures must be replaced with living shorelines rather than being repaired.

Li, W., Liu, H., Qin, C. (2022). A method for the extraction of shorelines from airborne lidar data in muddy areas and areas with shoals. *Remote Sensing Letters, 13*(5), 480-491. doi: 10.1080/2150704X.2022.2042616

- Researchers developed an algorithm that allowed them to use aerial lidar images to generate shorelines. This proved to be more accurate than contour tracing from normal aerial photography, especially in muddy and shoaled areas.

Bishop-Taylor, R., Nanson, R., Sagar, S., Lymburner, L. (2021). Mapping Australia's dynamic coastline at mean sea level using three decades of Landsat imagery. *Remote Sensing of Environment, 267*(15), 112734. doi: 10.1016/j.rse.2021.112734

- This paper acknowledges that one of the main difficulties of using satellite and aerial imagery to map shoreline change over years is the effect of pictures being taken at different points of tidal cycles. The researchers combatted this by using computer programs to clean image pixel data in order to remove artefacts, using the Modified Normalized Difference Water Index to accurately, reliably, and automatically extract shorelines from imagery, pixel-based tidal masking to automatically calculate pixel tide heights in imagery, and analyzing this data to create an annual median tidal composite relative to MSL.

Kyzar, T., Safak, I., Cebrian, J., Clark, M., Dix, N., Dietz, K., Gittman, R., Jaeger, J., Radabaugh, K., Roddenberry, A., Smith, C., Sparks, E. (2021). Challenges and opportunities for sustaining coastal wetlands and oyster reefs in the southeastern United States. *Journal of Environmental Management, 296,* 113178. doi: 10.1016/j.jenvman.2021.113178

- Some of the best defenses of shorelines, especially in the American southeast, are the natural stabilizing structures of marshes and coastal oyster reefs. These are becoming increasingly more threatened in the modern era due to sea level rise and coastal human development. Most southeastern coastal areas have experienced an increase in human development greater than the national average since 1996, leading to large amounts of pressure on and degradation of their marshes and oyster reefs. The researchers conclude that implementing cost-efficient low-impact development strategies, reducing eutrophication, pollution, and herbivore outbreaks, and removing or replacing shore hardening structures with living shorelines will help to reduce impacts on local marshes and oyster reefs. It stands to reason, then, that these activities would be beneficial to add to future shoreline management plans to increase the effectiveness of living shorelines.

Almeida, L.P., Efraim de Oliveira, I., Lyra, R., Scaranto Dazzi, R.L., Martins, V.G., Henrique da Fontoura Klein, A. (2021). Coastal Analyst System from Space Imagery Engine (CASSIE): Shoreline management module. *Environmental Modelling and Software, 140,* 105033. doi: 10.1016/j.envsoft.2021.105033

- Researchers are using an open-source web program known as CASSIE to map shorelines. CASSIE uses Google Earth Engine and can analyze any coastline, freshwater or ocean, anywhere on Earth. The user inputs the information they are searching for into the engine (area of interest, timeline, transects, etc), and CASSIE outputs a visual shoreline and shore data such as shore conditions and EPR rates.

Revell, D., King, P., Giliam, J., Calil, J., Jenkins, S., Helmer, C., Nakagawa, J., Snyder, A., Ellis, J., Jameison, M. (2021). A holistic framework for evaluating adaptation approaches to coastal hazards and sea level rise: A case study from Imperial Beach, California. *Water, 13*(9), 1324.

- Researchers evaluated 5 adaptation approaches (shoreline management strategies) for their effectiveness in long-term shore protection: armoring, nourishment, living shorelines, groins, and managed retreat. They found that armoring was the overall least effective method. Living shorelines provided the best public benefits, but managed retreat (defined as allowing the shoreline to gradually move inland as opposed to physically trying to hold it in place) provided the most effective long-term strategy to protect public resources.

Awad, M. and El-Sayed, H.M. (2021). The analysis of shoreline change dynamics and future predictions using automated spatial techniques: Case of El-Omayed on the Mediterranean coast of Egypt. *Ocean and Coastal Management, 205,* 105568.

- Researchers used three methods to automatically determine water/shoreline boundaries from satellite images: Tasselled Cap Transformations (TCT), modified normalized difference water index (mNDWI), and Water Index ($WI_{2015}$). These were then used to create polygons in ArcGIS of either water or non-water, which were then analyzed for EPR rates in DSAS.

Fitton, J.M., Rennie, A.F., Hansom, J.D., Muir, F.M.E. (2021). Remotely sensed mapping of the intertidal zone: A Sentinel-2 and Google Earth Engine methodology. *Remote Sensing Applications: Society and Environment, 22,* 100499. doi: 10.1016/j.rsase.2021.100499

- Researchers used the Sentinel-2 satellite program and Google Earth Engine to map intertidal zones. Sentinel-2 uses tide-calibrated satellite imagery to measure water

occurrence frequency. It is a satellite that collects imagery at the same time in the same place every day, which are then calibrated to the tidal stage at the time the image was taken.

Rangel-Buitrago, N., Neal, W.J., de Jonge, V.N. (2020). Risk assessment as a tool for coastal erosion management. *Ocean and Coastal Management*, *186*, 105099. doi: 10.1016/j.ocecoaman.2020.105099

- Researchers used the Coastal Erosion Risk Index, consisting of a Hazard Index and Vulnerability Index, to create a single numerical risk evaluation for areas of beach. The indexes include forcing processes (wave height, storm surge, littoral exposure), coastal susceptibility (dune height, percent washovers, beach width, beach slope, cliff/platform, rock types, structure, weathering), and socio-economic/ecological/cultural factors (land use, percent urbanized, population density, infrastructure, cultural heritage, conservation/protection status). Each of these factors are assigned a number 1-5 (low risk to high risk) based on certain aspects relative to the category (example: percent urbanized is given a value of 1 for less than 20% and a value of 5 for greater than 80%) The numbers are then entered into a formula, giving a single number for a given study area. This number is then used to determine if an area will have trends of accumulation, stability, erosion, or high erosion. Based on the results, areas can be given priority over others, and the most applicable course of action can be chosen.

Charbonneau, B.R., Cochran, C., Avenarius, C. (2019). What we know and what we think we know: Revealing misconceptions about coastal management for sandy beaches along the U.S. Atlantic Seaboard. *Journal of Environmental Management*, *245*, 131-142. doi: 10.1016/j.jenvman.2019.04.008

- For non-marshy, sandy beaches, resident tax payers were surveyed as to which long-term shoreline/beach management strategy they preferred and would be willing to pay taxes to fund: planted and fenced dune creation and management, hard structure (breakwater, seawall, etc) protection, periodic beach renourishment, or managed retreat. The vast majority of those surveyed said they would prefer dune creation over any other form of management, with beach renourishment being the distant second most popular choice. A 3/4ths majority of those surveyed also said that they would be willing to pay taxes to fund stabilization efforts and create penalties for landowners who did not maintain stabilization efforts on their property, rather than adopting a managed retreat strategy without taxes.

Doyle, T.B. and Woodroffe, C.D. (2018). The application of LiDAR to investigate foredune morphology and vegetation. *Geomorphology*, *303*, 106-121. doi: 10.1016/j.geomorph.2017.11.005

- Researchers used lidar to map foredune morphology. When correlated with ground RTK surveys, the lidar had an average $R^2$ of 0.96, making it an extremely accurate measuring tool. They also established biogeomorphic protocol to rapidly assess morphology and vegetation of the dunes. These parameters are elevation, percent vegetation cover,

vegetation height, a northern dune cross-section, and a southern dune cross-section, and can potentially be used to develop trends in dune morphology.

Stafford, S. and Guthrie, A.G. (2020). What drives property owners to modify their shorelines? A case study of Gloucester County, Virginia. *Wetlands, 40,* 1739-1750. doi: https://doi.org/10.1007/s13157-020-01358-6

- Researchers surveyed coastal landowners in Gloucester Co to determine trends in their reasoning for shoreline modification on their property. First, researchers found that in all applications for shoreline modification since 2012 that VIMS provided recommendations for, landowners followed those recommendations less than 50% of the time; however, out of those >50% that did not follow recommendations, only around 3% were denied. Shoreline armoring (defined as bulkheads, revetments, breakwaters, riprap, etc. with no living shoreline) is much more common than living shorelines, but living shoreline applications are increasing. Similarly, for properties with living shorelines, 70% of current landowners said they had installed them, as opposed to properties with bulkheads only where 25% of current landowners said they had installed them. However, for revetments only, 60% of current landowners installed them, and for breakwaters only, 80%.

  When extrapolated to the population of the county, researchers used survey results to estimate that approximately 52% of owned shorelines in Gloucester have no modification, about 10% have a living shoreline only or living shoreline/armored combination, about 6% have a bulkhead only, about 18% have a revetment only, about 1% have a breakwater only, and about 13% have some combination of armoring. However, revetments were the most popular modification since the 1980s, but in the last few years, living shorelines have become the most popular.

  In summary, researchers found that the more valuable and longer owned the property is, the more likely it is to be modified, while agricultural and natural areas are less likely. They also found that properties with structures that are closer to the shore are more likely to have armoring. Finally, in terms of erosion, nearly 100% of those surveyed had a positive or neutral view of their modifications, with the only unfavorable views being for bulkheads. Similarly, in terms of Bay health, only those with bulkheads and revetments had unfavorable views.

Smith, C.S., Rudd, M.E., Gittman, R.K. Melvin, E.C., Patterson, V.S., Renzi, J.J., Wellman, E.H., Silliman, B.R. (2020). Review of novel restoration strategies for shoreline protection. *Frontiers in Marine Science*, 7(434). doi: https://doi.org/10.3389/fmars.2020.00434

- This review specifically looks at studies conducted in regard to living shoreline systems. Most studies were conducted in North America, looked at shorelines less than 5 years old, and focused on ecological processes. Based on the review, living shorelines are

becoming increasingly more common and recognized as an important shoreline management practice. Most studies focused on ecological processes rather than ecological structure and species diversity, attributed to the fact that living shorelines are used for human services rather than purely ecological restoration. The review also found that studies show that living shorelines can stabilize sediment and protect coastal properties, but only about 20% of them compared living shoreline effectiveness to traditional hard armoring effectiveness. Therefore, the authors suggest that more comparative studies between the two would increase public and government willingness to implement living shorelines over traditional methods.

Safak, I., Norby, P.L., Dix, N., Grizzle, R.E., Southwell, M., Veenstra, J.J., Acevedo, A., Copper-Kolb, T., Massey, L., Sheremet, A., Angelini, C. (2020). Coupling breakwalls with oyster restoration structures enhances living shoreline performance along energetic coasts. *Ecological Engineering, 158,* 106071. doi: https://doi.org/10.1016/j.ecoleng.2020.106071.

- Researchers conducted experiments along the Intracoastal Waterway in Florida. Researchers tested the efficacy of living shoreline systems, in combination with breakwalls and gabions to facilitate oyster reef establishment and growth, in protecting coastal ecosystems and ecosystem services. They found that these combination systems increased sediment capture and retention, increased organic matter and ecosystem diversity/growth, dissipated wave energy from vessels, facilitated oyster reef establishment and growth, and advanced vegetation growth towards the water. Meanwhile, control sites with no living shorelines or other structures saw increased rates of sediment erosion, decreased organic matter, retreating vegetation, and no oyster reef establishment.

  They also used a new design of marsh grass fronted by gabions for oyster growth, fronted again by breakwalls consisting of wooden posts filled with branches. This provided a more natural setting to facilitate ecosystem growth, but was labor intensive, as the branches within the breakwalls needed to be replaced every few months.

Smee, D.L. (2019). Coastal ecology: living shorelines reduce coastal erosion. *Current Biology, 29*(11), R411-R413.

- The author states that one of the biggest concerns regarding living shoreline systems is that research concerning marsh vegetation’s impacts on erosion can be seen as inconclusive. They present a study that focused entirely on vertical and horizontal erosion of marshes in the presence of *S. alterniflora*, the absence of its above ground biomass, and the absence of its above and below ground biomass. The original researchers also took care to make sure that all sites had similar fetches, slopes, and wave energy. They found that the marshes with all biomass removed experienced significant erosion, marshes with above ground biomass removal experienced intermediate erosion, and marshes with all biomass in place experiend little to no erosion. The factor that this study did not take into consideration and the author of the review states should be analyzed more is varying amounts of wave exposure, as large amounts pf wave action can overwhelm the erosion-mitigating effects of vegetation.

Currin, C.A. (2019). Chapter 30: Living shorelines for coastal resilience. *Coastal Wetlands (Second Edition): An Integrated Ecosystem Approach,* 1023-1053. doi: https://doi.org/10.1016/B978-0-444-63893-9.00030-7.

- This paper is an analysis that outlines what living shorelines are, how they are constructed, how they work, different types of living shorelines, and their impacts on ecological functions and flora/fauna. The paper then goes on to list the different types of shoreline armor, how they function, and their impacts on erosion and ecological functions. It compares this to living shorelines and highlights the benefits living shorelines have over traditional armoring strategies.

Guthrie, A.G., Bilkovic, D.M., Mitchell, M., Chambers, R., Thompson, J.S., Isdell, R.E. (2022). Ecological equivalency of living shorelines and natural marshes for fish and crustacean communities. *Ecological Engineering, 176,* 106511. doi: https://doi.org/10.1016/j.ecoleng.2021.106511

- The researchers wanted to compare nekton communities at living shoreline sites and natural marsh sites. Living shorelines were paired with adjacent natural marsh areas for the comparison, and only hybrid gray/green living shorelines with a rock sill, clean sand fill, and planted marsh grasses were sampled. The nekton communities were sampled using fyke nets for abundance, condition, and biomass. The results found no significant difference between the nekton communities of the living shorelines and the natural marshes, suggesting that living shorelines provide an adequate ecosystem for aquatic species.

Polk, M.A., Eulie, D.O. (2018). Effectiveness of living shorelines as an erosion control method in North Carolina. *Estuaries and Coasts, 41,* 2212-2222. doi: https://doi.org/10.1007/s12237-018-0439-y

- Researchers conducted shoreline surveys at 12 sites with 17 living shorelines and 9 control areas, comparing the current shoreline with imagery from 1993. The sites ranged from seaward barrier islands, soundward barrier islands, river islands, and mainland shores, and the living shorelines varied in their composition, construction, and topography. Compared to the control sites, 12 of the 17 living shorelines slowed erosion, and 6 of the 12 actually started to accrete sediments.

Morris, R.L., La Peyre, M.K., Webb, B.M., Marshall, D.A., Bilkovic, D.M., Cebrian, J., McClenachan, G., Kibler, K.M., Walters, L.J., Bushek, D., Sparks, E.L., Temple, N.A., Moody, J., Angstadt, K., Goff, J., Boswell, M., Sacks, P., Swearer, S.E. (2021). Large-scale variation in wave attenuation of oyster reef living shorelines and the influence of inundation duration. *Ecological Application*, *31*(6), e02382. doi: https://doi.org/10.1002/eap.2382.

- The researchers studied the effectiveness of oyster reef living shoreline designs with regards to wave attenuation and oyster habitat suitability along the Atlantic and Gulf coasts. In order to be effective in both categories, the oyster reefs had to both reduce wave height and be inundated at least 50% of the time in order to be considered suitable habitat for oysters. They used 15 pairs of sites, one oyster reef and one control site per pair, in 5 locations: one in Louisiana, one in Alabama, one in Florida, one in Virginia, and one in New Jersey. The oyster reefs varied in size and construction. What was found was that, for all oyster reefs, only the ones that were considered unsuitable oyster habitat (less than 50% inundation time) significantly reduced wave height. Because of this, the researchers suggest that oyster reef living shoreline designs need to be reexamined in order to develop a design that can both sustain a healthy oyster population and effective reduce wave height.

Onorevole, K.M., Thompson, S.P., Piehler, M.F. (2018). Living shorelines enhance nitrogen removal capacity over time. *Ecological Engineering, 120,* 238-248. doi: https://doi.org/10.1016/j.ecoleng.2018.05.017.

- This study focuses on the effectiveness of living shoreline saltmarshes in reducing eutrophication through denitrification. The researchers sampled 4 living shoreline saltmarshes in Bogue Sound, NC, ranging from less than a year old to 20 years old. Each site included and was sampled near oyster reefs, saltmarshes, and sandflats. Denitrification was sampled by using gas fluxes of sediment cores to measure fluxes of dissolved nutrients and levels of $N_2O$. It was found that all sites had statistically similar denitrification rates (> 50%), and nitrogen removal significantly increased between the <1 year old site, the 2 year old site, and the 7 year old site, before decreasing at the 20 year old site. The was no significant difference in denitrification rates between the oyster reefs, marsh, and sandflats.

Davenport, T.M., Seitz, R.D., Knick, K.E., Jackson, N. (2018). Living shorelines support nearshore benthic communities in upper and lower Chesapeake Bay. *Estuaries and Coasts, 41,* 197-206. doi: https://doi.org/10.1007/s12237-017-0361-8.

- Researchers wanted to study the effects of living shorelines on the surrounding benthic community. The chose two study sites: one in the upper Bay that comprised a former bulkhead replaced by a hybrid gray/green living shoreline, and another in the lower Bay that comprised an eroding sandy bank replaced by a coir log living shoreline. The sites were surveyed over the course of 4 springs; one just prior to construction of the living shorelines, and 3 after their construction. Benthic fauna were collected by a suction apparatus inserted into the sediment, water samples were collected to measure salinity, dissolved oxygen, and temperature, and sediment cores were taken to measure grain size. Results for both sites showed that benthic infaunal biomass increased over time, as both the size and abundance of infauna increased. At the upper Bay site, infauna species composition also changed, showing a shift from a community of mostly polychaetes to a community of mostly bivalves.

Nunez, K., Rudnicky, T., Mason, P., Tombleson, C., Berman, M. (2022). A geospatial modeling approach to assess site suitability of living shorelines and emphasize best shoreline management practices. *Ecological Engineering, 179,* 106617. doi: https://doi.org/10.1016/j.ecoleng.2022.106617.

- This article outlines the features and accuracy of the Shoreline Management Model, which has been calibrated and validated for the Chesapeake Bay. The SMM is a computer program that uses available spatial data to recommend best management practices for both modified and unmodified shorelines. The model can be used to identify areas of shoreline where living shoreline systems would be appropriate to address erosion. The model uses presence of tidal marshes, beaches, SAV, riparian land cover, bank height, nearshore bathymetry, fetch, and erosion defense structures. Once all of these factors have been added to the model, it produces a best management strategy recommendation that is either living shorelines, traditional structures, or special considerations (areas with unique conditions that may not fit into a best management practice). The researchers calculated that the SMM produced results consistent with a field survey 82.5% of the time.

Spiering, D.W., Kibler, K.M., Kitsikoudis, V., Donnelly, M.J., Walters, L.J. (2021). Detecting hydrodynamic changes after living shoreline restoration and through an extreme event using a Before-After-Control-Impact experiment. *Ecological Engineering, 169,* 106306. doi: https://doi.org/10.1016/j.ecoleng.2021.106306.

- Researchers studied 3 sites over a 16-month period in Florida’s Mosquito Lagoon. The first site was a restored living marsh grass shoreline, the second was a natural mangrove shoreline, and the third was a bare shoreline with no vegetation. Water level sensors and wave loggers were placed nearshore and in the channel at each site, while a channel velocity sensor and wind speed sensor were placed in the channel, and a sediment dynamics sensor was placed nearshore. 9 weeks into the study, Hurricane Irma passed through the area, but did not destroy the living shoreline. In the first few months after its construction, the living shoreline system reduced current velocity and wave height by 62% and 83% respectively, but only if water levels were at or below the constructed breakwaters. If water levels exceeded breakwater height, current velocity actually exceeded the bare control site. It wasn’t until the end of the 16-month period that vegetation at the constructed site was established enough to produce similar current velocity and wave height reductions to the natural mangrove site, suggesting that living shoreline systems, at least in areas impacted by significant storm events, may need upwards of a year or longer before they can produce meaningful erosion control and shoreline protection.

Morris, R.L., Bilkovic, D.M., Boswell, M.K., Bushek, D., Cebrian, J., Goff, J., Kibler, K.M., La Peyre, M.K., McClenachan, G., Moody, J., Sacks, P., Shinn, J.P., Sparks, E.L., Temple, N.A., Walters, L.J., Webb, B.M., Swearer, S.E. (2019). The application of oyster reefs in shoreline protection: Are we over-engineering for an ecosystem engineer? *Journal of Applied Ecology, 56*(7), 1703-1711. doi: https://doi.org/10.1111/1365-2664.13390.

- This paper is an analysis of the effectiveness of oyster reef living shoreline systems. It uses studies from the US Atlantic and Gulf coasts to highlight any gaps in understanding the use of oyster reefs, find disconnects between oyster reef ecological and engineering functions, and shift focus to appropriate and effect reef designs. This analysis found that many oyster reef living shoreline designs do not resemble either natural reefs or traditional breakwater systems, failing in both goals of establishing oyster communities and protecting shorelines. Based on the varying oyster reef designs, the researchers are of the opinion that designing reef structures for optimal oyster settlement and growth is the better long-term strategy for both oyster communities and shore protection. They theorize that designing large structures that are not appropriate for oyster growth will initially reduce wave height and energy affecting the shoreline, but will become more and more ineffective over time, as the structures wear away and oysters do not develop; conversely, a structure designed for optimal oyster settlement and growth will not initially provide much shore protection, but will, as the oyster community grows and develops, function better as the reef naturally grows.

Silliman, B.R., He, Q., Angelini, C., Smith, C.S., Kirwan, M.L., Daleo, P., Renzi, J.J., Butler, J., Osborne, T.Z., Nifong, J.C., van de Koppel, J. (2019). Field experiments and meta-analysis reveal wetland vegetation as a crucial element in the coastal protection paradigm. *Current Biology*, *29*(11), 1800-1806. doi: https://doi.org/10.1016/j.cub.2019.05.017.

- This paper is both an experiment and an analysis of studies to highlight the underreported fact that vegetation loss from wetlands directly increases erosion rates on wave-impacted shorelines. For the experiment portion, researchers established 3 sites of tidal marsh. The first was a control site with natural vegetation intact, the second has all above-ground biomass removed, and the third had all above and below-ground biomass removed. The erosion rates of the control and the above-ground removal only site did not differ, but the erosion rates in the above and below-ground removal site were significantly higher, demonstrating that vegetation, especially below-ground vegetation (i.e. roots, rhizomes, etc.) are extremely important in controlling erosion. For the analysis, researchers looked at sites from other studies that were both vegetated and non-vegetated, and, using three different analyses, found the same result; that erosion was significantly higher in areas where vegetation had been removed.

Smith, C.S., Paxton, A.B., Donaher, S.E., Kochan, D.P., Neylan, I.P., Pfeifer, T., van Hoeck, R.V., Taylor, J.C. (2021). Acoustic camera and net surveys reveal that nursery enhancement at living shorelines may be restricted to the marsh platform. *Ecological Engineering, 166,* 106232. doi: https://doi.org/10.1016/j.ecoleng.2021.106232.

- Researchers wanted to survey fish populations at three different shoreline types: natural marshes, living shoreline marshes, and bulkheads. All three types were sampled in the shallow nearshore, and the marsh platform of the natural and living shoreline marshes were sampled. 4 living shoreline sites of either bagged oyster sills or granite, all constructed within a 3-year timeframe, were sampled with fyke nets in the marsh platform, and compared with nearby natural marsh sites. It was found that fish abundance and species richness was significantly higher at the living shoreline sites than the natural marsh sites. Next, 3 living shoreline sites, all constructed of granite and of varying ages, 3 bulkhead sites, all constructed of vinyl and of unknown ages, and 3 natural marsh sites were all sampled for fish abundance in the shallow nearshore with Dual-Frequency Identification Sonar (DIDSON). However, for these surveys, no significant differences between any of the sites were found. This, along with other similar studies, suggests that living shorelines are very effective at providing vegetated nursery habitats for fish, but provide no increased benefits for adult fish in the surrounding nearshore.

Polk, M.A., Gittman, R.K., Smith, C.S., Eulie, D.O. (2021). Coastal resilience surges as living shorelines reduce lateral erosion of salt marshes. *Integrated Environmental Assessment and Management, 18*(1), 82-98. doi: https://doi.org/10.1002/ieam.4447.

- The researchers studied 17 living shoreline sites 8 control sites along the NC coast before and after Hurricane Florence (cat 1) with RTK. All living shoreline sites, regardless of age, environmental variables, and design reduced lateral erosion of the fringing salt marshes compared to the unprotected control sites.

Cohn, J.L., Franz, S.C., Mandel, R.H., Nack, C.C., Brainard, A.S., Eallonardo, A., Magar, V. (2021). Strategies to work towards long-term sustainability and resiliency of nature-based solutions in coastal environments: A review and case studies. *Integrated Environmental Assessment and Management, 18*(1), 123-134. doi: https://doi.org/10.1002/ieam.4484.

- This review analyzed different studies of nature-based solutions to anthropogenic coastal impacts (sea level rise and other man-made erosion factors). The authors analyzed studies including living shoreline systems made of native plants, wave attenuation structures, and managed retreat practices. It included case studies from Lake Ontario, NY and Long Island, NY. They found that living shorelines are effective and sustainable when paired with nature-based wave attenuation structures. They also recommend adopting a managed retreat strategy along with living shorelines in areas where they are feasible and landowners are willing to participate.

Chambers, R., Gorsky, A.L., Isdell, R., Mitchell, M., Bilkovic, D.M. (2021). Comparison of nutrient accrual in constructed living shoreline and natural fringing marshes. *Ocean and Coastal Management, 199*, 105401. doi: ttps://doi.org/10.1016/j.ocecoaman.2020.105401.

- Thirteen pairs of constructed living shorelines and natural fringing marshes in the southern Chesapeake Bay were analyzed via soil cores from 3 parallel transects in the high and low marsh at each site, as well as vegetation samples. The soils and vegetation were analyzed for total organic content, carbon, nitrogen, and phosphorous. It was found that the natural marshes had higher nutrient and organic matter content due to their age, as the living shorelines were all between 2 and 16 will old. However, the rates of nutrient accumulation in the living shorelines suggest that, once they are old enough, they will function similarly to natural marshes in terms of nutrient and organic matter content.

Smith, C.S., Scyphers, S. (2019). Past hurricane damage and flood zone outweigh shoreline hardening for predicting residential-scale impacts of Hurricane Matthew. *Environmental Science and Policy, 101*, 46-53. doi: https://doi.org/10.1016/j.envsci.2019.07.009.

- Researchers surveyed waterfront property owners in Dare, Carteret, and Brunswick counties NC after Hurricane Matthew. Property owners were asked if their shorelines consisted of bulkheads, natural shorelines, or riprap. Results found that properties with natural shorelines suffered less damage to the home than those with hardened shorelines, though the researchers state this could be due to the fact that homes with hardened shorelines were typically closer to the water than those with natural shorelines. Results also showed that the biggest factor in damage to the shoreline itself was whether or not it had been previously damaged by hurricanes, but among those that had, more damage was caused to natural shorelines than to hardened shorelines.

Prosser, D.J., Jordan, T.E., Nagel, J.L., Seitz, R.D., Weller, D.E., Whigham, D.F. (2017). Impacts of coastal land use and shoreline armoring on estuarine ecosystems: an introduction to a special issue. *Estuaries and Coasts, 41*, 2-18. doi: https://doi.org/10.1007/s12237-017-0331-1.

- This paper analyzes 13 other papers written about the impacts of nearshore land use and shoreline armoring on water quality, SAV, fauna, and nearshore morphology. First, the papers show that shoreline armoring (bulkheads, riprap, etc.) cause scouring of the nearshore sediment from wave reflection, while natural and living shorelines do not. Second, nearshore land use deposits both sediment and nutrients into the water, which degrades water quality and negatively impacts SAV and fauna, both of which are important to maintaining a healthy natural or living shoreline. Third, shoreline armoring significantly reduces both overall abundance and diversity of nearshore SAV, though the primary threat to SAV is agricultural land use. Fourth, due to nearshore scouring and reduction of SAV, shoreline armoring has significant impacts on benthic fauna and fish. Finally, there is some evidence that shoreline armoring negatively impacts shorebird and waterfowl populations as well.

Smith, C.S., Puckett, B., Gittman, R.K., Peterson, C.H. (2018). Living shorelines enhanced the resilience of saltmarshes to Hurricane Matthew (2016). *Ecological Applications, 28*(4), 871-877. doi: https://doi.org/10.1002/eap.1722.

- Researchers studied 12 sites in NC from 2015-2017 for changes in surface elevation, *S. alterniflora* stem density, and structural damage. The sites were at 4 locations in NC, with 3 types of shoreline at each location: a hybrid gray/green living shoreline, a natural marsh, and a hardened structure, all of which were exposed to Hurricane Matthew in 2016. They found that living shorelines experienced significantly less erosion than natural and hardened shorelines, significantly more *S. alterniflora* growth than natural marshes, and significantly less damage than hardened shorelines, as no living shorelines needed repair after the storm compared to 3 of the 4 hardened shorelines requiring repairs.

Goelz, T., Vogt, B., Hartley, T. (2020). Alternative substrates used for oyster reef restoration: a review. *Journal of Shellfish Research, 39*(1), 1-12. doi: https://doi.org/10.2983/035.039.0101.

- Researchers used a text mining program in R to examine 96 studies regarding constructed/restored oyster reef substrates to determine which are the most common and which perform the best. Of the 96 studies, 76 were done in the US, with 37 in the Gulf of Mexico and 19 in the Chesapeake Bay. The most common substrates used were, in descending order: concrete, limestone, non-calcium stone, non-oyster shell, dredged shell, engineered reefs, and porcelain. Those substrates were then ranked for effectiveness in 4 categories: biological (supports oysters and associated species), structural (wave energy reduction, structural persistence, etc.), chemical (is it chemically suitable for oysters and will it pollute the water), and economic (is the substrate affordable and easy to transport). The substrates were then ranked by how well they met the four categories (strong, weak, conflicting data, or unknown). Limestone ranked highest performing strong in all categories, concrete and non-calcium stone ranked next performing strong in 3 categories and conflicting in 1 (structural for concrete and chemical for n.c. stone). Next highest was non-oyster shell, which performed strong in chemical and economic, but weak in biological and structural. Next was engineered reefs, which performed strong in structural, but remains unknown in all other categories. Lowest ranked were dredged shell and porcelain, which both performed weak in economic and are either conflicting or unknown in all other categories. More research needs to be done for a more accurate assessment of the substrates.

Zhang, X. and Nepf, H. (2021). Wave dampening by flexible marsh plants influenced by currents. *Physical Review Fluids, 6,* 100502. doi: https://doi.org/10.1103/PhysRevFluids.6.100502.

- Researchers conducted laboratory experiments using marsh grasses of varying flexibility in a wave tank with wave gauges and a current-inducing water pump. The results found included that the distribution of marsh grasses by flexibility influenced wave energy dissipation (the “natural” distribution of increasing flexibility towards the water provides the most wave reduction), current velocity influenced wave energy dissipation (slower currents allowed more time for energy to be dissipated amongst the vegetation), and current direction influenced wave energy dissipation (currents flowing opposite to wave direction dissipated more energy than currents flowing with wave direction).

Welch, L., Liu, X., Kahanda, I., Reddivari, S., Umapathy, K. (2021). Vegetation coverage in marsh grass photography using convolutional neural networks. *The International Florida Artificial Intelligence Research Society Conference Proceedings, 34.* doi: https://doi.org/10.32473/flairs.v34i1.128498.

- Researchers have developed new convolutional neural network models (a type of AI) to analyze photos of marsh grass in order to determine vegetation coverage. They tested 3 models: LeNets-5, AlexNet, and mAlexNet in their ability to accurately estimate

vegetation cover in photos from St. Augustine marshes. They found that all models were able to achieve estimation rates as high as 99% accurate, but AlexNet and mAlexNet were able to reach those higher accuracies more consistently, 96% to LeNet-5's 95%. Furthermore, mAlexNet is able to work as well as AlexNet, but at faster speeds and greater efficiency.

Booth, T.D., Cox, S.E., Meikle, T.W., Fitzgerald, C. (2006). The accuracy of ground-cover measurements. *Rangeland Ecology & Management*, *59*(2), 179-188. doi: 10.2111/05-069R1.1.

- Researchers analyzed 20 1m$^2$ color posters using 7 different techniques: steel-point frame, laser-point frame, line-point interception, ocular estimation, digital grid overlay, and VegMeasure automated software. Of the 7 methods, steel-point frame and line-point intercept were the most accurate (99% and 98%, respectively), but all non-automated methods were greater than 92% accurate. Meanwhile, the automated software was only 70% accurate, suggesting that conventional methods are a more accurate means of determining vegetation cover from photographs. (Note: this study is from 2006 and computer software has greatly improved since then)

Obanawa, H., Yoshitoshi, R., Watanabe, N., Sakanoue, S. (2020). Portable LiDAR-based method for improvement of grass height measurement accuracy: comparison with SfM methods. *Sensors*, *20*(17), 4809. doi: 10.3390/s20174809.

- Researchers analyzed 50cm by 50cm grass areas in western Japan before and after cutting using a UAV (drone) structure from motion (SfM) camera, a pole mounted-SfM camera, and a hand-held LiDAR, which were compared to conventional ruler methods. Point cloud data from each method was compared using DSMs from before cutting and after cutting to determine the height from each cell in the point cloud. Of these methods, LiDAR was the most accurate. However, it should be noted that the authors list many factors that could have possibly affected their results.

University of Idaho College of Natural Resources. Principles of vegetation measurement & assessment and ecological monitoring & analysis. https://www.webpages.uidaho.edu/veg_measure/Modules/Lessons/Module%205(Density)/5_2_Plot-based_Techniques.htm

- Instructional lesson sampling vegetation. Defines concepts of density, biomass, cover, and frequency, and tells how to design and sample a quadrat.

Sea Grant, Virginia. Elevation data brings oyster restoration to new heights. http://vaseagrant.org/seaside-oyster-reefs/?fbclid=IwAR01zBMTXHCKmGD5TypB3WY5Y8yoVN5hJFXlbyVscLBcxviVSDCaniZN5k0

- A student at UVA is collecting elevation data along with other information such as high water marks and algae cover to determine which factors best suit oyster reef growth and survival.

Isdell, R.E., Bilkovic, D.M., Guthrie, A.G., Mitchell, M.M., Chambers, R.M., Leu, M., Hershner, C. (2021). Living shorelines achieve functional equivalence to natural fringe marshes across multiple ecological metrics. *PeerJ, 9,* 11815. doi: https://doi.org/10.7717/peerj.11815.

- Researchers compared 13 pairs of living shorelines and natural fringing marshes around the Chesapeake Bay to see how well the living shorelines functioned ecologically compared to natural marshes. They used 6 factors to judge ecological function: the biomass and diversity of nekton, the biomass and diversity of plants, the biomass and diversity of invertebrates, the organic content of the soil, the use by herons, and the use by terrapins. In every category but soil organic content, living shorelines functioned statistically the same as natural marshes. Living shorelines did not perform as well in soil organic content, which the researchers attribute to them being constructed with low-organic content sand.

Andrews, E.A. (2020). Legal and policy challenges for future marsh preservation in the Chesapeake Bay region. *Wetlands, 40,* 1777-1788. doi: https://doi.org/10.1007/s13157-020-01389-z.

- This article outlines the importance of coastal wetlands in preventing damages from storm events and flooding, as well as the challenges facing their protection and restoration. One of the challenges mentioned is that the importance of wetlands in preventing flooding may be downplayed due to the fact that data used for predicting flooding are based on historical storm frequency and water levels as opposed to increasing future levels, and the fact that water level and tide monitoring data are lacking. Another is that expensive, long-term mitigation policies are not appealing politically to America's short-term and repeated election cycles. The author also points out that most American policies tend to be reactionary instead of preventative. The article ends with providing some suggestions for increasing marsh protection policy such as public education and outreach, preventative planning, increased funding, and open community discussion.

Mariotti, G. and Hein, C.J. (2022). Lag in response of coastal barrier-island retreat to sea-level rise. *Nature Geoscience.* doi: https://doi.org/10.1038/s41561-022-00980-9.

- Researchers found that the Virginia Barrier Islands (VBI) in the Chesapeake Bay experience a lag of retreat in response to climate change. They found that the retreat of the VBIs responded to rates of sea level rise from a century or more ago, rather than modern SLR trends. As such, the VBIs have not shown an increase in retreat corresponding to the increase of SLR in the last few decades; however, barrier island retreat responds proportionally to SLR, meaning that a drastically increasing SLR will reduce the lag time of barrier island retreat. Because of this, the researchers predict that VBI retreat rates will increase by as much as 50% in the next 100 years, and possibly more if SLR rates continue to increase.

Glass, E.M., Garzon, J.L., Lawler, S., Paquier, E., Ferreira, C.M. (2017). Potential of marshes to attenuate storm surge water level in the Chesapeake Bay. *Limnology and Oceanography, 63*(2), 951-967. doi: https://doi.org/10.1002/lno.10682

- Researchers studied water levels and attenuation rates at two marshes in VA on the Chesapeake Bay over a 3-year period consisting of 21 flood events at the first site and 52 at the other. During minor to major events, the marshes at both sites were able to reduce wave amplitude by approximately 0.01-0.025 cm. During major storm events with levels of high upper marsh inundation, the attenuation rates decreased significantly. The researchers also found that certain geographical features within the marshes, such as channels, levees, and elevated surrounding forests also reduced attenuation rates. The researchers conclude that marsh areas in the Chesapeake Bay are best suited for wave attenuation during low to normal water level events, but will be less effective during major storm and flooding events.

Giannopoulos, G., Lee, D.Y., Neubauer, S.C., Brown, B.L., Franklin, R.B. (2019). A simple and effective sampler to collect undisturbed cores from tidal marshes. *bioRxiv,* (pre-print). doi: https://doi.org/10.1101/515825.

- Researchers outline their design of a soil core sampling device for tidal marshes. The device design is: a 3-inch diameter PVC tube (variable length) with a saw-tooth opening to cut through root mats on the sampling end, a coupling and flange on the other end, an industrial stopper, and a plunger consisting of a 1-inch diameter PVC tube capped with a 1-inch diameter cap with a 3-inch diameter PVC disk attached. The device is used by inserting the saw-tooth end into the ground, holding the device by the flange, and rotating it downwards to the desired depth. Once the depth is reached, the stopper is attached to the above-ground end, and the tube is removed from the ground. The stopper creates a vacuum that ensures the core remains intact and inside the tube. The stopper is then removed, and the plunger is inserted into the flanged end to extract the intact core from the tube. The researchers conclude that this device functions just as well as commercial-made samplers, is lighter and more manageable for field work, and only costs approximately $45 to make at the time of writing the article.

Humphreys, A., Gorsky, A.L., Bilkovic, D.M., Chambers, R.M. (2021). Changes in plant communities of low-salinity tidal marshes in response to sea-level rise. *Ecosphere, 12*(7), e03630. doi: https://doi.org/10.1002/ecs2.3630

- Researchers studied 465 $km^2$ of tidal marshes in James City County, comparing their tidal marsh inventories (TMI) with respect to the special distribution of invasive *Phragmites australis* and native *Spartina alterniflora* between 1980 and 2014. Based on observations of TMIs, *Phragmites* presence increased by 5.84 $km^2$ while *Spartina* presence only increased by 0.02 $km^2$. Researchers then exposed seeds of varying other native species to soil from areas of established *Phragmites* populations under varying levels of inundation and salinity. In low-salinity (0-5 ppt) environments, many of the native seedlings germinated regardless of inundation levels and no *P. australis* or *S. alterniflora*

germinated, but in higher-salinity environments, fewer native seedlings germinated. However, when researchers repeated the treatment with the addition of *P. australis* and *S. alterniflora* seeds, the number of native seedlings to germinate significantly decreased, especially under higher levels of inundation. Based on these results, the researchers conclude that sea-level rise will continue the shift of low-salinity marsh habitats to *S. alterniflora* and, especially, *P. australis* dominated communities.

Lipcius, R.N. and Burke, R.P. (2018). Successful recruitment, survival and long-term persistence of eastern oyster and hoked mussel on a subtidal, artificial restoration reef system in Chesapeake Bay. *PLoS ONE, 13*(10), e0204329. doi: https://doi.org/10.1371/journal.pone.0204329

- Researchers installed an artificial oyster reef consisting of 5 stacked modules in the Rappahannock River at a depth of 7m. The reef consisted of 75 $m^2$ of surface area and covered 5$m^2$ over river bottom. It was installed in 2000 and sampled in 2005 for bivalve settlement and growth. It was found that the structure contained a surface area of 28-168 $m^{-2}$ of oysters and 14-2177 $m^{-2}$ mussels; the highest recorded number for an artificial reef. Over half of the oysters were of reproductive age, and biomass and condition indices for oysters and mussels were high and positively correlated, while parasite prevalence and intensity were low. These results show this particular oyster reef to be one of the most successful artificial oyster reefs ever installed in terms of bivalve recruitment and growth.

Hogan, S. and Reidenbach, M.A. (2022). Quantifying tradeoffs in ecosystem services under various oyster reef restoration designs. *Estuaries and Coasts, 45,* 677-690. doi: https://doi.org/10.1007/s12237-021-01010-4

- Researchers used 4 designs of artificial oyster reef structures to determine which design was best in terms of wave attenuation, oyster settlement and growth, and benefits to the surrounding ecosystem. The designs were oyster castles arranged in the following configurations: 1 row 2 tiers high, 1 row 4 tiers high, 3 rows 2 tiers high, and 3 rows 4 tiers high. Results showed that the 4-tier high design functioned best in terms of wave attenuation and overall oyster number and density. All designs showed an increase in infaunal diversity and sediment organic matter. The results showed no significant differences between the 1-row designs and the 3-row designs. The researchers conclude that the height of the structures is the most important design element in terms of overall reef effectiveness.

Fivash, G.S., Stuben, D., Bachmann, M., Walles, B., van Belzen, J., Didderen, K., Temmink, R.J.M., Lengkeek, W., van der Heide, T., Bouma, T.J. (2021). Can we enhance ecosystem-based coastal defense by connecting oysters to marsh edges? Analyzing the limits of oyster reef establishment. *Ecological Engineering, 165,* 106221. doi: https://doi.org/10.1016/j.ecoleng.2021.106221

- Researchers created stable substrate for oyster growth and placed it along a tidal marsh and mudflat area of coastline from the meso to macro-tidal zones to establish the range of possible successful oyster reefs, as well as to find the ideal location for coastline defense.

Researchers found that artificial reefs could successfully establish and grow well above the natural range limit with the addition of stable substrate into the marsh. With this, they determined the ideal location for coastal defense to be the halfway point between MLW and MHW.

Chowdhury, M.S.N., La Peyre, M., Coen, L.D., Morris, R.L., Luckenbach, M.W., Ysebart, T., Walles, B., Smaal, A.C. (2021). Ecological engineering with oysters enhances coastal resilience efforts. *Ecological Engineering, 169,* 106320. doi: https://doi.org/10.1016/j.ecoleng.2021.106320

- This article analyzes artificial oyster reef designs in the US, Netherlands, Australia, and Bangladesh to determine what contributes to oyster reefs successfully aiding coastal resilience. The found that all designs can be successful in terms of establishing and growing oyster reefs, as well as providing coastal resilience benefits. The factors that lead to artificial reefs being unsuccessful are where and how they are placed, the physical and chemical conditions of the water and immediate surrounding environment, the turbidity of the water, the condition of the substrate in which they are placed, and interactions with predators and humans. The researchers conclude that for an artificial reef to be successful, it should be eco-engineered to the environment it is placed in, taking all of the aforementioned factors into account.

Nitsch, C.K., Walters, L.J., Sacks, J.S., Sacks, P.E., Chambers, L.G. (2021). Biodegradable material for oyster reef restoration: first-year performance and biogeochemical considerations in a coastal lagoon. *Sustainability, 13*(13), 7415. doi: https://doi.org/10.3390/su13137415

- Researchers created and tested a new, biodegradable material to be used in artificial oyster reef construction in place of traditional plastic materials such as mesh bags like Vexar. The ne material, Biodegradable Ecosystem Engineering elements (BESE), is made from potato waste starch and designed to be both biodegradable and nutrient-enriching for the surrounding environment. The researchers tested the BESE elements in both field and laboratory environments to determine its ability as an oyster reef substrate, its breakdown rate, and its ability to supply the environment with nitrogen, phosphorous, and dissolved organic carbon. The results showed that BESE performed comparable to traditional plastic mesh as an oyster reef substrate, broke down to a half-life of approximately 4-7 years, and released large amounts of nutrients into the environment, though not enough to significantly change the nutrient composition of the surrounding sediment.

Schoonees, T., Mancheno, A.G., Scheres, B., Bouma, T.J., Silva, R., Schlurmann, T., Schuttrumpf, H. (2019). Hard structures for coastal protection, towards greener designs. *Estuaries and Coasts. 42,* 1709-1729. doi: https://doi.org/10.1007/s12237-019-00551-z.

- Researchers wanted to find ways to reduce the negative impacts of hard shoreline protective structures, and came up with 3 general methods: hybrid designs with hard and “soft” (i.e. living shorelines) components, mitigating changes to the natural environment

caused by hard structures, and ecologically improving the hard structures. The first method involves hybrid living shoreline systems similar to our breakwater/sill systems. The second method discusses creating textured surfaces to the hardening structures, using different types of rocks to weather at different times to mimic natural nutrient levels, and using things like artificial oyster reefs and "BIOBLOCKS" as the building materials to provide better habitat for plant and animal life. The last method is similar to the first in that it involves the use of both hard and living components (plants), but it also discusses building the hardening structures in a way that they mimic a natural shoreline such as vegetated revetment structures (revetments made from structures that have spaces to plant vegetation on the actual hardening structure) and building them so that they are submerged during a normal high tide cycle to simulate natural shoreline and allow for the natural movement of biota. The majority of these strategies seem to be largely theoretical at this point, as the researchers do not have any tangible data on their performance, and have only simulated them via numerical models and computer programs.

Zarnoch, C.B. (2021). Species interactions may enhance resilience and ecosystem services within an urban living shoreline project. *New York State Water Resources Institute, Cornell University.* https://wri.cals.cornell.edu/sites/wri.cals.cornell.edu/files/shared/2020_Zarnoch_Final.pdf

- Researchers studied the effects of supplementing an urban living shoreline system made of *S. alterniflora* with native ribbed mussels (*G. demissa*) on enhancing the growth of the marsh and its nitrogen-removal ecosystem services. A barren area of shoreline along the Harlem River in NY was developed into a living shoreline consisting of 6 plots with just marsh grass, 6 plots with marsh grass and mussel cages, and 6 plots of barren sand. For all tests excluding nitrate/nitrite flux (sediment respiration rates, nitrogen gas flux, soluble phosphorous flux, ammonium flux, nitrate/nitrite flux) the plots with mussels and marsh grass achieved the highest rates, while the barren sand had the lowest. The marsh grass only plots achieved the highest nitrate/nitrite fluxes. The planted plots, both with and without mussels, had higher sediment organic matter and carbon content than the barren plots, but were not significantly different from each other.

Stafford, S.L. (2020). Encouraging living shorelines over shoreline armoring: Insights from property owners' choices in the Chesapeake Bay. *Coastal Management, 48*(6), 559-576. doi: https://doi.org/10.1080/08920753.2020.1823667

- Researchers surveyed coastal landowners in Gloucester Co to determine trends in their reasoning for shoreline modification on their property. First, researchers found that in all applications for shoreline modification since 2012 that VIMS provided recommendations for, landowners followed those recommendations less than 50% of the time; however, out of those >50% that did not follow recommendations, only around 3% were denied. Shoreline armoring (defined as bulkheads, revetments, breakwaters, riprap, etc. with no living shoreline) is much more common than living shorelines, but living shoreline applications are increasing. Similarly, for properties with living shorelines, 70% of current landowners said they had installed them, as opposed to properties with

bulkheads only where 25% of current landowners said they had installed them. However, for revetments only, 60% of current landowners installed them, and for breakwaters only, 80%.

When extrapolated to the population of the county, researchers used survey results to estimate that approximately 52% of owned shorelines in Gloucester have no modification, about 10% have a living shoreline only or living shoreline/armored combination, about 6% have a bulkhead only, about 18% have a revetment only, about 1% have a breakwater only, and about 13% have some combination of armoring. However, revetments were the most popular modification since the 1980s, but in the last few years, living shorelines have become the most popular.

In summary, researchers found that the more valuable and longer owned the property is, the more likely it is to be modified, while agricultural and natural areas are less likely. They also found that properties with structures that are closer to the shore are more likely to have armoring. Finally, in terms of erosion, nearly 100% of those surveyed had a positive or neutral view of their modifications, with the only unfavorable views being for bulkheads. Similarly, in terms of Bay health, only those with bulkheads and revetments had unfavorable views.

Turner, J.S., St-Laurent, P., Friedrichs, M.A.M., Friedrichs, C.T. (2021). Effects of reduced shoreline erosion on Chesapeake Bay water clarity. *Science of the Total Environment, 769*, 145157. doi: https://doi.org/10.1016/j.scitotenv.2021.145157.

- Researchers wanted to test the differences in water clarity of the Chesapeake Bay between previous conditions of high erosion and sediment input and contemporary conditions with lowered rates due to shoreline protections. They used current water clarity data from monitoring stations as well as historical data going back as far as 1998. These data were used with several models including a model of Bay estuarine processes and a model of sediment transport throughout the Bay. They found that differences in water clarity varied depending on the season. In the winter months, the new reduced erosion conditions improved water clarity from the older conditions as there were less sediment particles suspended in the water column; however, during the spring and summer months, water clarity did not improve due to an increase in organic processes suspending organic solids in the water column in what is defined as the "Organic Fog Zone."

Bilkovic, D.M., Isdell, R.E., Guthrie, A.G., Mitchell, M.M., Chambers, R.M. (2021). Ribbed mussel Geukensia demissa population response to living shoreline design and ecosystem development. *Ecosphere, 12*(3), e03402. doi: https://doi.org/10.1002/ecs2.3402

- Researchers wanted to develop reasons why native ribbed mussels usually present in Atlantic living shorelines and native marshes were largely absent in the Chesapeake Bay. They surveyed 13 paired natural marshes and living shoreline systems ranging from 2-16 years old to theorize factors affecting mussel recruitment. They found that mussels were significantly more abundant in natural marshes than living shorelines, even though the pairs were adjacent to one another. The first theory was that living shorelines fronted by structures such as rock sills were preventing the settlement of larvae in the marsh, but when they sampled the living shorelines for larvae, all sampled areas contained them, meaning that the structures do not prevent access and settlement. However, what they did find was that the sediment used to build living shorelines created unsuitable habitat for larvae settlement and juvenile mussel survivability. Because living shorelines are constructed with coarse, clean sand, it does not provide the high organic content and surface algae juvenile mussels need to survive before the begin filter feeding as adults. Because of this, the researchers believe that the sand and sediment used in the construction of living shoreline systems is a limiting factor for mussel settlement. They also theorize that, because living shoreline vegetation is planted in a grid system, the marsh grasses are too far apart to provide suitable habitat for the mussels, leading to increased predation of them.

Komar, P.D. and Allan, J.C. (2010). "Design with Nature" strategies for shore protection- The construction of a cobble berm and artificial dune in an Oregon State Park. *Puget Sound Shorelines and the Impacts of Armoring- Proceedings of a State of the Science Workshop, May 2009: U.S. Geological Survey Scientific Investigations Report 2010*(5254), 117-126.

- Researchers built a nature mimicking cobble berm in Oregon's Cape Lookout State Park to mitigate erosion and wave action. They first surveyed natural cobblestone beaches along the Oregon coast to ensure the rocks they used were similar sizes. The design they chose consisted of an artificial dune constructed by using geotextile cubed bags filled with sand, which were then topped with loose sand and planted with native grasses. The dune was then fronted by a "scour blanket," a ditch filled with sand and rocks, which was then covered with a graded slope of cobblestone. The entire project was completed for a cost of $125,000 (though it was constructed using work-release inmate labor) in 2000. The berm was effective in preventing flooding of the upland, but by 2008, it had lost 5000 cubic meters of stone which needed to be replenished. By 2009, when this study was being written, parts of the berm had eroded away so much that the geotextile bags became exposed. The researchers conclude that the berm is effective with continuous maintenance, and that the design may be improved upon by "imagination and creativity."

Bayle, P.M., Kaminsky, G.M., Blenkinsopp, C.E., Weiner, H.M., Cottrell, D. (2021). Behaviour and performance of a dynamic cobble berm revetment during a spring tidal cycle in North Cove, Washington State, USA. *Coastal Engineering, 167,* 103898. doi: https://doi.org/10.1016/j.coastaleng.2021.103898

- Researchers monitored a 60 m section of a dynamic cobble berm revetment over 10 days in January 2019 using lidar, GPS ground survey, revetment thickness, and RFI tagged cobblestones. Over the 10 days, the revetment experienced erosion up to 0.5 m in some areas. It also experienced transport of the cobblestone, both laterally and seaward, but the stones never traveled further than the revetment toe seaward. During the survey timeframe, the revetment prevented flooding of the upland behind it, and protected the sand beneath it. Researchers found that the primary drivers of erosion were significant

wave height and water level height, though the revetment did experience both erosion and accretion during tidal cycles. The researchers also admit that the revetment will need to be renourished as time goes on.

Winters, M.A., Leslie, B., Sloane, E.B., Gallien, T.W. (2020). Observations and preliminary vulnerability assessment of a hybrid dune-based living shoreline. *Journal of Marine Science and Engineering, 8*(11), 920. doi: https://doi.org/10.3390/jmse8110920

- Researchers used an unmanned aerial vehicle (UAV) to monitor the construction and post-construction performance of a hybrid dune structure at Cardiff State Beach in Encinitas, CA. The structure was constructed using a combination of sand, cobble, rip-rap, and vegetation to mimic a natural cobble beach. It was constructed by digging a 5 ft deep trench filled with sand on the seaward side and geotextile bags on the landward side. The geotextile fill was topped with revetment stone (rip-rap) while the sand was topped with cobblestones. Above that, the dune was constructed out of sand to an elevation of 22 ft, above the 100-year storm surge height, which was then planted with native vegetation. In the post-construction surveys (May 2019 to April 2020), the dune elevation and size remained largely unchanged, and the backshore of the beach was protected from storm surges and flooding. However, storm water runoff deeply infiltrated the dune and created gullies which required emergency maintenance. The researchers conclude that comprehensive studies of the hybrid dune designs are needed to determine their effectiveness.

Reed, D., van Wesenbeeck, B., Herman, P.M.J., Meselhe, E. (2018). Tidal flat-wetland systems as flood defenses: Understanding biogeomorphic controls. *Estuarine, Coastal and Shelf Science, 213,* 269-282. doi: https://doi.org/10.1016/j.ecss.2018.08.017.

- A review of how natural tidal flat-wetlands protect coastlines, and improvements that can be made to them to increase their effectiveness. The researchers look primarily at 3 types of tidal flat-wetlands, list their limiting factors, and propose potential improvements that can be made. The first type is prograding marsh and accreting tidal flats (a gentle sloping marsh that is accreting seaward), which has current and predicted limiting factors of continued sediment deposition to maintain elevation in the face of sea level rise and space to continue prograding seaward. The proposed improvements for this are to maintain or second type is marsh cliff with rejuvenation and dynamic tidal flats (a marsh with seaward vegetated cliffs formed from collapsing blocks of consolidated marsh retained in the intertidal zone), which has current and predicted limiting factors of continued sediment deposition to maintain elevation in the face of sea level rise, maintenance of eroded sediment in the transition zone, and space to migrate landward. The proposed improvements are to maintain or increase sediment supplies, manage realignment of the marsh, and limit wave energy to current levels. The last type is retreating marsh and eroding tidal flats (a marsh with a steep seaward cliff, no sediment retention in the intertidal zone, and eroding tidal flats), which has current and predicted limiting factors of reducing elevation in the tidal frame, reducing tidal flat elevation, no sediment retention in the intertidal zone, and space to migrate landward. The proposed

improvements are to retain and/or deposit sediment in the intertidal zone, manage realignment of the marsh, and construct new marsh substrate and/or limit wave energy at the marsh margin.

Saintilan, N., Kovalenko, K.E., Guntenspergen, G., Rogers, K., Lynch, J.C., Cahoon, D.R., Lovelock, C.E., Friess, D.A., Ashe, E., Krauss, K.W., Cormier, N., Spencer, T., Adams, J., Raw, J., Ibanez, C., Scarton, F., Temmerman, S., Meire, P., Maris, T., Thorne, K., Brazner, J., Chmura, G.L., Bowron, T., Gamage, V.P., Cressman, K., Endris, C., Marconi, C., Marcum, P., St. Laurent, K., Reay, W., Raposa, K.B., Garwood, J.A., Khan, N. (2022). Constraints on the adjustment of tidal marshes to accelerating sea level rise. *Science, 377*(6605), 523-527. doi: 10.1126/science.abo7872.

- Researchers analyzed 97 marsh sites in the eastern US, the UK, South Africa, and Australia to determine how well they will be able to respond to sea level rise. For the US and UK marshes, it is likely they will reach equilibrium points in the face of low sea level rise, as their sedimentation rates positively correlate with sea level rise, increasing their elevation with the rising water levels. However, under moderate to severe sea level rise, they will likely not be able to increase in elevation fast enough and will be replaced by unvegetated mud flats. It also depends on a variety of factors such as inundation duration and depth, plant productivity, atmospheric $CO_2$, and tidal hydrodynamics and river discharge. Based on surveys of marsh sedimentation and water levels, less than half of accreted sediments translated to elevation gain, which decreased with higher rates of sea level rise. Based upon these observations, the researchers conclude that the point where sea level rise surpasses marshes' natural ability to respond by increasing in elevation is between 5 and 10 mm per year, and may be even lower in other types of marshes in other parts of the world.

Takahashi, H., Zdravkovic, L., Tsiampousi, A., Mori, N. (2022). Destabilization of seawall ground by ocean waves. *Geotechnique*, (ahead of print). doi: https://doi.org/10.1680/jgeot.21.00420

- Researchers used centrifuge models to determine how wave action on the shoreline and sediment under and around seawalls causes them to fail, with focus of fluid viscosity, sediment porosity, and wave height. They were able to demonstrate two ways in which failure occurred. Failures occurred due to erosion of the sediment in front of the wall, as well as saturation of the sediment behind the wall due to wave overtopping and ground runoff, causing both instability of the ground, as well as pressure forces on the structure. The first method of seawall failure to be demonstrated was "floating" or an uplifting force on a panel of the wall due to the pressure caused by wave overtopping, which was dependent on the viscosity of the water and whether or not the seawall has a seal in place. For low viscosity water, the absence of a seal caused much quicker failure, while the presence of a seal experienced just as many failures, though delayed in the time in which the failures occurred. For higher viscosity water (made by using dissolved cellulose to mimic high organic content), the presence of a seal actually increased the effects of

pressure-related failure. The second demonstrated failure method was by ground sliding, which occurred in several different ways. The first was due to increased weight and fluctuating suction and degree of saturation of the ground beneath the wall, the second was due to the seepage force underneath the wall caused by backwash, and the third was due to increased pressure behind the wall from saturation combined with the uplifting force against the bottom of the wall.

Molino, G.D., Carr, J.A., Ganju, N.K., Kirwan, M.L. (2022). Variability in marsh migration potential determined by topographic rather than anthropogenic constraints in the Chesapeake Bay region. *Limnology and Oceanography LETTERS, 7*(4), 321-331. doi: https://doi.org/10.6073/pasta/d57c49f666bd8b7ad692a5230573e020

- Researchers quantified potential sea-level driven conversion of upland to marsh for the Chesapeake Bay. Historical data shows that in the last 150 years, 400 $km^2$ of upland around the Chesapeake Bay has converted to marsh, and that trend is continuing to accelerate with increasing sea level rise. Based upon their predictory models, by 2100, the total area of upland to marsh conversion for NOAA's lower SLR prediction is 1050 $km^2$ and 3748 $km^2$ for NOAA's higher prediction. They also found that anthropogenic use of the upland has little effect on its conversion to marsh, and it is instead the topography and elevation that are the significant factors.

Sudol, T.A., Noe, G.B., Reed, D.J. (2020). Tidal wetland resilience to increased rates of sea level rise in the Chesapeake Bay: Introduction to the special feature. *Wetlands, 40,* 1667-1671. doi: https://doi.org/10.1007/s13157-020-01391-5

- A collection of papers from the Marsh Resilience Summit in the Chesapeake Bay Region. 10 research papers regarding sea level rise impacts on marshes in the Bay have been summarized. The first papers to be summarized outline the process of using dredged sediment from the Bay for marsh creation. One paper states that the sediment must be dried before it is used so that it develops the proper chemical processes and contents to promote the development of a healthy marsh. The second paper shows how a created marsh from this process increases in elevation at the same pace as sea level rise, has high primary production and vegetation growth, and sequesters carbon equivalently to natural marshes. The next summaries deal with marsh migration and erosion, specifically how low-lying uplands around the Bay have been converting to marshes, especially "valley" marshes more so than other types of marshes. The next section deals with future marsh migration projections, which predict that over half of current tidal marshes will disappear by 2100, and what those losses translate to. One paper focuses on the loss of native mussel populations, which is predicted to decline by over 50% by 2050, leading to decreased water quality in the Bay. Another discusses how sea level rise and erosion are leading to increased amounts of residential properties with some type of shore protection, most of which are armored, though there are a variety of factors affecting the decision (this paper Stafford & Guthrie 2020 has been listed previously above). The last section discusses social, legal, and policy influences. One paper states that better wetland migration planning relies on a thorough understanding of the socio-economic needs of rural coastal uplands. Another paper outlines the factors that must be included in a comprehensive wetland mitigation strategy, which are: planning, data, voluntary land acquisitions, legal tools, and community engagement. The final paper discusses the policy challenges faced by marsh preservation and community resilience; namely, the relocation of communities that are or will be affected by marsh migration and sea level rise. One possible source for doing this is the new FEMA Building Resilient Infrastructure and Communities program, which funds areas adopting a "managed retreat" strategy.

Bigalbal, A., Rezaie, A.M., Garzon, J.L., Ferreira, C.M. (2018). Potential impacts of sea level rise and coarse scale marsh migration on storm surge hydrodynamics and waves on coastal protected areas in the Chesapeake Bay. *Journal of Marine Science and Engineering, 6*(3), 86. doi: https://doi.org/10.3390/jmse6030086

- Researchers studied the impacts on natural protected areas in the Bay from storm surges exacerbated by sea level rise. They studied 4 areas by using historical and synthetic storms to generate models for current and future scenarios, which include SLR projections and marsh migration patterns. They found that the maximum depth in the protected areas corresponded linearly with SLR, but other properties such as inundation, max wave height, and current velocities were dependent on a wide array of factors. For example, one area is expected to be completely flooded by storm surges under current conditions, while others would not be, even under the highest SLR projections. This is due largely to the topography of the areas, but is also dependent on storm pathways and intensities. However, all areas are expected to have at least 70% flooding from storm surges under the highest SLR prediction, and all impacts facing the areas increase significantly with a 1m threshold of SLR.

Le Cozannet, G., Bulteau, T., Castelle, B., Ranasinghe, R., Woppelmann, G., Rohmer, J., Bernon, N., Idier, D., Louisor, J., Salas-y-Melia, D. (2019). Quantifying uncertainties of sandy shoreline change projections as sea level rises. *Scientific Reports, 9,* 42. doi: 10.1038/s41598-018-37017-4

- Researchers used one of two models, the Bruun Rule and the Probabilistic Coastline Research (PCR) model, to quantify the erosive impact of sea level rise while accounting for its future uncertainty. The Bruun Rule is the historically used model and assumes landward translation of the beach profile as sea level rises. The PCR model is newer and quantifies sediment losses at the dune toe during storms and sediment gains due to aeolian transport between storms. Using 3 different sea level rise trend predictions, RCP 2.6, 4.5, and 8.5, The researchers calculated shoreline change projections using both the Bruun Rule and PCR. The Bruun Rule projections show very little chance of of shorelines expanding seaward, and have large rates of uncertainty due to sea level rise variability. The PCR projections are more even in terms of landward and seaward shoreline movement, and also have much smaller rates of uncertainty as they are less sensitive to sea level rise. Both projection methods predict that a strong increase in shoreline erosion will not occur before 2050, which gives proper authorities time to plan the best course of action to protect against erosion and sea level rise. They conclude by stating that more research into coastal impact models is needed so that more accurate management strategies can be chosen.

Elsey-Quirk, T., Mariotti, G., Valentine, K., Raper, K. (2019). Retreating marsh shoreline creates hotspots of high-marsh plant diversity. *Scientific Reports, 9,* 5795. doi: https://doi.org/10.1038/s41598-019-42119-8

- Researchers studied the effects of marsh edge retreat on plant diversity by using a plant competition model. Wave action on the marsh edge extending 20 m landward causes distinct gradients in vegetation structure due to physical-sedimentary disturbances. These disturbances and competition trigger high rates of plant diversity in the different zones, but as sea level rises and marsh retreat increases, the available space for high marsh plants (the most diverse and competitive zone) is likely to decrease, leading to a decrease in overall diversity of the marsh.

Johnson, E.E., Medina, M.D., Bersoza Hernandez, A.C., Kusel, G.A., Batzer, A.N., Angelini, C. (2019). Success of concrete and crab traps in facilitating eastern oyster recruitment and reef development. *PeerJ, 7,* e6488. doi: 10.7717/peerj.6488

- Researchers tested two substrates, concrete and recycled crab traps, over the course of 22 months at 5 sites in northwestern Florida to determine which one performed better at recruiting oyster larvae and developing oyster reefs. The crab traps were left intact, and the concrete was formed into a rectangular shape with a hollow middle. They observed that the concrete structures were settled more quickly than the crab traps and had higher densities of spat and juvenile oysters, the crab traps had larger volumes of reefs than concrete, and both had similar biomass and number of adult oysters. They also observed that structures placed at lower elevations that were more frequently inundated had higher oyster size, abundance, and biomass than those at higher elevations.

Hughes, Z.J., FitzGerald, D.M., Wilson, C.A., Pennings, S.C., Wieski, K., Mahadevan, A. (2009). Rapid headward erosion of marsh creeks in response to relative sea level rise. *Geophysical Research Letters, 36,* L03602. doi: doi:10.1029/2008GL036000.

- Researchers used aerial imagery to study the morphological changes of tidal creeks in SC in response to local relative sea level rise. The analyzed photographs from 1968-2008 to observe the changes, and what they determined was a headward erosion rate of approximately 1.9m per year, suggesting it is unable to keep up with the local sea level rise rate of >3.2mm per year. According to their field observations, the sediments of the area are largely comprised of a thick, dense mud underneath a thinner layer of dense and highly organic mud, the creek beds are lower than the marsh platform and create a circular depression that is frequently flooded during a tidal cycle, and the water flow of the creeks is mostly ebb-tide dominated. The frequent inundation of the marsh platform combined with vegetation dieback and invertebrate burrowing caused a barren and depressed area beyond the channel, leading to an increase in erosion. Based on these observations, they conclude that the atypical morphological structure of the creeks and their headward erosion is due to biophysical feedbacks and substrate collapse.

Beheshti, K.M., Wasson, K., Angelini, C., Silliman, B.R., Hughes, B.B. (2021). Long-term study reveals top-down effect of crabs on a California salt marsh. *Ecosphere, 12*(8), e03703. doi: https://doi.org/10.1002/ecs2.3703.

- Researchers studied saltmarshes on the CA coast for the effects of crab populations on marsh vegetation and soil responses. They studied 5 marsh sites and exposed them to two different treatments: reduced crab populations or natural (ambient) crab populations. The reduced crab treatment was done by using crab traps to trap and remove crabs from the area. Crab traps were used in all areas in order to document size and sex to determine crab biomass, but caught crabs were placed back into the area for the natural treatments. Vegetation biomass and percent cover and sediment bulk density, cores, and accretion were also measured. The measurements took place over the course of 5 years every August and September. They found that decreasing crab populations increased vegetation biomass and bulk density, and that the marsh resilience-affecting factors of root biomass and sediment bulk density decreased linearly with increasing crab burrows. They therefore conclude that shore crabs are exerting top-down control on marsh vegetation, sediment, and resilience.

Holdredge, C., Bertness, M.D., Altieri, A.H. (2009). Role of crab herbivory in die-off of New England salt marshes. *Conservation Biology, 23*(3), 672-679. doi: https://doi.org/10.1111/j.1523-1739.2008.01137.x

- Researchers studied 12 marshes around the Cape Cod, MA area for the most common and easy to identify type of marsh die-off, which is denuded, burrow-riddled creek banks. Researchers used visual inspection to quantify the extent of marsh die-off as the proportion of the length of the creek bank by denuded, burrow-riddled substrate with evidence of crab herbivory on bordering cordgrass. They also measured the proportion of native cordgrass herbivory at each area. At 9 of the 12 marshes (3 marshes did not allow trapping) they used pitfall traps to quantify crab density. They then set up experimental procedures by having areas of free access to vegetation by crabs, and areas of exclusion. They also tethered crabs to track predation rates on them. What was found was that free access areas experienced much greater cordgrass die-offs than exclusion areas. They also found, through the tethering and pitfall experiments, that predation of crabs was very low in Cape Cod compared to high predation rates in tethering experiments conducted in the similar habitat of Narragansett Bay, RI, which correlated with the much higher crab densities found in Cape Cod compared to Narragansett Bay. This supported their hypothesis that low predation on crabs is causing higher rates of marsh die-offs, as Cape Cod has many areas of marsh die-offs, low rates of crab predation, and high crab densities, while Narragansett Bay has few areas of marsh die-offs, high rates of crab predation, and low crab densities.

Bikker, J., Lawson, J., Wilson, S., Rochman, C.M. (2020). Microplastics and other anthropogenic particles in the surface waters of the Chesapeake Bay. *Marine Pollution Bulletin*, *156*, 111257. doi: https://doi.org/10.1016/j.marpolbul.2020.111257

- Researchers sampled the upper Chesapeake Bay surface waters for microplastics. The majority of microplastics consisted of polyethylene (32%), polypropylene (13%), and polystyrene (9%). They also hypothesize based on other papers that the majority of microplastics come from effluent wastewater systems.

Mitchell, M., Isdell, R.E., Herman, J., Tombleson, C. (2021). Impact assessment and management challenges of key rural human health infrastructure under sea level rise. *Frontiers in Marine Science, 8*, 631757. doi: 10.3389/fmars.2021.631757

- Researchers wanted to quantify the effects of sea level rise-induced flooding and saltwater intrusion on rural septic systems and adjacent water ways. They started by using GIS Emerging Hot Spot Analysis tools to identify areas of high amount of septic repair permits located near the shoreline between 2008 and 2018. However, this technique was abandoned after it proved to provide very poor ability in predicting future damage. Overall, they were able to identify areas of constant hot spots, which they theorized were areas that were unsuitable for septic systems, areas of sporadic hot spots that may be due to sea level variability or periods of aging systems, and emerging hot spot areas that are due to either changing water level conditions or septic systems reaching the end of their lifespan. Based on these, they concluded that the last two examples warranted further study to determine if the hot spots are related to sea level rise and changing conditions, or if they are just due to old systems. The second method they used was to identify high density areas of failures, which they found to be largely located near waterbodies. They theorize this is either due to constant high water table levels, or due to sea level and/or precipitation-induced flooding, and that further research needs to be done on these areas as well. They conclude that further research is needed, and that some form of state-wide data collection is needed, as these areas pose significant potential impacts to human health and water quality.

Stephenson, K., Ferris, W., Bock, E., Easton, Z.M. (2021). Treatment of legacy nitrogen as a compliance option to meet Chesapeake Bay TMDL requirements. *Environmental Science & Technology*, *55*(20), 13593-13601. doi: https://doi.org/10.1021/acs.est.1c04022

- Researchers tested to see if using denitrifying spring bioreactors to remove legacy nitrogen from groundwater was as effective as conventional agricultural and urban methods with 3 different classes of "buyers" in the Chesapeake Bay watershed. The three classes were permitted point sources, permitted municipal stormwater systems (MS4s), and state nonpoint managers (NPS). The bioreactors work by being installed within groundwater flows to filter the groundwater using microbial denitrification, which converts water-soluble $NO_3$ to inert $N_2$ gas. These bioreactors have recently been approved for use by the Chesapeake Bay Program. Through testing of cost effectiveness, administration costs, and performance of denitrification, they found that, overall,

conventional methods perform better. However, they believe that the bioreactors can still provide a beneficial service and be used in addition to conventional methods to achieve lower TMDL levels.

Palinkas, C.M., Sanford, L.P., Koch, E.W. (2017). Influence of shoreline stabilization structures on the nearshore sedimentary environment in mesohaline Chesapeake Bay. *Estuaries and Coasts, 41,* 952-965. doi: https://doi.org/10.1007/s12237-017-0339-6

- Researchers studied the effects of shoreline structures on the nearshore habitat by evaluating sediment characteristics and sediment accumulation rates in response to breakwaters, riprap, hybrid living shorelines, and "soft" living shorelines. They did this by taking sample cores to analyze the sediment mud content, organic content, and $^{210}$Pb to measure age. Their findings included: sediments tended to be finest at soft living shorelines and breakwaters, sediments tended to be coarsest at hybrid living shorelines, soft living shorelines had the highest sediment organic content, hybrids had the lowest organic content, sedimentation rates decreased for soft living shorelines and breakwaters, sedimentation rates remained unchanged for rip rap, and sedimentation rates increased at hybrid sites. Most of the sites did not have SAV, but of the 4 that did, both breakwaters and one of two rip rap sites increased SAV.

Seitz, R.D., Aguilera, S., Wood, M.A., Lipcius, R.N. (2019). Production and vertical distribution of invertebrates on riprap shorelines in Chesapeake Bay: A novel rocky intertidal habitat. *Estuarine, Coastal, and Shelf Science, 228,* 106357. doi: https://doi.org/10.1016/j.ecss.2019.106357

- Researchers wanted to measure species diversity, secondary production, and vertical distribution of invertebrates on armored shoreline habitats, as well as measuring and comparing the benthic epifaunal production on armoring with infaunal production in natural soft-bottom shorelines. They surveyed three sites in each of two rivers along the Chesapeake Bay. They found that 1) epifaunal production on armoring was 7 times higher than natural infaunal production, 2) vertical distribution was similar between natural and armored shorelines, 3) species diversity was higher on armored shorelines, and 4) secondary productivity was higher on armored shorelines. Based on the results, they conclude that armored shorelines, at least from an invertebrate standpoint, increase species diversity and richness as well as increase productivity over that of natural, soft-bottom shorelines.

Shen, Y., Tahvildari, N., Morsy, M.M., Huxley, C., Chen, T.D., Goodall, J.L. (2022). Dynamic modeling of inland flooding and storm surge on coastal cities under climate change scenarios: transportation infrastructure impacts in Norfolk, Virginia USA as a case study. *Geosciences, 12*(6), 224. doi: https://doi.org/10.3390/geosciences12060224

- Researchers developed models of flood effects on Norfolk infrastructure with effects from climate change and sea level rise. Flood areas were created using drone footage and records of previous flooding. They created models using storm surge data and urban flooding data to assess flooding under current (2020) conditions. They then used these models to assess future flooding scenarios under relative sea level rise and climate change-affected rainfall for 2070. Under 2020 conditions, rainfall-induced flooding causes far more impacts on transportation infrastructure than tidal flooding. However, under predicted 2070 conditions, tidal flooding will be the dominant impacting force. By 2070, tidal nuisance flooding (minor flooding of streets, sidewalks, and other infrastructure) is predicted to be a daily occurrence, and the total link close time (the time transportation infrastructure is shut down due to flooding) caused by tidal nuisance flooding is predicted to be 4 times higher than that caused by current 2020 50-year storm surge flooding.

Tang, J., Lyu, Y., Shen, Y., Zhang, M., Su, M. (2017). Numerical study on influences of breakwater layout on coastal waves, wave-induced currents, sediment transport and beach morphological evolution. *Ocean Engineering, 141*, 375-387. doi: 10.1016/j.oceaneng.2017.06.042.

- Researchers created a numerical model of breakwater influence on coastal wave and sediment processes using several equations that consider wave refraction, wave diffraction, wave breaking, wave-induced nearshore current, wave radiation stresses, sediment transport, and bedload. The model and its equations were tested against the results from the Army Corps' Large-scale Sediment Transport Facility, which concluded that the numerical model and the large-scale test produced similar findings. This means that the model can be used accurately for real-world breakwaters and their environments to accurately predict the effects of waves, sediment transport, and other coastal processes for specific designs.

Berkowitz, J.F., Beane, N.R., Philley, K.D., Hurst, N.R., Jung, J.F. (2021). An assessment of long-term, multipurpose ecosystem functions and engineering benefits derived from historical dredged sediment beneficial use projects. *US Army Corps of Engineers Engineer Research and Development Center, ERDC/EL TR-21-4.* doi: http://dx.doi.org/10.21079/11681/41382.

- Researchers outlined methods for and results from using dredged benthic sediment for beneficial use. The summary of their methods includes the following: Samples of the dredged materials were collected in the field and transported back to the lab in coolers, where they were homogenized and analyzed for moisture content, bulk density, loss on ignition for percent organic matter, pH, salinity, ammonium, nitrate, soluble reactive phosphorus, total carbon, total nitrogen, and total phosphorus. Triplicate 10cm soils samples were collected from each location to determine belowground biomass following 1970s assessment period methods. After homogenization, samples were dried and analyzed for moisture content. They were then ground and re-homogenized for organic matter content analyzation. Ammonium, nitrate, and soluble reactive phosphorous were analyzed using field moist soil, which was filtered, acidified, and measured using a calorimetric automated discrete analyzer. Carbon and nitrogen were analyzed via an elemental combustion system, and total phosphorous was analyzed via the ashing-digestion method. Salinity and pH were measured by creating a slurry of field moist

samples and DI water, and belowground biomass was measured by sieving out roots and rhizomes, which were then dried, weighed, and compared to the total core area.

The researchers outline the basic methods for beneficial use of dredged material. The material must first be analyzed using the aforementioned methods to determine that it is acceptable for use as habitat (primarily focusing on the salinity and nutrient contents). If it is deemed acceptable, the dredged material may be placed along the shore, where it can be graded and planted to create wetland habitat. They note that many of the historical beneficial use projects required no additional maintenance once completed. They then note that many of the ecological functions of these created wetlands have many linked engineering benefits such as wave attenuation, elevation maintenance, sediment retention, and many others. They outline that all ecosystem functions of the created wetlands (physical, habitat, and biogeochemical) provide varying engineering benefits. Using these criteria, they determined that all 6 of their historic beneficial use research sites achieved both the desired ecological and engineering functions. They also determined that beneficial use projects should focus on achieving these outlined ecological and engineering functions rather than replicating adjacent reference habitats in order to maximize their success.

Gilmour, C., Bell, T., Soren, A., Riedel, G., Riedel, G., Kopec, D., Bodaly, D., Ghosh, U. (2018). Activated carbon thin-layer placement as an in-situ mercury remediation tool in a Penobscot River salt marsh. *Science of the Total Environment, 621,* 839-848. doi: https://doi.org/10.1016/j.scitotenv.2017.11.050.

- Researchers tested 4 different methods of thin-layering materials for their effectiveness at reducing MeHg pollution in water and soils of a salt marsh. They tested activated carbon, biochar, $FeCl_2$, and lime. Each method was spread over one plot and monitored for 2 years in comparison to two adjacent but untreated control plots. The activated carbon performed best, reducing MeHg water concentrations by over 90% in one month. Biochar had little to no effect on MeHg water concentrations, and increased soil MeHg concentrations. Both $FeCl_2$ and lime had no effect on MeHg concentrations. The only mention of effects on soil MeHg concentrations is regarding biochar, there is no mention of the effects by the other 3 treatments.

Ganju, N.K. (2019). Marshes are the new beaches: Integrating sediment transport into restoration planning. *Estuaries and Coasts, 42,* 917-926. doi: https://doi.org/10.1007/s12237-019-00531-3

- This researcher challenges the way that marshes are currently managed and restored through sediment renourishment, especially by using dredged sediment. They argue that dredging adjacent tidal channels can cause them to refill with sediment from the marsh surface or elsewhere within the marsh system. They also argue that shoreline protection strategies that prevent erosion of the marsh edge are harmful to the marsh's natural processes of migration and sediment transport. They instead argue that any management strategy for a marsh system should include sediment transport research and modeling in order to determine the best course of action so as to not impede natural processes.

Hardaway, C.S. Jr., Milligan, D.A., Wilcox, C.A., Meneghini, L.M., Comer, T.R. (2005). The Chesapeake Bay breakwater database project hurricane Isabel impacts to four breakwater systems. *Virginia Institute of Marine Science*, William & Mary, Gloucester Point, VA. doi: https://doi.org/10.21220/V5M13F

Milligan, D. A., Hardaway, C., Wilcox, C. A., & Priest, W. I. (2018) Oyster Bag Sill Construction and Monitoring at Two Sites in Chesapeake Bay. Virginia Institute of Marine Science, College of William and Mary. https://doi.org/10.25773/n2v0-td81

The oyster bag sill is a living shoreline management strategy that can create habitat, mitigate erosion, and provide climate change adaptation in Chesapeake Bay. These shore protection structures restore oyster and other shellfish habitat, and as they will not be harvested, they lead to long-term habitat creation. The assessment of existing sites that have been in place for several years indicates that in low fetch situations (<1 mile), oyster bag sills can provide shore protection through the creation or stabilization of marsh. The design of the sill should be site specific; larger fetches should have larger structures, and the bags should be placed closer to the eroding marsh scarp particularly along sites with a sand platform. When placed farther from the eroding marsh scarp, the top bags tended to roll toward the shoreline. No bag movement occurred on the sills that consisted of 6 bags. Sites that were filled with sand and planted with grass had thriving marshes. However, initial monitoring of several oyster bag sills installed without sand fill and marsh plantings indicates that sediment can be deposited behind the structure allowing marsh grass to grow riverward. The existence of natural oysters at the site or along shorelines nearby is a good indication that spat may attach to the bags thereby working to cement the bags together.

Milligan, D.A., Hardaway, C.S. Jr., Wilcox, C.A., DiNapoli, N.J. (2021). Living shoreline sea-level resiliency: Performance and adaptive management of existing sites year 3 summary report. *Virginia Institute of Marine Science,* William & Mary, Gloucester Point, VA. doi: https://doi.org/10.25773/sfsv-bc33

Hardaway, C.S. Jr., Milligan, D.A., Wilcox, C.A., Milligan, A.C. (2019). Living shoreline sea level resiliency: Performance and adaptive management of existing breakwater sites, year 2 summary report. *Virginia Institute of Marine Science,* William & Mary, Gloucester Point, VA. doi: https://doi.org/10.25773/jpxn-r132

Hardaway, C.S. Jr., Milligan, D.A., Wilcox, C.A. (2018). Living shoreline sea-level resiliency: Performance and adaptive management of existing sites. *Virginia Institute of Marine Science,* William & Mary, Gloucester Point, VA. doi: https://doi.org/10.25773/nnbj-m745

## Year 2

Mitchell, M., Bilkovic, D.M. (2019). Embracing dynamic design for climate-resilient living shorelines. *Journal of Applied Ecology, 56,* 1099-1105. doi: 10.1111/1365-2664.13371

- Article analyzes best ways for living shorelines to be resilient and adapt in the face of sea level rise. They conclude that designs that more closely mimic the natural environment are the most resilient, as they can adapt using feedback loops like natural shorelines. The factors that should be considered in designing resilient living shorelines are 1) designs and locations that allow for natural landward marsh retreat in the face of rising sea levels, 2) healthy plant communities that focus on species diversity and vegetation density rather than traditional grid planting, maximizing productivity and sediment retention, 3) utilizing sill structures that enhance sedimentation while not limiting faunal access to the marsh (they mention sill windows) to allow oyster growth to occur behind the sills to increase stability. The also acknowledge that not all living shorelines will be able to naturally adapt to rapid sea level rise, and that maintenance will be necessary. Their preferred form of maintenance is thin-layering from dredged sediments

Safak, I., Angelini, C., Norby, P.L., Dix, N., Roddenberry, A., Herbert, D., Astrom, E., Sheremet, A. (2020b). Wave transmission through living shoreline breakwalls. *Continental Shelf Research, 211*, 104268. doi: https://doi.org/10.1016/j.csr.2020.104268

- Researchers studied wave transmission through living shoreline breakwalls using both field observations and theoretical methods. They used breakwaters made of tree branches at varying porosities and tides to measure the wave transmission from boat wakes. The lower porosity breakwater had an average transmission rate of 53% and transmission increased as water depth increased. The higher porosity breakwater experienced and average transmission rate of 83% and had significantly less variation corresponding to water depth.

Morris, R.L., La Peyre, M.K., Webb, B.M, Marshall, D.A., Bilkovic, D.M., Cebrian, J., McClenachan, G., Kibler, K.M, Walters, L.J., Bushek, D., Sparks, E.L., Temple, N.A., Moody, J., Angstadt, K., Goff, J., Boswell, M., Sacks, P., Swearer, S.E. (2021). Large-scale variation in wave attenuation of oyster reef living shorelines and the influence of inundation duration. *Ecological Application, 31(6),* e02382. doi: https://doi.org/10.1002/eap.2382

- The researchers studied the effectiveness of oyster reef living shoreline designs with regards to wave attenuation and oyster habitat suitability along the Atlantic and Gulf coasts. In order to be effective in both categories, the oyster reefs had to both reduce wave height and be inundated at least 50% of the time in order to be considered suitable habitat for oysters. They used 15 pairs of sites, one oyster reef and one control site per pair, in 5 locations: one in Louisiana, one in Alabama, one in Florida, one in Virginia, and one in New Jersey. The oyster reefs varied in size and construction. What was found

was that, for all oyster reefs, only the ones that were considered unsuitable oyster habitat (less than 50% inundation time) significantly reduced wave height. Because of this, the researchers suggest that oyster reef living shoreline designs need to be reexamined in order to develop a design that can both sustain a healthy oyster population and effective reduce wave height.

Polk, M.A., Gittman, R.K., Smith, C.S., Eulie, D.O. (2021). Coastal resilience surges as living shorelines reduce lateral erosion of salt marshes. *Integrated Environmental Assessment and Management, 18(1),* 82-98. doi: https://doi.org/10.1002/ieam.4447.

- The researchers studied 17 living shoreline sites 8 control sites along the NC coast before and after Hurricane Florence (cat 1) with RTK. All living shoreline sites, regardless of age, environmental variables, and design reduced lateral erosion of the fringing salt marshes compared to the unprotected control sites.

Polk, M.A., Eulie, D.O. (2018). Effectiveness of living shorelines as an erosion control method in North Carolina. *Estuaries and Coasts, 41,* 2212-2222. doi: https://doi.org/10.1007/s12237-018-0439-y

- Researchers conducted shoreline surveys at 12 sites with 17 living shorelines and 9 control areas, comparing the current shoreline with imagery from 1993. The sites ranged from seaward barrier islands, soundward barrier islands, river islands, and mainland shores, and the living shorelines varied in their composition, construction, and topography. Compared to the control sites, 12 of the 17 living shorelines slowed erosion, and 6 of the 12 actually started to accrete sediments.

Spiering, D.W., Kibler, K.M., Kitsikoudis, V., Donnelly, M.J., Walters, L.J. (2021). Detecting hydrodynamic changes after living shoreline restoration and through an extreme event using a Before-After-Control-Impact experiment. *Ecological Engineering, 169*, 106306. doi: https://doi.org/10.1016/j.ecoleng.2021.106306.

- Researchers studied 3 sites over a 16-month period in Florida’s Mosquito Lagoon. The first site was a restored living marsh grass shoreline, the second was a natural mangrove shoreline, and the third was a bare shoreline with no vegetation. Water level sensors and wave loggers were placed nearshore and in the channel at each site, while a channel velocity sensor and wind speed sensor were placed in the channel, and a sediment dynamics sensor was placed nearshore. 9 weeks into the study, Hurricane Irma passed through the area, but did not destroy the living shoreline. In the first few months after its construction, the living shoreline system reduced current velocity and wave height by 62% and 83% respectively, but only if water levels were at or below the constructed breakwaters. If water levels exceeded breakwater height, current velocity actually exceeded the bare control site. It wasn’t until the end of the 16-month period that vegetation at the constructed site was established enough to produce similar current velocity and wave height reductions to the natural mangrove site, suggesting that living shoreline systems, at least in areas impacted by significant storm events, may need upwards of a year or longer before they can produce meaningful erosion control and shoreline protection.

Vien, P. (2020). Testing the influence of water depth in design of created oyster reef for living shoreline applications. *University of Central Florida Electronic Theses and Dissertations, 2020-,* 1451. doi: https://purls.library.ucf.edu/go/DP0027145

- The author wanted to understand how water depth relative to the crest of submerged artificial oyster reef structures influences nearshore hydrodynamic processes and sediment transport or retention in nearshore areas. The conducted a study on bagged oyster shell reefs, continuous and gapped, located 3m (intertidal) from edge of vegetation (EOV) and 12m (subtidal) from EOV. The 3m reefs showed greater wave attenuation than the 12m reefs. Gapped vs continuous reefs showed no significant difference in sediment accretion, but the 12m reefs showed 20% more accretion than the 3m reefs. Overall, despite the lower wave attenuation of the 12m reefs, they experienced greater sediment retention and accretion than the 3m sites. The entire project area (all 4 reefs) produced a total net gain of 418.5 $m^3$ of sediment, with an average accretion height of 7.9 cm after 3 years.

Spiering, D. (2019). Analysis of hydrodynamic and bathymetric gradients in Canaveral National Seashore following living shoreline and oyster restoration. *University of Central Florida Electronic Theses and Dissertations,* 6395. doi: http://purl.fcla.edu/fcla/etd/CFE0007535

- An unmodified control site and restored site, consisting of emergent vegetation planting and oyster breakwater structures, were analyzed using Before-After-Control-Impact to determine hydrodynamic and bathymetric variations among the sites. The combination of vegetation and oyster breakwaters showed a 46% reduction in wave velocity compared to the control site. Additionally, the nearshore slope of the restored site was compared with a nearby seawall site, and the seawall site had a 161% steeper nearshore slope due to toe scouring.

Dutta, S., Biber, P.D., Boyd, C.A. (2021). Nearshore sediment comparisons among natural, living, and armored shorelines in Mobile Bay, Alabama. *Southeastern Naturalist, 20(1),* 135-151. doi: https://doi.org/10.1656/058.020.0114

- Researchers studied 2 project sites, each with a natural shoreline, living shoreline, and hardened shoreline for sediment composition. They found that the hardened shorelines were over 90% sand and contained significantly less carbon and nitrogen than the other two shoreline types.

McClenachan, G.M., Donnelly, M.J., Shaffer, M.N., Sacks, P.E., Walters, L.J. (2020). Does size matter? Quantifying the cumulative impact of small-scale living shoreline and oyster reef restoration projects on shoreline erosion. *Restoration Ecology, 28(6),* 1365-1371. doi: https://doi.org/10.1111/rec.13235

- Researchers wanted to establish an affordable, cost-effective method to monitor the long-term impacts of smaller living shoreline and oyster reef projects on shorelines and their

erosion rates. They found that they could use the DSAS tool in ArcGIS to accurately quantify cumulative shoreline change for small-scale projects. Using satellite imagery from USGS Earthexplorer, the were able to determine in $m^2$/year the net change, which happened to be accretion due to the projects, of each project shoreline, showing that DSAS and satellite imagery is an accurate and cost-effective form of shoreline monitoring.

Young, S.S., Rao, S., Dorey, K. (2021). Monitoring the erosion and accretion of a human-built living shoreline with drone technology. *Environmental Challenges, 5,* 100383. doi: https://doi.org/10.1016/j.envc.2021.100383

- Researchers used a drone (dji Phantom 4 Pro) to monitor the shoreline change of a 240m-long living shoreline. From the drone imagery, they created an orthographic mosaic, a digital terrain model (DTM), and a digital surface model (DSM). The imagery was georeferenced with a ground survey. Drone imagery of the shoreline was taken before and after the living shoreline construction as a test of accuracy, and the estimation of the shoreline change from the drone imagery was within a 3% difference of the known amount of fill used to create the living shoreline, suggesting that this method of monitoring is very accurate. Between 2020 and 2019 (LS built in 2018), the researchers calculated that 14.7% of the shoreline experienced erosion, but 52% experienced accretion, thus demonstrating the effectiveness of both the living shoreline as well as the drone imagery monitoring.

Winters, M.A., Leslie, B., Sloane, E.B., Gallien, T.W. (2020). Observations and preliminary vulnerability assessment of a hybrid dune-based living shoreline. *Journal of Marine Science and Engineering, 8(11),* 920. doi: https://doi.org/10.3390/jmse8110920

- Researchers used a high resolution unmanned aerial vehicle (UAV) to analyze and assess the construction and evolution of several hybrid dune living shorelines. The imagery from the UAV was used to create detailed, high quality DEMs, DTMs, DSMs, and orthoimagery to identify vulnerable areas and areas in need of maintenance. These, combined with tide, storm event, and other ecological/meteorological data, created a highly detailed monitoring system of the living shorelines. This is a highly detailed and accurate, although expensive, monitoring system.

Nunez, K., Rudnicky, T., Mason, P., Tombleson, C., Berman, M. (2022). A geospatial modeling approach to assess site suitability of living shorelines and emphasize best shoreline management practices. *Ecological Engineering, 179,* 106617. doi: https://doi.org/10.1016/j.ecoleng.2022.106617

- The authors have created a geospatial modeling system called the Shoreline Management Model (SMM). The SMM uses input variables such as presence of tidal marsh, beach, SAV, riparian land cover, bank height, nearshore bathymetry, fetch, and existing erosion control structures to output a recommended shoreline management practice, which was found to agree with on-site assessments 82.5% of the time. The model runs as an ArcGIS tool, and was calibrated using Chesapeake Bay shorelines. The recommendation output categories are the following: non-structural living shoreline, maintain beach or offshore breakwater with beach nourishment, hybrid gray/green living shoreline, revetment, bulkhead, groin field with beach nourishment, and special cases where expert advice is needed.

Rawat, P., Yusuf, J.E., Covi, M. (2021). Cognitive bias in decision making about development permits for living shorelines: The case of wetland boards in Virginia localities. *Ecological Engineering, 173,* 106423. doi: https://doi.org/10.1016/j.ecoleng.2021.106423

- Researchers conducted interviews of wetland board chairs and staff to determine what factors influenced their decision making. They interviewed 6 local wetland boards in Virginia's Chesapeake Bay region; 1 board chair and 1 staff member from each. They found that all board chairs had been on the board for at least 7 years, but half did not have past experience in similar board positions. All but one board chair were over 60 years of age. All board chairs had some form of post-high school education or training, and 3 staff members had graduate degrees, while another had a Bachelor's degree. In all interviews, all 12 participants mentioned that the Shoreline Management Handbook and recommendations/guidelines from government agencies (VIMS, VMRC, USACE) are important to their decision-making process. They also noted that the most important factors in accepting a project were confirming that detrimental erosion is occurring, no habitat destruction will occur, and there is no net loss of wetlands. In terms of living shorelines, 5 of the 6 board chairs confirmed that living shorelines were a typical project, but some interviewees noted that landowners prefer hardening structures over living shorelines. While all interviewees responded that technical guidelines and data were important in their decision-making process, a majority also responded that compromising and avoiding conflict with property owners played an important role as well. Some interviewees also responded that previous projects and decisions factored into their decision-making process. While most interviewees admitted that social factors (compromise, avoiding conflict) affected their decisions, all responded that they believed their permit decisions were balanced between technical/environmental factors and social factors.

Brown, J. (2018). Water, water everywhere: How nature can help. *The Nature Conservancy, 2018 Carolinas Climate Resilience Conference,* Presentation.

- Outlines the ability of hybrid gray/green living shorelines and natural marshes to withstand storm surges (Hurricane Matthew) as opposed to hardened shorelines. It also compares the unit costs of various shoreline management strategies (coir log living shoreline, beach renourishment, marsh sills, ecologically-enhanced revetment, bulkhead, oyster breakwaters, traditional breakwaters) to show that, on a per unit basis, they are all very similar. However, it also compares the costs of 200 linear feet of a concrete bulkhead, vinyl bulkhead, rip rap, and oyster shell living shorelines to show that the living shoreline is the cheapest option, while the concrete bulkhead is the most expensive (roughly triple the living shoreline).

Sicangco, C., Collini, R., Martin, S., Monti, A., Sparks, E. (2021). Cost-benefit analysis of a small-scale living shoreline project. *NOAA PLACE:SLR.* Retrieved from: https://repository.library.noaa.gov/view/noaa/48521

- A cost-benefit analysis of a living shoreline in the Gulf Coast compared to the local standard of bulkheads. The area is a 150 ft section of shoreline in Mississippi that was previously bulkheaded. The bulkhead failed, and was replaced with an oyster castle and planted vegetation living shoreline. They created the living shoreline under the assumption that it would withstand Category 1 and 2 hurricanes and be effective for at least 60 years. The total cost for the project was $14,514, about half that of what they say is the cost of a bulkhead of the same size. They also conducted a study of bulkhead owners which valued the yearly maintenance cost of a bulkhead at $31/m, totaling a yearly cost of approximately $1,417 for their project area. Therefore, they conclude that the initial cost of the living shoreline saved approximately $15,000 and will save approximately $85,020 in repair costs over the stated 60-year timeframe. They also conclude that a living shoreline could be up to 3.25 times the cost of a bulkhead initially and still be more cost-effective over 60 years.

Herbert, D., Astrom, E., Bersoza, A.C., Batzer, A., McGovern, P., Angelini, C., Wasman, S., Dix, N., Sheremet, A. (2018). Mitigating erosional effects induced by boat wakes with living shorelines. *Sustainability, 10*(2), 436. doi: https://doi.org/10.3390/su10020436

- Researchers studied the effects of boat wakes on the shoreline of the Intercoastal Waterway in Florida with and without living shorelines. They note that the boat wakes create a high-energy environment that erodes and degrades natural habitat and creates a steep nearshore bathymetry. For their test, they experimented with a living shoreline design consisting of PVC framed, stacked branch breakwalls fronting BESE and gabion oyster reefs. The 6 experiment sites consisted of 3 treatments: 1) an un modified control shoreline, 2) a living shoreline with a 30 cm high branch breakwall, and 3) a living shoreline with 60 cm tall branch breakwall. They tracked boat wake and wave activity with data loggers and used a computer algorithm to determine the porosity of the breakwalls. They do not mention any results comparing their treatments, but they do note that boat wakes occasionally exceeded their highest breakwall at 60 cm. They also used their designs' performances to calculate the ideal porosity of a breakwall for minimizing sediment displacement and maximizing wave energy dissipation, which was determined to be 0.25. Their breakwalls were determined, via the algorithm, to have a porosity of 0.64, though they note it is likely higher due to problems with the algorithm. They address that their design has a porosity much greater than the ideal amount, but they note that a breakwall of 0.25 porosity would essentially be a hardening structure, and therefore cause toe scouring and eliminate the ecological benefits of a living shoreline. They conclude by stating this information can be used to optimized future living shoreline breakwall designs.

Young, A., Runting, R.K., Kujala, H., Konlechner, T.M., Strain, E.M.A., Morris, R.L. (2023). Identifying opportunities for living shorelines using a multi-criteria suitability analysis. *Regional Studies in Marine Science, 61,* 102857. doi: https://doi.org/10.1016/j.rsma.2023.102857

- Researchers created a model to determine areas where soft and hybrid living shorelines were most applicable. They used 14 criteria (not in journal, only available in supplementary data) in their model and applied it to the entire coastline of the Australian state of Victoria. The model concluded that 74% of the total coastline was suitable for hybrid living shorelines, 65% was suitable for soft living shorelines, and 4% was not suitable for a living shoreline. Of the coastline that is already hardened, the model concluded that 67% was suitable to be replaced by a soft living shoreline, and 69% was suitable to be replaced by a hybrid living shoreline

Zhu, L., Wang, H., Capurso, W., Niemoczynski, L., Hu, K., Snedden, G. (2020a). Field observations of winda waves in upper Delaware Bay with living shorelines. *Estuaries and Coasts, 43,* 739-755. doi: https://doi.org/10.1007/s12237-019-00670-7

- The researchers wanted to study the effects of constructed oyster reefs on wave attenuation. They set 6 pressure transducers at a 4-year old oyster reef (oyster castles) living shoreline in New Jersey to measure wave variations over the course of 2 months and 4 winter storms. The height of the oyster structures ranged from 0.4 to 0.8 meters. They found that the crests of the oyster reefs were completely submerged for 85% of the time due to the site’s large tidal range. They also found that high energy waves originating in the Atlantic experienced little to no reduction in energy after passing through the oyster reefs, and in some cases, conditions behind the oyster reefs led to an amplification of wave height and energy behind the oyster reefs.

Baldauf, T. (2021). Quantifying the effect of ship wake on commonly used living shoreline treatments. *University of Delaware, Senior Thesis.* Retrieved from: https://udspace.udel.edu/server/api/core/bitstreams/fe501e48-e3f2-445b-904d-018e915cde31/content

- The author used current meters and pressure sensors at two constructed living shoreline sites in the Delaware River to measure the effects of their design on attenuating waves caused by shipping lanes over a two-week period. The first design consisted of pairs of coir logs and modified coir logs filled with oyster bags, held in place by metal stakes. The second design used unmodified coir logs fronted by a stacked branch breakwater, forming a “T” shape. Sensors were placed in front of and behind the structures. Data analyzation did not occur for the “T” designs, as they broke under the stress of the waves. As for the first design, the coir logs reduced wave height by an average of 4% and reduced wave energy a minimum of 20% to a maximum of 60%, suggesting they have at least some impact on boat wake-generated waves.

Ghiasian, M., Rossini, M., Amendolara, J., Haus, B., Nolan, S., Nanni, A., Bel Had Ali, N., Rhode-Barbarigos, L. (2019). Test-driven design of an efficient and sustainable seawall structure. *HENRY: Hydraulic Engineering Repository*, 1222-1227. doi: https://doi.org/10.18451/978-3-939230-64-9_122

- The authors have created a novel design for a modular seawall that can be used as part of a hybrid living shoreline system. The design is called “SEAHIVE” and consists of modular hollow, porous concrete structures that can be round, rectangular, or hexangular with varying sizes and numbers of perforations. The structures are made of low alkalinity, fiber reinforced concrete (FRC) and non-corrosive rebar to avoid both

structural degradation and environmental pollution. The structures can be topped with or front a sand fill and vegetation living shoreline. The structures are being tested in a wave tank system at the University of Miami under conditions similar to those found in locations around Florida, as well as storm conditions ranging from tropical storm to category 5 hurricane. Research is currently ongoing in order to develop maximum efficiency designs for a variety of wave energy environments.

Salatin, R., Wang, H., Chen, Q., Zhu, L. (2022). Assessing wave attenuation with rising sea levels for sustainable oyster reef-based living shorelines. *Frontiers in Built Environment, 8,* 884849. doi: 10.3389/fbuil.2022.884849

- Researchers used wave observations from 6 places around the constructed oyster reef (COR) (oyster castles) living shoreline at Gandys Beach in Delaware Bay to create models in FUNWAVE-TVD phase-revolving Boussinesq model in order to examine the hydrodynamics around the living shoreline. Observations were conducted in the winter over the course of 4 nor'easters. The models were used to determine the effectiveness of wave attenuation by the CORs in a variety of wave environments and depths as well as into the future in the face of sea level rise. Wave attenuation effectiveness varied with wave height, height of the COR relative to water depth, and water circulation patterns. Notably, the tallest COR at the highest elevation achieved the greatest wave attenuation, but it also had the largest portion of its structure in and above the critical exposure boundary (CEB), or area in which oyster growth is unlikely, meaning the structure is not optimized for oyster growth. However, they also found that over the next 100 years, sustainable wave attenuation capacity occurs when suitable habitat is provided that will shift the optimal growth zone (OGZ) with rising sea levels. Therefore, in order to create a resilient COR in the face of sea level rise, it needs to be placed initially within the current OGZ but also allow for a climbing OGZ so that oyster growth on the COR can shift at the same rate as sea level rise. Their model also suggests that the timeframe to achieve a COR that reaches its maximum wave attenuation capacity and then continues to maintain it with sea level rise is approximately 9 years. Therefore, to be truly sustainable while achieving maximum effectiveness, a COR needs to be placed such that it will remain within the OGZ for at least 9 years but also be able to grow with sea level rise.

Wang, H., Chen, Q., Wang, N., Capurso, W.D., Niemocyznski, L.M., Zhu, L., Snedden, G.A., Holcomb, K.S., Lusk, B.W., Wilson, C.W., Cornell, S.R. (2023). Monitoring of wave, current, and sediment dynamics along the Chincoteague living shoreline, Virginia. *USGS Open-File Report, 2023*-1020. doi: https://doi.org/10.3133/ofr20231020

- Researchers studied the effects of an oyster castle living shoreline in the low energy environment of Chincoteague on wave, current, and sediment dynamics. They played a limited role in wave attenuation, which was found to be dependent on water depth, wind speed and direction, and bathymetry. When the oyster castles reached above or just below the water line, they achieved wave attenuation rates of 39.7%, while they achieved rates of 38.6% when fully submerged. The oyster castles did perform well at retaining sediment eroding from the marsh edge and tidal flats, however. It was also found that the castles were fully submerged over 60% of the time, leading to an enhanced oyster habitat and increased oyster settlement, growth, and shell density. The researchers also found that shoreline erosion at the site was largely dependent on nearshore bathymetry and tidal

currents rather than wave energy, suggesting that wave attenuation may not be the main factor to focus on when constructing shore protection.

Zhu, L., Huguenard, K., Zou, Q.P., Fredriksson, D.W., Xie, D. (2020b). Aquaculture farms as nature-based coastal protection: Random wave attenuation by suspended and submerged canopies. *Coastal Engineering, 160,* 103737. doi: https://doi.org/10.1016/j.coastaleng.2020.103737

- Researchers wanted to test the effectiveness of suspended mussel farm aquaculture on wave attenuation as a proposed component of a living shoreline system. They first conducted theoretical models using a cantilever-beam model (simulating kelp forests and other SAV, a suspended rope or beam attached to the bottom) and a buoy-on-rope model (simulating shellfish aquaculture, a suspended rope attached to both a floating buoy at the top and anchored to the bottom). These models helped to determine what should be expected in terms of wave energy passing through them. They then used this information to conduct a real-world study of a mussel farm in Saco Bay, Maine. The site consisted of both a buoy-on-rope model (in the form of the “mussel dropper” aquaculture) and a cantilever-beam model (in the form of a SAV meadow). The researchers studied the effects of each obstacle type on wave energy during a storm event. What they found was that, when the water levels became higher and wave energy became greater, the mussel farming structures performed far better at dissipating wave energy than the SAV, as the floating mussel farm rose with the water levels. They therefore theorize that the floating aquaculture structures would perform well in the face of sea level rise as well. They conclude by proposing the incorporation of floating aquaculture structures into living shoreline designs as both an effective and adaptive means of wave attenuation as well as providing an ecological and economical benefit.

Sella, I., Hadary, T., Rella, A.J., Riegl, B., Swack, D., Perkol-Finkel, S. (2022). Design, production, and validation of the biological and structural performance of an ecologically engineered concrete block mattress: A nature-inclusive design for shoreline and offshore construction. *Integrated Environmental Assessment and Management*, *18*(1), 148-162. doi: https://doi.org/10.1002/ieam.4523

- Researchers have developed an articulated concrete block mattress (ACBM) composed of marine construction-grade concrete with added “ecological enhancements” (the exact materials are listed as sensitive information) that are designed to facilitate the growth of calcium carbonate-based marine invertebrates on the structures while also providing nutrients to the surrounding biota. The article lists the increase of biodiversity and density on and around the experimental structures compared to traditional ACBMs as its main advantage. However, it also lists other advantages such as a prolonged structure life and increased resistance to storms and other high energy factors due to its “calcitic crust” created by the calcium carbonate-based marine life attached to the structures, as well as a low cost of construction and placement ($10-$18 total per square ft). They conclude that this new material, made by ECOncrete Tech Ltd and BESSER Company, can be an ecologically, structurally, and economically beneficial addition to shore protection. The experimental design added them as an outer protective layer to riprap, but they can also be used to cover stone sills and breakwaters of hybrid living shorelines.

Bredes, A.L., Miller, J.K., Kerr, L., Brown, D.R. (2022). Observations of wave height amplification behind an oyster castle breakwater system in a high-energy environment: Gandys Beach, NJ. *Frontiers in Built Environment, 8,* 884795. doi: https://doi.org/10.3389/fbuil.2022.884795

- Researchers studied wave attenuation of an oyster castle breakwater living shoreline project constructed on The Nature Conservancy's Gandys Beach Preserve in New Jersey. The preserve is a 1-mile long stretch of shoreline in a high-energy environment and has a tidal range of 2 meters. Researchers used high-frequency pressure sensors and an acoustic doppler current profiler (ADCP) to monitor the wave attenuation at four locations along the oyster castle breakwater. They found that when the water levels were lower and the oyster castles emerged above the waterline, they worked as effective means of wave attenuation. However, they are much less effective at wave attenuation when submerged below the waterline, with effectiveness inversely related to water level. They also found that, during winter storm events, the oyster castles actually amplified wave energy by as much as 80%. These results suggest that oyster castles are not suited for this high-energy wave environment, and will become less and less effective in the face of sea level rise.

Morris, R.L., Boxshall, A., Swearer, S.E. (2020). Climate-resilient coasts require diverse defense solutions. *Nature Climate Change, 10,* 485-487. doi: https://doi.org/10.1038/s41558-020-0798-9

- A short outline of when the use of living shorelines is appropriate, how to determine when soft (non-structural) and hybrid living shorelines are most appropriate, and why living shorelines are important from a resilience and economic standpoint. The authors created a hazard intensity vs urgency spectrum chart for quick and basic shore management selection. They mention how living shorelines are more resilient and long-term solutions for shore protection, but they do not provide immediate results like hardened shorelines. They also mention how, in the face of climate change, living shorelines are a more resilient and adaptive strategy compared to traditional hardening measures, and are therefore also more sustainable and cost-effective in a long-term setting.

Ciritci, D., & Turk, T. (2020). Assessment of the Kalman filter-based future shoreline prediction method. *International Journal of Environmental Science and Technology, 17,* 3801-3816. doi: https://doi.org/10.1007/s13762-020-02733-w

- Researchers tested the Kalman filter-based prediction method, as well as predictions made by using end point rate (EPR), linear regression rate (LRR), and weighted linear regression rate (WLR), to determine the accuracy of predicting shoreline positions in 10 and 20 years into the future. Assessments were done using historical imagery of two shorelines on the Turkish coast dating back to 1975 and 1984. All tests were conducted in ArcGIS using the Digital Shoreline Analysis System (DSAS) 5.0.

  The Kalman filter is an algorithm that works by using measurements conducted over time that contain noise and inaccuracies (such as variations in shoreline imagery) to predict a future projection based upon the historical measurements. This information is not given in the article and had to be researched elsewhere.

From statistical analyses done on each test, they found that the most accurate method of shoreline prediction is done by the WLR method, and shorter distances (i.e. the 10-year timeframe) are more accurately predicted than longer ones.

Hutton, N.S., & Allen, T.R. (2020). The role of traditional knowledge in coastal adaptation priorities: The Pamunkey Indian Reservation. *Water*, *12*(12), 3548. doi: https://doi.org/10.3390/w12123548

- The authors state the importance of using traditional ecological knowledge (TEK) in shoreline management decision-making. They tested a system to allow residents of the Pamunkey Indian Reservation to log and share areas of concern that should be included in shoreline protection efforts to reduce impacts from coastal flooding and storm events. This information can then be used alongside typical methods of shoreline management planning. The authors collected TEK data by having the residents recount hazard and socio-economic experiences, as well as identify areas of concern when presented with sea level rise maps predicting the next 60 years. These data were recorded in GIS and put into a resilience matrix. Using the information from the TEK, the management plan results focused on structural solutions to protect residences, heritage sites, and access points.

Kerr, L., Brown, D., Miller, J.K. (2020). Cost and effectiveness analysis of select New Jersey living shoreline projects. *Stevens Institute of Technology, Davidson Laboratory.* Retrieved from: https://www.conservationgateway.org/ConservationPractices/Marine/crr/library/Documents/ED_SIT_DL_20_9_CV5%20Cost%20Effectiveness%20Final%20Report.pdf

- This is a summary of an analysis of the effectiveness and cost of living shoreline projects compared to traditional hardening structures. The effectiveness of living shorelines was determined over a two-year period by studying their effects on edge stabilization and wave attenuation. Five sites were studied: two coir log sites, two hybrid gray/green sites, and one oyster castle site. The oyster castle and two hybrid gray/green sites reduced erosion rates over the two-year period compared to rates from the previously unprotected shorelines. The two coir log sites were inconclusive due to lacking historical imagery to compare rates. The hybrid gray/green sites averaged wave attenuation rates of over 50%, while the oyster castle site's rates varied with tides, but experienced an overall average rate of 31%. In terms of cost, the initial construction rates for living shorelines are much lower than traditional hardening structures. Initial living shoreline costs range from $45 to $1,661 per linear foot, while hardening structure costs range from $437 to $3,507 per linear foot. When compared over a 60-year period, the estimated difference in cost is smaller, but overall, living shorelines are still significantly cheaper than hardening structures.

Hendricks, J., Mason, P., Herman, J., Hershner, C. (2023). Prioritizing the protection and creation of natural and nature-based features for coastal resilience using a GIS-based ranking framework – an explorable approach. *Frontiers in Marine Science, 10,* 1005827. doi: 10.3389/fmars.2023.1005827.

- Researchers used ArcMap GIS modeling to show inundation pathways (IP) of natural and nature-based features (NNBF; wetlands, living shorelines, beaches, etc.) and linking them

to vulnerable infrastructure to demonstrate locally-relevant benefits of NNBF in the Chesapeake Bay. NNBF datasets were collected from local, state, and national sources and compiled into a complete dataset for the entirety of Virginia's Chesapeake Bay and Atlantic Ocean shoreline. NNBF types were categorized as either beach, dune, hybrid living shoreline, non-tidal wetland, scrub-shrub, tidal marsh, or wooded. Shorelines were categorized as either urban or rural, and important community infrastructure was included.

IP's were created using modified least-cost analyses on elevation data to connect the most likely path of water from the shore to building footprints. Areas of NNBF were measured for the number of IP's that intersected them to provide an assessment of their importance, as NNBF areas with more IP's are more important in terms of protecting infrastructure. NNBF were further ranked in terms of importance by using a Coastal Benefit Index (CBI) to determine 4 factors: NNBF flooding mitigation potential (physical characteristics and elevation to mitigate flooding), coastal building benefit (number of IP's in a NNBF), critical community facility benefit (type of building and its role and importance to a community), and co-benefit potential (ability of NNBF to be used for federal/state incentives). This scoring method can both rank current NNBF and target areas without NNBF for potential restoration/construction sites.

Of the area included in this survey, 70% contained NNBF with tidal marshes being the most common form. Southern Tidewater and the Peninsula (Hampton/Newport News) had more NNBF with IP's than without, while the Middle Peninsula, Northern Neck, and Eastern Shore all had more NNBF with no IP's. This means that Southern Tidewater and the Peninsula have the greatest importance of their NNBF as they contain large amounts of important infrastructure in low elevation areas. The Middle Peninsula and Eastern Shore also have many NNBF in low elevation areas, but do not contain as much infrastructure, and the Northern Neck does not contain as many NNBF in low elevation areas. Of existing NNBF types, hybrid living shorelines (gray/green and oyster sills) have the highest CBI, followed by tidal and non-tidal wetlands. Wooded, scrub, dune, and hybrid breakwaters had much lower CBI scores, and beaches had the lowest. The majority of NNBF had 1-10 IP's. The information can be viewed in an interactive map tool on the AdaptVA website.

Leone, A., Tahvildari, N. (2022). Comparison of spectral wave dissipation by two living shoreline features in a sheltered tidal bay. *Estuaries and Coasts, 46,* 323-335. doi: https://doi.org/10.1007/s12237-022-01140-3

- A comparison of the wave attenuation abilities of a hybrid gray/green living shoreline and an oyster reef ball living shoreline in Norfolk, VA. Using pressure sensors around each system, the wave energy was measured in front of and behind each system for a course of 27 days. Due to tidal cycling, the hybrid gray/green system was inundated 28% of the time, while the reef balls were inundated 94% of the time. The average energy reduction of the hybrid gray/green system was 40%, while the reef balls was 13%, and the difference was likely mostly due to inundation levels. For the hybrid gray/green systems, over half (27%) of wave energy reduction was due solely to the rock sill.

Hardaway, C., Milligan, D. A., & Duhring, K.D. (2021). Living Shoreline Design Guidelines for Shore Protection in Virginia's Estuarine Environments, Version 3.0. Virginia Institute of Marine Science, William & Mary.

- A comprehensive guide to designing site-specific living shorelines based on a wide array of local factors.

Priest, III, W.I. (2017). Chapter 10: Practical living shorelines. *Living Shorelines: The Science and Management of Nature-Based Coastal Protection,* 185-210.

- The section about planting native species for living shorelines mentions that using a high nitrogen content, slow-releasing fertilizer is beneficial to the plants because the sand fill is usually cleaned and lacks nutrients, so the fertilizer will release to feed the plants slowly without overwhelming and harming them.

## Appendix B: Captain Sinclair's Recreational Area West Shoreline Management Plan

# Captain Sinclair's Recreational Area West
# Shoreline Management Plan

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**September 2023**

# Executive Summary

Captain Sinclair's Recreational Area (CSRA) is located on the Severn River and Whittaker Creek in Gloucester County, Virginia. In 2016, a shoreline management plan was developed for CRSA, and a hybrid gapped stone sill living shoreline system and oyster bag sills were installed on the site in 2016 and 2017, respectively. Recently, the 100-acre western peninsula, Captain Sinclair's Recreational Area–West (CRSA-W), with 2 miles of shoreline across Whittaker Creek from the original shoreline management area was acquired by the Middle Peninsula Chesapeake Bay Public Access Authority (MP-PAA) and assimilated into CRSA.

The goal of this project is to determine how erosion can be managed at CSRA-W in coordination with MP-PAA's goals. The objective was to create a plan that provides the reasoning and knowledge to incentivize reach-based shore protection, habitat enhancement and future coastal resiliency that best aligned with the property owner's preferences, priorities, and ability to fund the project. Shore erosion and coastal resiliency was analyzed holistically to find ways for problems to be solved on a reach basis in a manner that aligns with the property owner's personal priorities and available funding resources.

A remote site assessment of the property was conducted to determine the physical characteristics, habitat shifts, and shoreline change rates over time of the site. This was followed by an on-site real-time kinematic elevation survey, nearshore sediment sampling, and up-to-date photography of the site. The site has both low energy and medium-energy wave environments. The western shoreline has low energy, and the eastern shore has very low energy. The southern points are exposed to medium energy, but the shoreline between them is low energy. The site has a low elevation, with an average marsh elevation of 3.25 ft MLW and a maximum upland elevation of 5 ft MLW. As such, the area is especially threatened by flooding from storm surge and sea level rise. Overall, it was determined that the western and southern shorelines are experiencing the highest rates of erosion, which has been increasing in recent years.

Ultimately, four different management options were created. The first option is to do nothing and allow the marsh to retreat naturally. The second option is the construction of hybrid stone sill living shoreline systems along the site. The third option is the construction of intertidal oyster reefs along the site, and a variety of proprietary and non-proprietary design examples have been presented. The final option is to incorporate the use of thin layer placement (TLP) to restore and build the marsh habitat with dredged sediment.

The MP-PAA regularly utilizes its public properties to help facilitate and test shoreline protection products which are both innovative and new to the Commonwealth. One such product, Quickreef, offered to donate units to demonstrate technology at a low to moderate energy shoreline location on an MP-PAA owned property. Since the effectiveness of the Quickreef units will be evaluated and better understood by the time construction occurs at the CSRA-W property, Middle Peninsula Planning District Commission staff on behalf of the MP-PAA selected to design Quickreef sill living shoreline systems as a first possible targeted

location solution amongst the proposed concepts in areas with firmer nearshore sediment with the higher upland areas, along with the construction of both larger Natrx concrete oyster reef structures and smaller intertidal oyster reefs in the softer nearshore areas. They have also expressed interest in pursuing TLP and marsh enhancement in the future. The shoreline management plan has factored in strategies for the MP-PAA to acquire funding and permitting for these designs, and is focused on the implementation of this project. This report provides an overall summary of the site assessment, shore survey, data analysis, and management planning undertaken for the site.

# Table of Contents

# 1 Introduction

## 1.1 Site Location and Project Information

Captain Sinclair's Recreational Area (CSRA) is located on the Severn River and Whittaker Creek in Gloucester County, Virginia (Figure 1-1). The western peninsula across Whittaker Creek from Captain Sinclair's Recreational Area (CSRA-W) was recently acquired by the Middle Peninsula Chesapeake Bay Public Access Authority (MP-PAA) and assimilated into the entirety of the recreational area. The western peninsula is adjacent to the area of CSRA where a shoreline management plan was developed in 2016 (Milligan et al., 2016). In addition, a gapped stone sill and oyster bag sills were installed in 2016 and 2017, respectively to maintain the marsh at the main CSRA site.

The CSRA-W property extends along Whittaker Creek to the Severn River then westward at Whittaker Point, up the Severn River for a total of about 2 miles. It is a tract of land consisting of about 100 acres. Shoreline erosion, historically, is greater along the more open reaches of the Severn River that are more exposed such as the areas at Whittaker and School Neck Points. These areas along with the western shore are eroding from the water side, but also are being converted to non-vegetated wetlands on the interior marsh. The wooded areas are shrinking and ghost trees occur.


*Figure 1-1. Location of Captain Sinclair's Recreational Area - West within the Chesapeake Bay.*

The goal of this project was to determine how erosion can be managed and the marshes protected in lower energy environments at CSRA-W in coordination with MP-PAA's goals. The objective is to create a plan that provides the reasoning and knowledge to incentivize reach-based shore protection while also providing habitat enhancement and future coastal resiliency. The goal is to look at shore erosion, marsh restoration, and coastal resiliency holistically along a reach and find ways for problems to be solved on a reach basis. This report provides a summary of the site assessment, shore survey, data analysis, and management planning undertaken for the site.

## 1.2 Define Problem

The shoreline along CSRA-W is mostly low, eroding marsh shoreline along with associated habitats, mostly high and low marsh with some forested upland and some invasive Phragmites (Figure 1-2). The marsh coast is eroding at about -1.0 ft /year, but oysters are plentiful along the shoreline. Additionally, the interior of the marsh has been degrading for some time. The MP-PAA has plans to enhance the property for public use. Protecting the shoreline, enhancing habitats, and increasing public usage opportunities are goals for this site.


*Figure 1-2. on Captain Sinclair's West.*

# 2 Methods

## 2.1. Existing GIS Data

For the site assessment, existing geographic information system (GIS) data were used from various sources (Table 2-1). This included imagery data from both VGIN and the VIMS Shoreline Studies Program databases.

The site boundary shapefile was determined from Virginia parcel data available online. Public oyster grounds, public clamming grounds, and private leases were obtained from the Virginia Marine Resources Commission online data. Shorelines digitized from the vertical, rectified imagery were obtained from the Shoreline Studies Program database. The submerged aquatic vegetation (SAV) composite footprint between 2016 and 2021 WAS obtained from the VIMS SAV program as was the 2022 imagery used in the habitat change analysis.

Table 2-1. Listing of existing GIS data used for the site assessment.

| Name | Type | Information |
|---|---|---|
| Imagery | Vertical, rectified imagery | VIMS Shoreline Studies Program Mosaics (1937, 1958, 1960, 1968, 1978)<br>USGS 1994 Digital Orthoquadrangles<br>VGIN Mosaics (2002, 2007, 2009, 2011, 2017 and 2021)<br>https://vims-wm.maps.arcgis.com/apps/webappviewer/index.html?id=cd5cf9b788d0407fb9ba5ffb494e9bae<br>VIMS SAV Program 2022 imagery |
| Lidar | 2018 NGS data | https://coast.noaa.gov/dataviewer/#/lidar/search/ |
| Site boundary | Shapefile | Virginia Parcel layer |
| Oysters | GIS Server file | Baylor Grounds and private leases.<br>https://webapps.mrc.virginia.gov/public/maps/chesapeakebay_map.php |
| Shorelines | Shapefiles | SSP Shorelines: 1937, 1958, 1960, 1968, 1978, 1994, 2002, 2007, 2009, 2011, 2017, 2021 |
| Submerged Aquatic Vegetation (SAV) | GIS Server file (2016-2021) | VIMS SAV program<br>https://www.vims.edu/research/units/programs/sav/access/maps/index.php |

## 2.2 Shore Change

The extension Digital Shoreline Analysis System (DSAS) from the US Geological Survey (USGS) was used to calculate the End Point Rates and Linear Regression Rates (EPR and LRR). The EPR calculation used just 2 shorelines, the beginning and the ending shoreline and represents a net change between dates. The LRR calculation used the beginning and ending shorelines as well as any intervening shorelines and calculates a best fit line to represent the rate of change. The process involved creating baselines in ArcMap parallel and offshore from the 1937, 1953, 1960, 1968, 1978, 1994, 2002, 2007, 2009, 2007, 2009, 2013, 2017, and 2021 digitized shorelines. Perpendicular transects were generated every 33 feet along the baselines. This transect shapefile ultimately contained the End Point Rates and Linear Regression Rates data at each transect. That data was transposed onto a point adjacent to the shoreline. Each point was categorized based on the EPR and colorized to represent each category listed in Table 2-2. Several time periods were analyzed for change: 1937-2021 (LRR used all shorelines), 1937-1994 (LRR used 1937, 1953, 1960, 1968, 1978, & 1994 shorelines), 1994-2009 (LRR used 1994, 2002, 2007, & 2009 shorelines), and 2009-2021 (LRR 2009, 2013, 2017, and 2021 shorelines).

Table 2-2. Rate of change categories for shore change analysis.

| Rate | Category |
|---|---|
| >+10 ft/yr | Very high accretion |
| +10 to +5 ft/yr | High accretion |
| +5 to +2 ft/yr | Medium accretion |
| +2 to +1 ft/yr | Low accretion |
| +1 to 0 ft/yr | Very low accretion |
| 0 to -1 ft/yr | Very low erosion |
| -1 to -2 ft/yr | Low erosion |
| -2 to -5 ft/yr | Medium erosion |
| -5 to -10 ft/yr | High erosion |
| >-10 ft/yr | Very high erosion |

## 2.3 Marsh Change

The marsh, sand, non-vegetated wetland (interior water), and forested (tree) areas were digitized on the 1978 and 2022 mosaics. The polygons were attributed according to the features they represented. The water polygons, such as ponds, were deleted from the final product. To visually view the changes, especially within the marsh areas, a union between 1978 and 2022 was performed. This union allowed for the changes to be visually shown by various symbology and for the statistical changes to be calculated. In general, if after a union with 1978 and 2021, 1978 showed marsh but none was seen in 2021, it was then considered a loss. If there was no marsh in 1978 but some showing in 2021, then that was considered a gain in marsh area. If both years showed marsh, there was no change in those areas. Any other features, except marsh, that either changed or stayed the same, were labeled as ‘not marsh’, since the only feature of real concern are the marshes and forested areas.

## 2.4 Site Survey

The site was surveyed on 19 April 2023 on foot using a Trimble R12 real-time kinematic global positioning system (rtk-gps). Transects were surveyed by walking from the back marsh to the nearshore, taking points at specific geographic features such as changes in vegetation, top of scarp, and toe of the beach as well as changes in elevation (Figure 2-1). This was done along selected profiles to field check habitats visible in the imagery and elevations in the lidar data. Horizontal datum was Universe Transverse Mercator (UTM), North America Datum (NAD)83, in meters. The vertical datum was North American Vertical Datum (NAVD)88, meters.

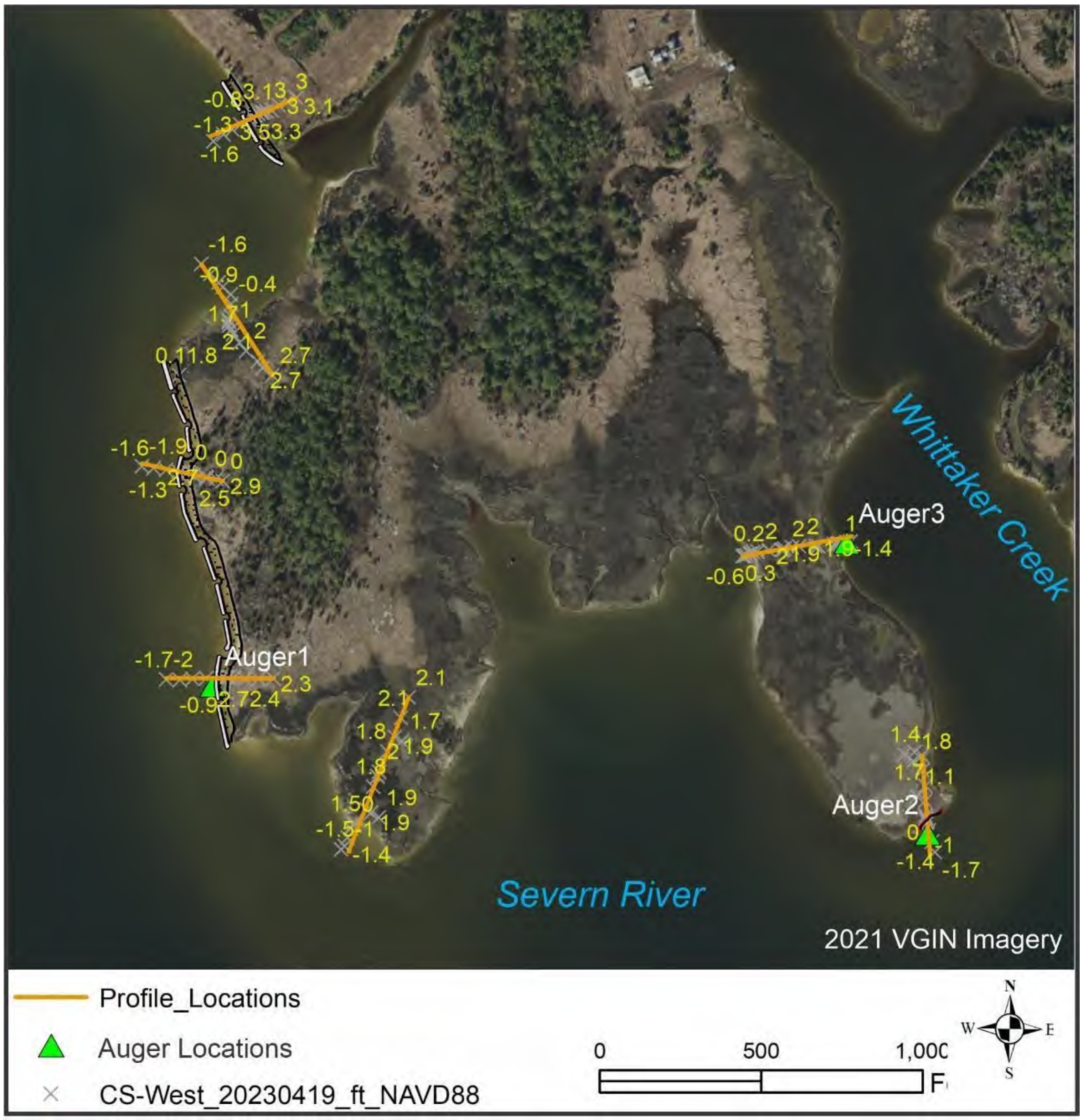


*Figure 2-1. Location of survey points and augers taken during the site survey on April 19, 2023.*

The data were processed in Trimble Business Center to convert from meters to feet. The data were converted from NAVD88 to mean low water (MLW) using Shoreline Studies Program's Google Earth datum converter (https://www.vims.edu/research/units/programs/ssp/shoreline_management/living_shorelines/class_info/tideranges_and_conversions/index.php). At CSRA-W, the difference between NAVD88 to MLW is 1.4 ft.

Ground photos were taken at the site to provide a basis for monitoring the site through time. The photo locations were rectified and input to GIS so that their location could be mapped.

A geotechnical analysis of the sediment in the nearshore occurred during the survey. Augers were taken by hand alongshore (Figure 2-1). Sediment samples were taken at 1 ft and 2 ft deep. The samples were field classified for color and texture using the Unified Soils Classification System (USCS). In addition, sediment samples were processed for percent gravel, sand, silt, and clay by the VIMS Coastal Geology Lab. The auger logs and sediment analysis results are shown in Appendix A.

# 3 System Assessment

## 3.1 Physical Setting

### *3.1.1 Shore Setting*

A system assessment includes both remote sensing data and a site visit to determine site-specific conditions (Hardaway et al., 2017). CSRA-W has shoreline on the Severn River and Whittaker Creek. The marsh consists of Holocene deposits that are very low and easily flooded during severe storm events (Figure 3-1). The maximum upland height is about 4 feet North American Vertical Datum 88 (NAVD88) which occurs on the western side of the property which is where the tree stands are. The southern side and the marsh adjacent to Whittaker Creek are lower. The lowest area is marsh at Whittaker Point where the non-vegetated wetland is expanding. Most of the marsh is only 3-3.5 ft above MLW.

The nearshore stability adjacent to the marsh varied around the site (3-2). Based on a visual assessment during the site survey, the nearshore was categorized. Only one area had a firm bottom (Area 1). This area is mostly sandy beach and nearshore with a small eroding peat scarp

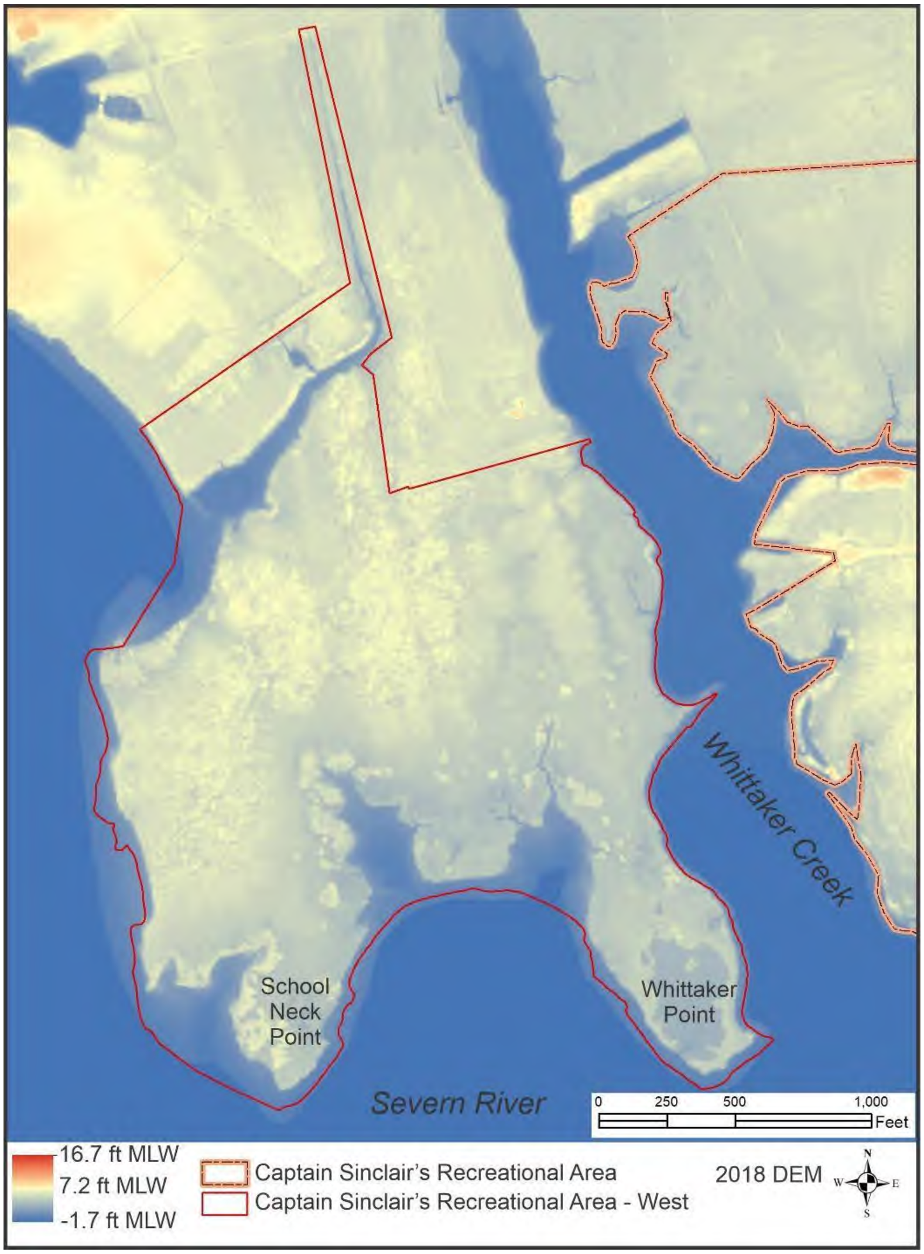


*Figure 3-1. Digital elevation map showing Captain Sinclair's West that most areas of the marsh are very low.*

*Phragmites australis, Spartina cynosuroides, J. virginiana, Pinus spp*. and saltbushes. The adjacent upland is an emergent freshwater wetland with *P. Australis, Pinus spp*. and saltbushes. Area 2 and in the embayment between the two Points was classified as extremely soft with surveyors sinking more than 2 ft. It has a low eroding marsh with *S. patens, J. roemerianus,* saltbushes and a section of eroding forest with ghost trees (Figure 3-3-2). Oysters are abundant in the nearshore.


*Figure 3-2. Bottom type based on a limited physical and visual inspection during the site assessment survey.*


*Figure 3-3. 1) Area 1 has a sandy shoreline and nearshore and a firm bottom stability. 2) Area 2 has a soft bottom with eroding march and abundant oysters. Photo credit, Shoreline Studies Program, VIMS.*

Area 3 and 4 were semi-firm with surveyors only sinking 0.5-1 ft in the nearshore zone. Submerged aquatic vegetation is abundant in the nearshore (Figure 3-3-3), an eroding marsh scarp with *S. patens, J. roemerianus, P. australis*, saltbushes, and many ghost tree roots along the shoreline. Area 4 (Figure 3-3-4) is slightly lower and has shrubs along the backshore rather than trees but the same marsh species exist as in Area 3. Area 5 is a small, muddy embayment where does not have erosional scarp, and many oysters are present in the nearshore (Figure 3-3-5).


*Figure 3-3. 3) Area 1 has a sandy shoreline and nearshore and a firm bottom stability. 4) Area 2 has a soft bottom with eroding marsh and abundant oysters. Photo credit, Shoreline Studies Program, VIMS.*

Areas 6-9 were soft with surveyors sinking 1-2 ft deep (Figure 3-2). Area 6 is on School Neck Point (Figure 3-3-6). It has a small marsh scarp with *S. alterniflora* low marsh intersected by high marsh consisting of *S. patens, J. roemerianus, and P. australis*. Area 7 is at Whittaker Point which has the tallest marsh scarp at the site. It only has *S. alterniflora, S. patens, J. roemerianus*. Area 8 is the non-vegetated wetland on the interior of Whittaker Point (Figure 3-3-8). It is surrounded by a mix of low and high marsh plants, but no scrub/shrub. The evolution of the non-vegetated wetland is shown in Figure 3-4. The marsh has only recently broken through on the southwest side between 2017 and 2021 opening up the area to tidal fluctuations on a regular basis (Figure 3-4). Area 9 is sheltered on Whittaker Creek and only has marsh scarps in several areas (Figure 3-3-9).


*Figure 3-3. 5) Small, muddy embayment that has abundant oysters on the shoreline. 6) School Neck Point has an erosional marsh scarp with areas of high marsh separating low marsh. 7) Whittaker Point has the tallest marsh scarp at the site. Photo credit, Shoreline Studies Program, VIMS.*


*Figure 3-3. 8) This marsh area has been converted to non-vegetated wetland and recently became open to the Severn River. 9) is shelters on Whittaker Creek and has only minor scarping. Photo credit, Shoreline Studies Program, VIMS.*

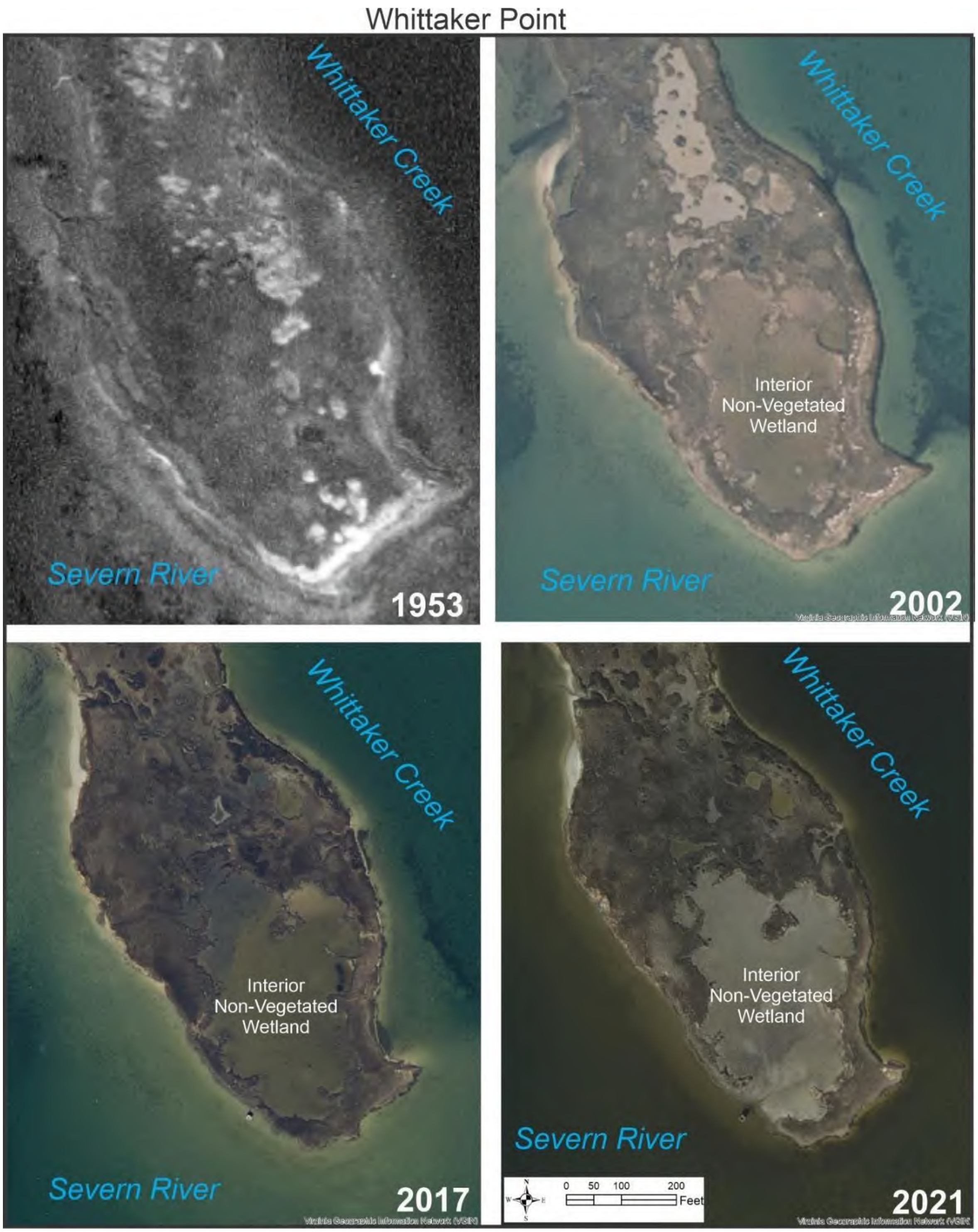


*Figure 3-4. Evolution of the non-vegetated wetland at Whittaker Point. The shoreline broke through between 2017 and 2021 opening up the marsh to tidal fluctuations on a regular basis.*

### *3.1.2 Shore Change Analysis*

A detailed shoreline change analysis was performed for this site. The rates of change in four timeframes were examined: 1937-1994, 1994-2009, 2009-2021, and the long-term rate 1937-2021 (Figure 3-5). The rates varied around the site and during different timeframes (Table 3-1). The erosion rate was much higher between 2009 and 2021 than it was during 1937-1994. In general, the west facing and south facing shorelines had the highest erosion rates. These shorelines had very low (0 to -1 ft/yr) and low (-1 to -2 ft/yr) erosion rates. However, some time periods had higher rates of medium (-2 to -5 ft/yr) and high (-5 to -10 ft/yr) erosion. The rates of shoreline change are greater in the 2009-2021 timeframe than they are in the other time frames.

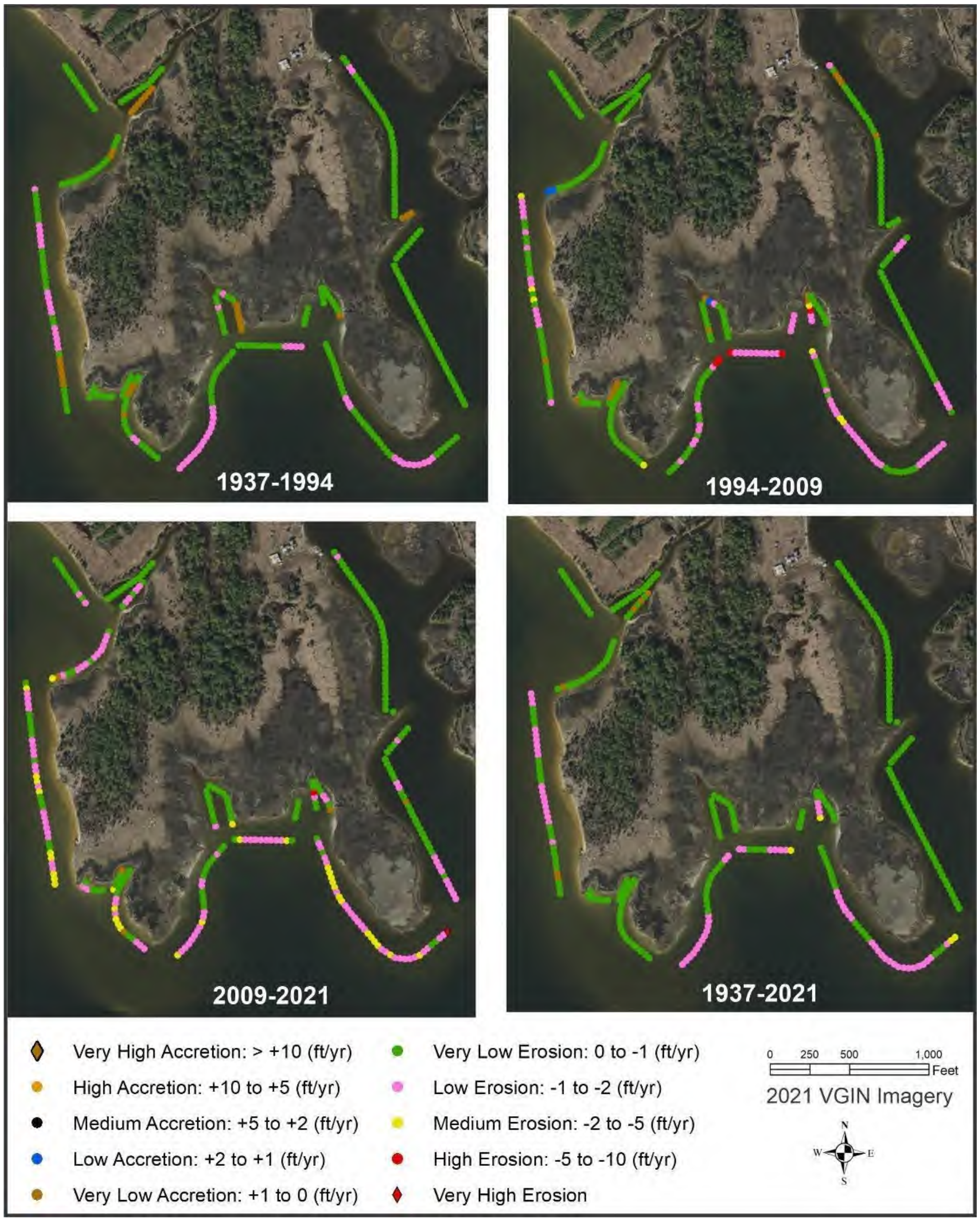


*Figure 3-5. End Point shoreline change rates for different time periods.*

Table 3-1. Average rates of change around Captain Sinclair's West.

| Timeframe | Average End Point Rate (ft/yr) | Average Linear Regression Rate (ft/yr) |
|---|---|---|
| 1937-1994 | -0.5 | -0.5 |
| 1994-2009 | -0.8 | -0.8 |
| 2009-2021 | -1.1 | -1.1 |
| 1937-2021 | -0.6 | -0.6 |

### *3.1.3 Habitat Change Analysis*

Habitats were mapped using aerial imagery taken in 1978 and 2022 (Figure 3-6). Marsh, forested, sand, upland, and non-vegetated wetland areas were outlined and their total area calculated. The maps show that the forested areas have decreased significantly since 1978 (Table 3-2), and water area inside the marsh has increased.

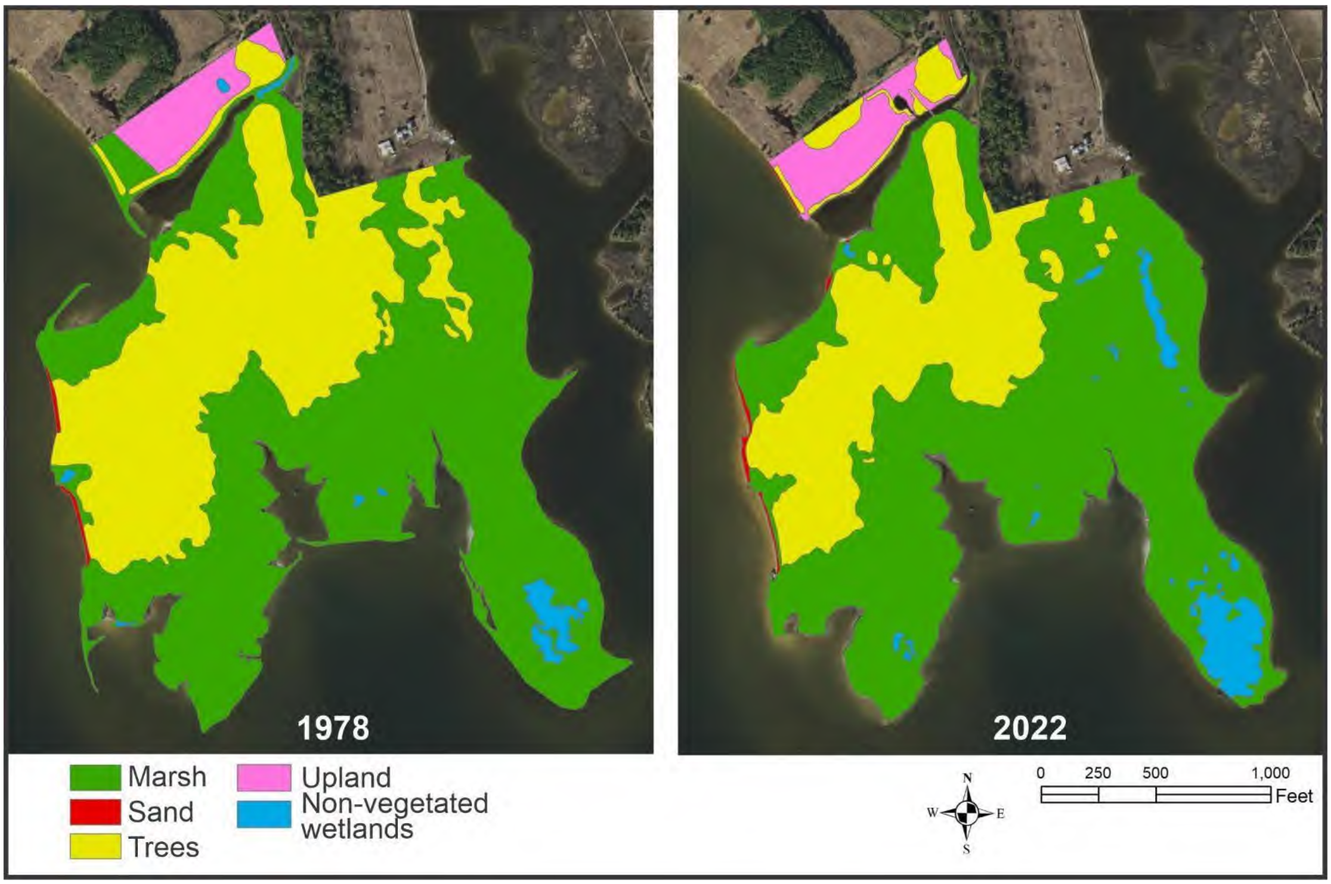


*Figure 3-6. Habitat change between 1978 and 2022.*

Overall marsh area has not changed significantly because as marsh was eroded from the edges of the property, it was able to migrate into the forested areas. In 1978, marsh was 54 acres, and in 2022, marsh was 53 acres resulting in only about 1 acre of overall loss (Figure 3-7). Marsh loss is depicted as red. In addition, open water expansion within the marsh also resulted in net marsh habitat loss. Marsh gain (depicted as green) is mostly the result of marsh migration into the forested areas. Overall net results are that marsh was lost from the edges of the marsh and to interior ponding. Forested areas were lost due to sea-level rise which allowed marshes to migrate landward (Figure 3-8).

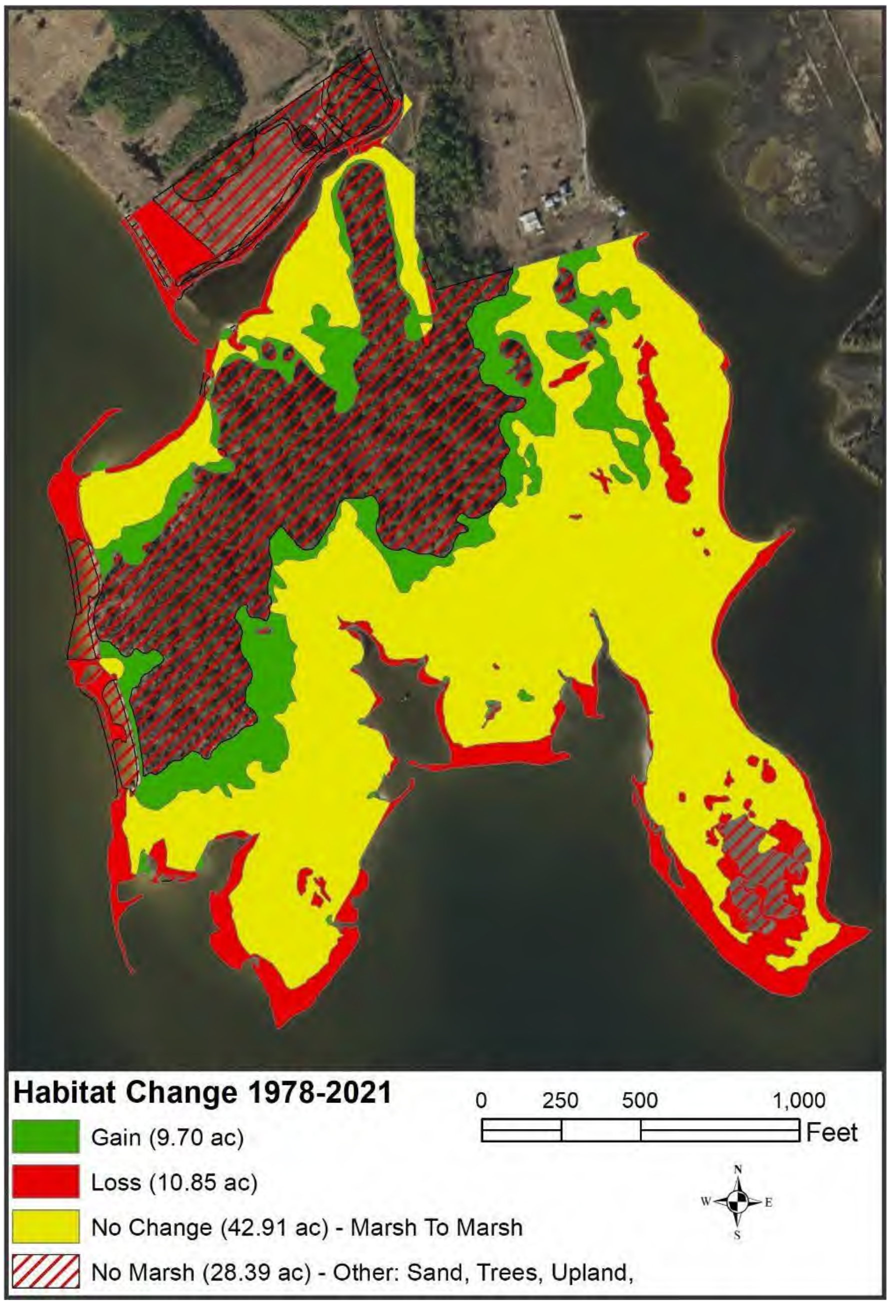


*Figure 3-7. Net habitat changes at Captain Sinclair's West.*


*Figure 3-8. Ghost trees indicate where the forested lands previously were. As sea-level rose, the trees died out leaving just remnants as the marsh migrated into the area.*

Table 3-2. Marsh, sand, and forested habitats mapped in 1978 and 2022.

| Year | Marsh (acre) | Sand (acre) | Upland (acre) | Forested (acre) | Interior Water (acre) | Total Acres |
|---|---|---|---|---|---|---|
| 1978 | 53.8 | 0.2 | 3.2 | 33.1 | 1.4 | 91.7 |
| 2021 | 52.6 | 0.3 | 3.5 | 23.1 | 1.8 | 81.3 |
| Change | -1.2 | +0.1 | +0.3 | -10 | +0.4 | -10.4 |

An invasive grass known as Phragmites, which is found intermittently around Chesapeake Bay, was present on the CSRA-W property. *Phragmites australis* is a tall coarse grass with a feathery seed head. Commonly known as Reed Grass, it is a familiar invader of disturbed low or marsh areas. The broad, acutely tapering leaves, the characteristic seed head, and very long rhizomes are trademarks of this giant grass which can grow 12 feet high.

It is a very aggressive plant, as the long, creeping rhizomes enable this grass to propagate quickly. Reed Grass often competes successfully with other, more valuable marsh plants such as cordgrass, in some brackish marshes. This competition is of potential concern to wetlands managers (Silberhorn, 1976).

### *3.1.4 Elevations*

The maximum land elevations in the area are about +5 ft MLW in the forested areas (Figure 3-1). The top of the peat scarp ranges between +2.3 and +3.7 ft. The nearshore bathymetry is an important element along these shore reaches. The west facing shoreline has the shallowest nearshore depths (Figure 3-9), but the south-facing shoreline has the longest distance to the 6 ft contour which may significantly attenuate waves impacting the shore. Channel depths are deeper adjacent to the south-facing shoreline which would allow larger waves to travel into the River during storms. The depths along Whittaker Creek are slightly larger than around the rest of the shoreline. This steeper nearshore would allow waves from boat wake to impact the coast, but the shoreline is generally protected from wind waves.

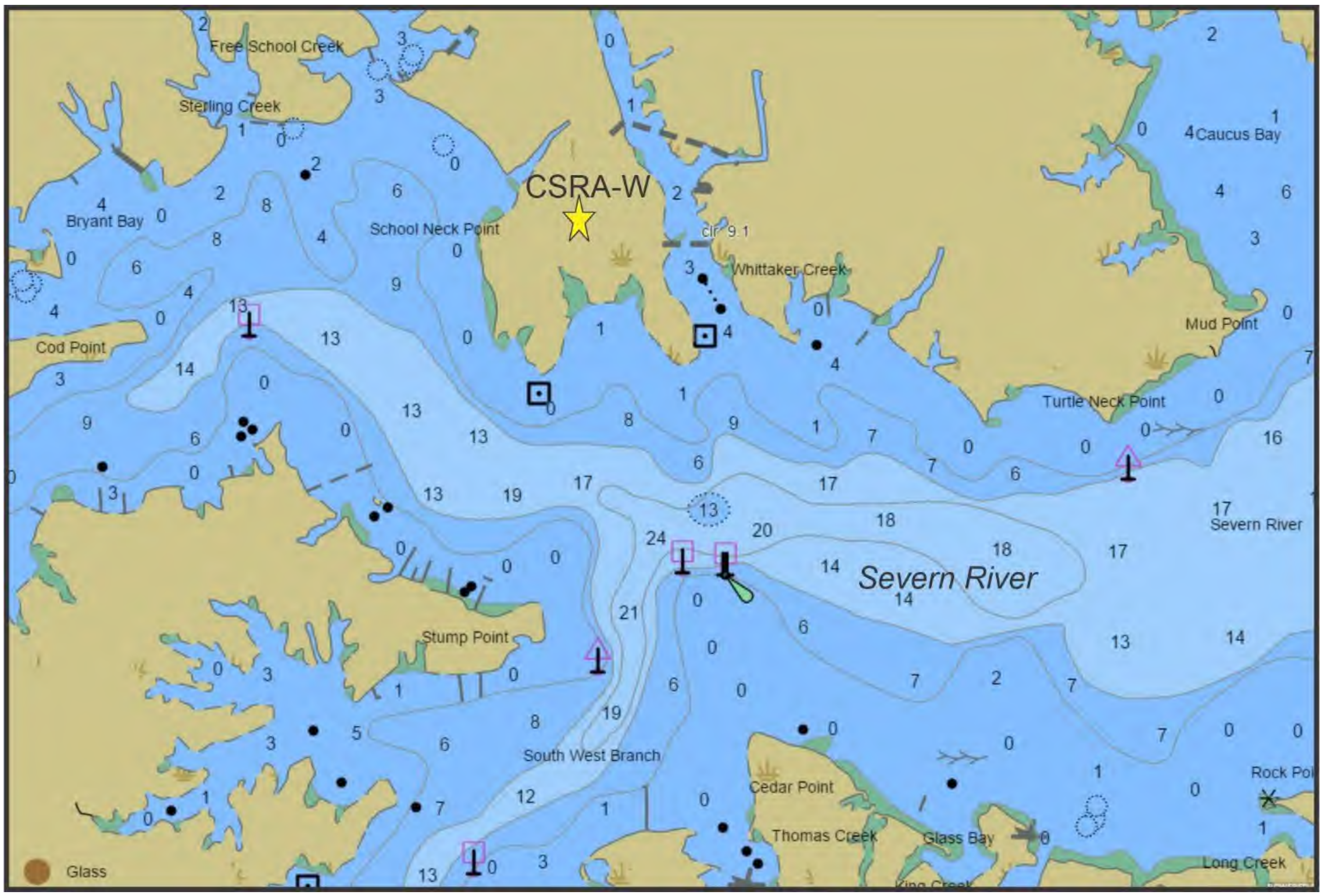


*Figure 3-9. Bathymetric map of the Severn River near Captain Sinclair's West. Deeper waters are adjacent to the south-facing shoreline, but the west-facing shoreline has the shallowest water. https://www.nauticalcharts.noaa.gov/enconline/enconline.html*

The roads in this area will be impacted by sea-level rise (Figure 3-10). The roads that provide access to CSRA-W are at 2 ft – 3.3 ft NAVD88 and will be flooded during storms.

## 3.2 Hydrodynamic Setting

### *3.2.1 Tide Range and Water Levels*

The mean tide range at CSRA-W is 2.3 ft. The storm surge frequencies for the 10, 50, 100, and 500-year events are 6.1 ft, 7.3 ft, 7.7 ft, and 9.6 ft MLW, respectively (FEMA, 2021, Transect 19). The entire preserve is either in Flood Zone VE or AE which means they are subject to inundation by the 1% annual chance (100 year) event. Along the shoreline, the VE zone has additional hazards associated with storm-induced waves.

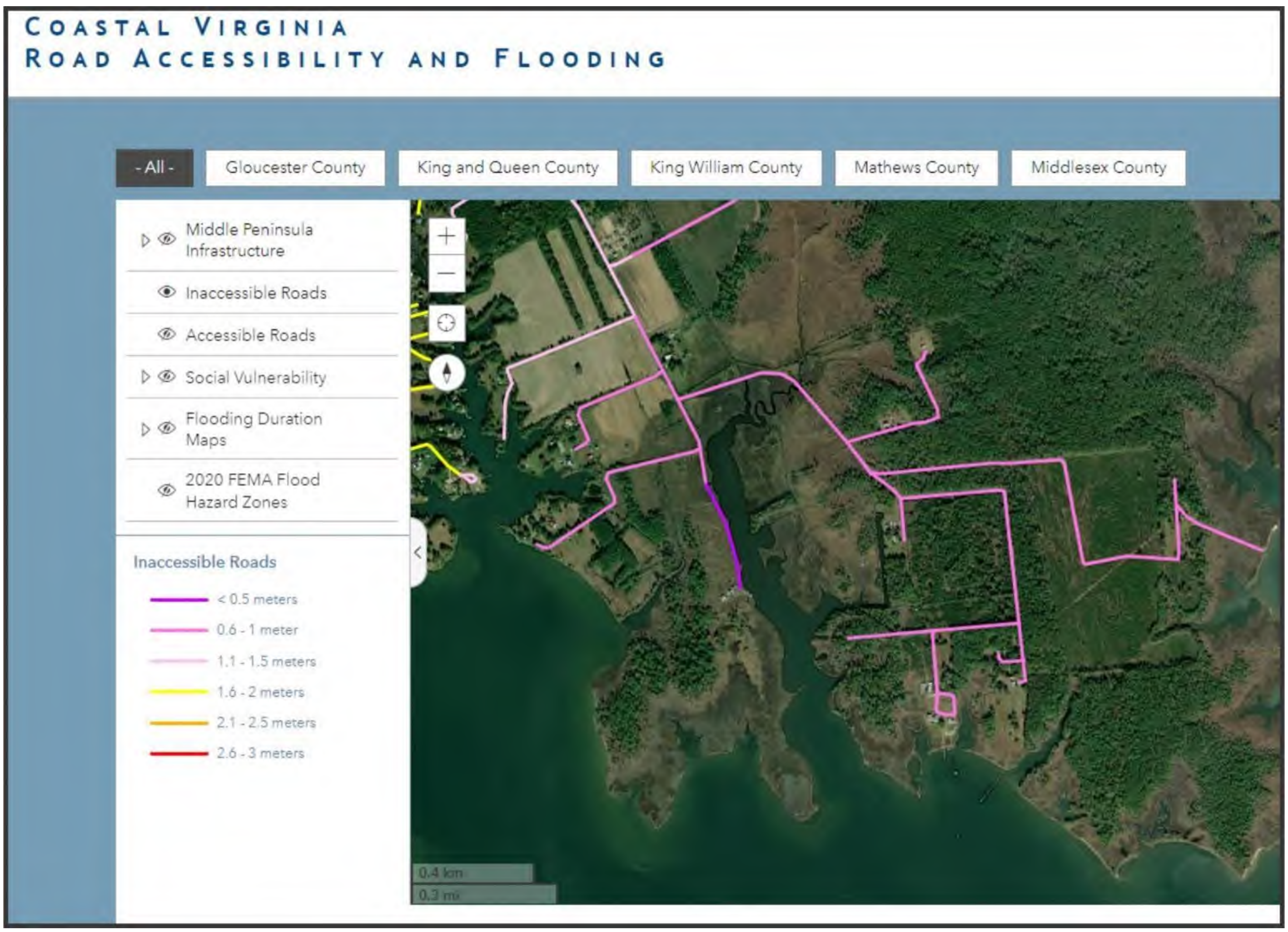


*Figure 3-10. Elevation of roads at Captain Sinclair. The roads are low and are vulnerable to flooding during storms.*
https://cmap22.vims.edu/Roads_Impacts/Inaccessible/index.html

### 3.2.2 *Sea-level rise*

The NOAA observed sea-level trend from the nearby Gloucester Point tide gauge shows an increase of 4.73 millimeters/year with a 95% confidence interval of +/- 0.32 mm/year based on monthly mean sea level data from 1950 to 2022, which is equivalent to a change of 1.60 feet in 100 years (Figure 3-11). However, this historical data does not consider the recent acceleration of sea-level rise that is projected to continue into the future. Using the NOAA SLR intermediate-high scenario, SLR would continue to force changes to habitat such as inundation of marshes and loss of forest. NOAA's sea-level rise viewer shows that when sea level rises 1 ft above MHHW by 2040 much of the marsh at CSRA-W will be flooded (Figure 3-12). The marsh should be able to migrate into the higher areas. It's likely that the treed areas will convert to marsh.

Using NOAA's intermediate high SLR prediction, by 2040 (+1.18 ft MHHW), much of the access road will be continually be flooded. With 2 ft of SLR, most of CSRA-W will be under water by 2060 (Figure 3-12).

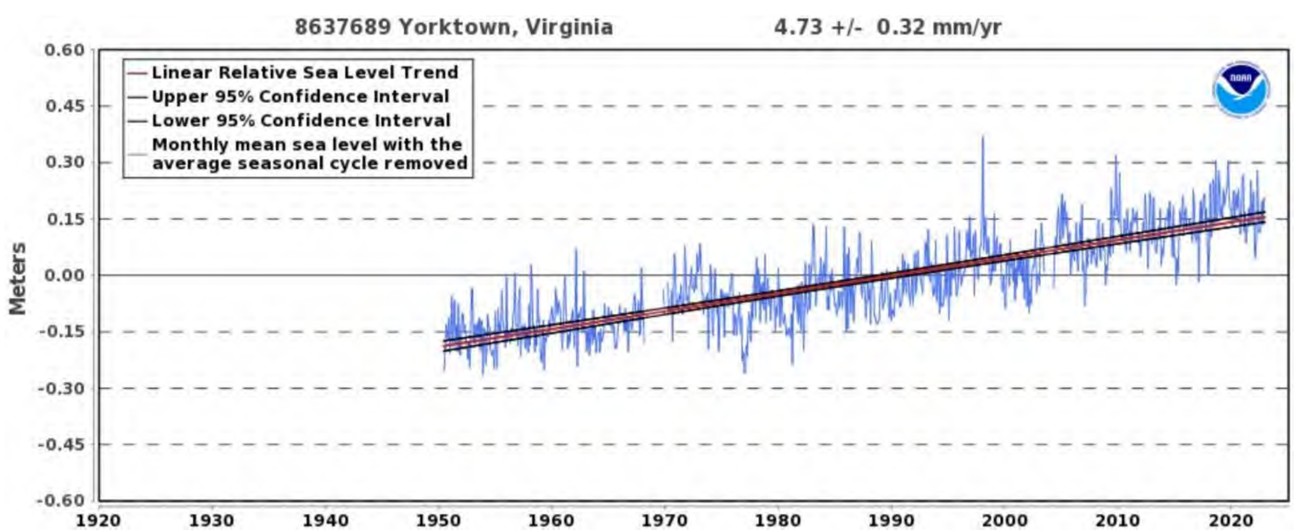


*Figure 3-11. Sea-level rise measured by the NOAA tide gauge at Gloucester Point, VA over the last 70 years.* *https://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?id=8635027#tab50yr*

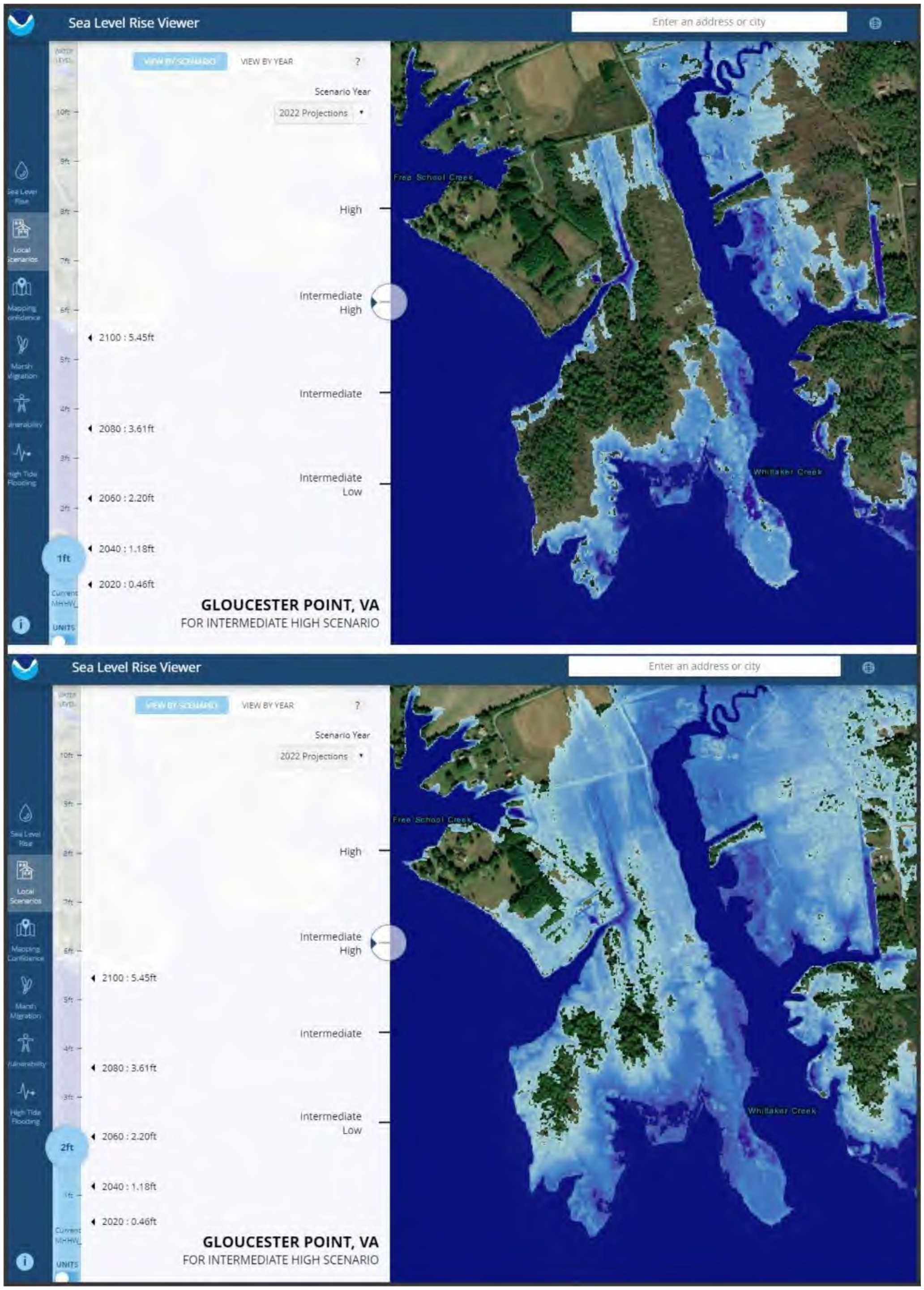


*Figure 3-12. Se-level rise (SLR) predictions made by NOAA modeled at Captain Sinclair for 1 ft MHHW SLR (top) and 2 ft MHHW SLR (bottom).* *https://coast.noaa.gov/digitalcoast/tools/slr.html*

### *3.2.3 Wave Climate*

The wind driven wave climate operating throughout Chesapeake Bay is determined by fetch exposure and wind speeds. In the case of CSRA-W, the site has 3 different fetch environments. The west facing shoreline has an average fetch of 1 mile with a longest fetch of 1.7 miles. The south facing shoreline, mostly School Neck Point and Whittaker Point, has a much larger fetch environment with an average fetch of 5.9 miles and a longest fetch of 24.1 miles out the mouth of the Severn River and Mobjack Bay across Chesapeake Bay. The east facing Whittaker Creek shoreline has a minimal fetch of 0.1 miles. However, the MP-PAA is in the process of fixing the boat ramp at Whittaker Creek and in the future, boat wake could become an issue depending on use. A 40-mph wind provides a significant wave of 3.7 feet in 4.7 feet of water at the shoreline.

## 3.3 Marine Resources

Marine resources adjacent to the project site are assessed in order to determine if the proposed shoreline project will impact them. These resources include private oyster leases, Baylor grounds, public clamming grounds, and SAV. Oyster leases near the project shoreline are shown in Figure 3-13 where no leases or Baylor grounds will be impacted. The 2016-2020 footprint shows that the SAV can reside very close to the shoreline so any shoreline project needs to be landward of that boundary. No public clamming grounds occur near the site.


*Figure 3-13. Marine resources in the vicinity of the project. SAV is mapped by VIMS and the oyster leases and grounds were downloaded from VMRC.*

Five oyster reefs occur in Mobjack Bay (VOSARA, 2023). The stock assessment from oyster reefs in Mobjack Bay is necessary to determine if shore protection based on oyster reefs will recruit spat. Recruitment was good in these reefs in 2019, and Brown's Bay 1 (Figure 3-14), the largest reef in Mobjack Bay, had the highest density of market oysters in 2021. Oysters occur in the substrate along the site indicated that the site is a good candidate for intertidal oyster reef installation.

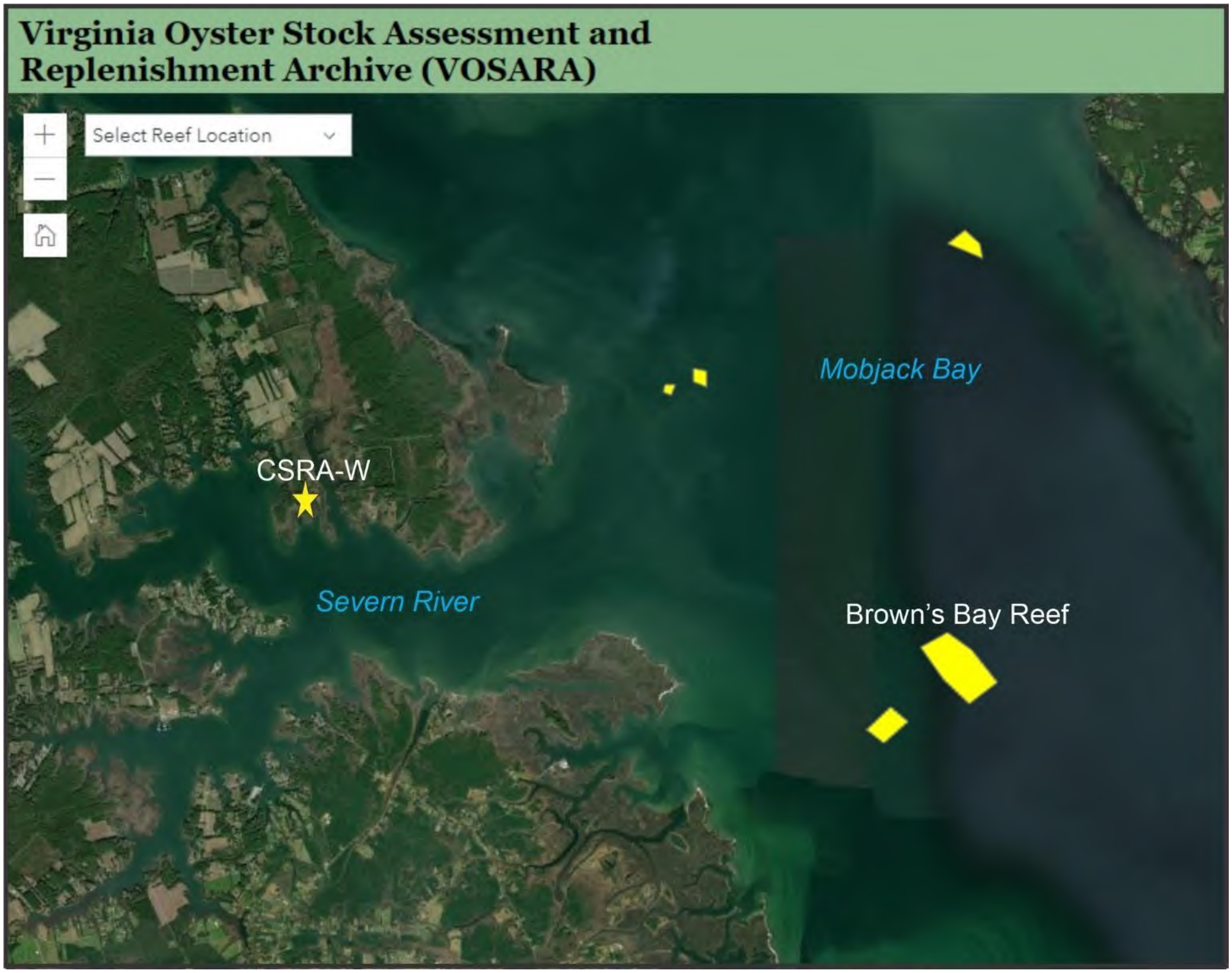


*Figure 3-14. Location of oyster reef (shown in yellow) in Mobjack Bay adjacent to the Severn River.* https://cmap22.vims.edu/VOSARA/

# 4 Alternatives and Final Design

## 4.1 Site Design Options

The shoreline analyzed for shore protection is located along the CSRA-W peninsula. It is mostly a low eroding marsh coast with some wooded uplands and field. The shoreline has a low energy western facing section that has a slightly higher upland and a harder sand bottom. The eastern-facing shoreline along Whittaker Creek is very low energy although increased boat traffic could increase waves there. School Neck Point and Whittaker Point face medium wave energies though the area between them is low energy. In addition to the recommended strategies, this shoreline management plan has factored in strategies for the MP-PAA to acquire funding and permitting for the designs. This site requires varying levels of shore protection due to the different fetch conditions at the site.

After the analysis, several options for shoreline management were created along the project coast. They include:

1. Do Nothing: This would allow the shoreline to continue eroding and costs nothing. This option is also recommended where the bottom is extremely soft.
2. Hybrid Rock Marsh Sill System
3. Intertidal Oyster Reefs
4. Thin-Layering of Sediment

In the case of CSRA-W coast, most of the marsh coast is 2 ft under water during the 10-year event. The key to securing the eroding marsh shoreline is to install a system that will survive constant fluctuating water levels and the wind/wave climate while remaining intact over time.

### *4.1.1 Hybrid Rock Marsh Sill Living Shoreline*

Hybrid rock marsh sill living shorelines are recommended for all levels of energy environments, as they are the most effective in terms of wave attenuation and resilience and they provide habitat restoration. They can be sized smaller and closer to the shoreline for lower energy areas and larger and higher with wider marshes for medium energy areas. The section of shoreline along the west of the site is suitable for marsh restoration and protection using rock sills with sand and marsh grass planting. Along the upper west shoreline, 2 sills are recommended. They have a 50 ft gap to allow access to the water for recreation (Figure 4-1). South of there along the treed area and adjacent marshes, 9 sills are recommended. Most have 10-20 ft gaps, but the shore between sills 4 and 5 is wider to allow recreational access to the water (Figure 4-2).

The hybrid rock sills are not recommended at School Neck or Whittaker Points even though they are medium energy areas. The bottom is too soft to support the structures. In addition, SAV is very close to the shoreline in these areas. To correctly size the system, the rock and sand would have to be placed in the SAV zone.


*Figure 4-1. Hybrid living shoreline consisting of rock sills, sand fill, and marsh grass plantings. The sills are gapped to allow access.*


*Figure 4-2. Hybrid living shoreline consisting of rock sills, sand fill, and marsh grass plantings. One larger gap was created to allow access.*

### *4.1.2 Intertidal Oyster Reefs*

Intertidal oyster reefs are being used as shore erosion mitigation in many areas of the Bay. In recent times, many proprietary and non-proprietary structures have been developed. The goal of these structures is to recruit oysters and develop a reef along the shoreline that will reduce the waves impacting the shoreline. Generally, oyster reefs are typically best suited for eroding marsh shorelines in low to medium energy environments where the goal is to reduce the low-water impinging wind-driven waves that undercut the marsh peat causing chronic erosion. However, depending on the products used and their size, they could be used in higher energy environments. The use of this type of products will allow and encourage oyster growth, which, in turn, will help stabilize the marsh edge. These types of intertidal oyster reef, have erosion control capability and contribute to habitat enhancement as oyster reefs and the associated attraction of a variety of fish species. Unlike engineered rock structures, a level of protection cannot be provided for these structures. The intertidal reefs are limited in elevation because oysters won't grow above MHW.

The list of concrete structures used for living shorelines included in this report is selective, with materials known to the authors and by no means is it intended to be exhaustive. The materials shown have been used with some success in Chesapeake Bay. Though some of the structures on the list are propriety, this report does not advocate for any particular product; it is provided for information only. Property owners must decide which product suits their needs best in terms of cost and installation.

- Oyster bags are mesh bags filled with oyster shells (Figure 4-3A). They are stacked in a triangular configuration that can be sized to the shoreline situation. A recent oyster sill installation showed that the bags are successful at oyster recruitment as well as being used by other organisms. The bags slowed down erosion and allowed some sediment to accumulate landward of the sill. However, marsh erosion still occurred. As the oyster reefs age, it is anticipated that the coastal profile will become gradual enough to allow marsh to grow. These cost about $3 per bag and can be placed by volunteers. These may not be appropriate for high energy areas because the bags can roll before the oysters cement them together.
- Oyster castles® are pre-formed concrete structures that are stacked together (Figure 4-3B). Oysters grow on the many sides of the structure essentially gluing the blocks together. These too can be placed by volunteers. Oyster shells are sometimes placed on the castles after installation to enhance recruitment. These are limited in elevation as it is difficult to stack more than 3 layers of units. (https://blogs.ubc.ca/royaloysteRS/2014/11/25/oysters-thriving-on-man-made-castles-

installed-on-south-carolinas-shores/;
https://www.delmarvanow.com/story/news/local/virginia/2017/08/28/concrete-castles-oysters-erosion/587651001/)

- Diamond and X-Reefs are two shapes of pre-cast concrete that have shells embedded in the structure (Figure 4-3C). These are proprietary structures. Oyster spat may prefer to attach to oyster shells so these forms have the ease of pre-cast concrete but could allow for better spat settlement. These structures are larger than the previous two and require construction equipment for installation. (https://www.dailypress.com/news/dp-nws-evg-biogenic-water-reefs-20170630-story.html).


*Figure 4-3. A) An oyster bag sill installation at CSRA just after installation (left) and after 5 years (right) (Photo credit: Shoreline Studies Program, VIMS). B) A typical oyster castle just after installation (left) and after oysters have grown (right) Images obtained from https://blogs.ubc.ca/royaloysters/2014/11/25/oysters-thriving-on-manmade-castles-installed-on-south-carolinas-shores/. C) Diamond reefs (left) and X-reefs (right) just after installation (Courtesy of R. Burke, CNU)*

- Natrx (https://natrx.io/) is a company that provides adaptive infrastructure for shore protection (Figure 4-4). Their proprietary modules are designed by engineers to a specific site, 3D printed, and transported to the site. Though used in other areas, only a few Natrx installations have occurred in Chesapeake Bay. As such, the authors consider this an innovative technique which will need to monitored. The structures can be 3D printed into various shapes with varying degrees of "pore space" where oyster spat can settle and colonize, and modules can be created to be stacked in higher energy areas. Cost is a consideration. Because the modules need to be placed with construction equipment, they cost more than the structures that can be placed by volunteers; however, they may be more appropriate for higher energy shorelines as they can be created heavier to withstand larger wave climates. The fact that these structures have copyright restrictions leading to sole source designation could be problematic from a practical marine construction application.

The proposed Natrx design for this site consists of a line of single-layer, 3D printed concrete cubes called "ExoForms" (Figure 4-5). The cubes are concrete structures measuring 34 in$^3$ (±2 inches on each side) with a central, interior pore space. The cubes are placed in 3 sections along the site. The company feels these would be appropriate along the southern points and in the area between them. These structures will weigh approximately 2,000 lbs. so the soft bottom is a consideration that must be addressed.

*Figure 4-4. Several configurations of 3D printed Natrx modules used at low and high energy sites.*

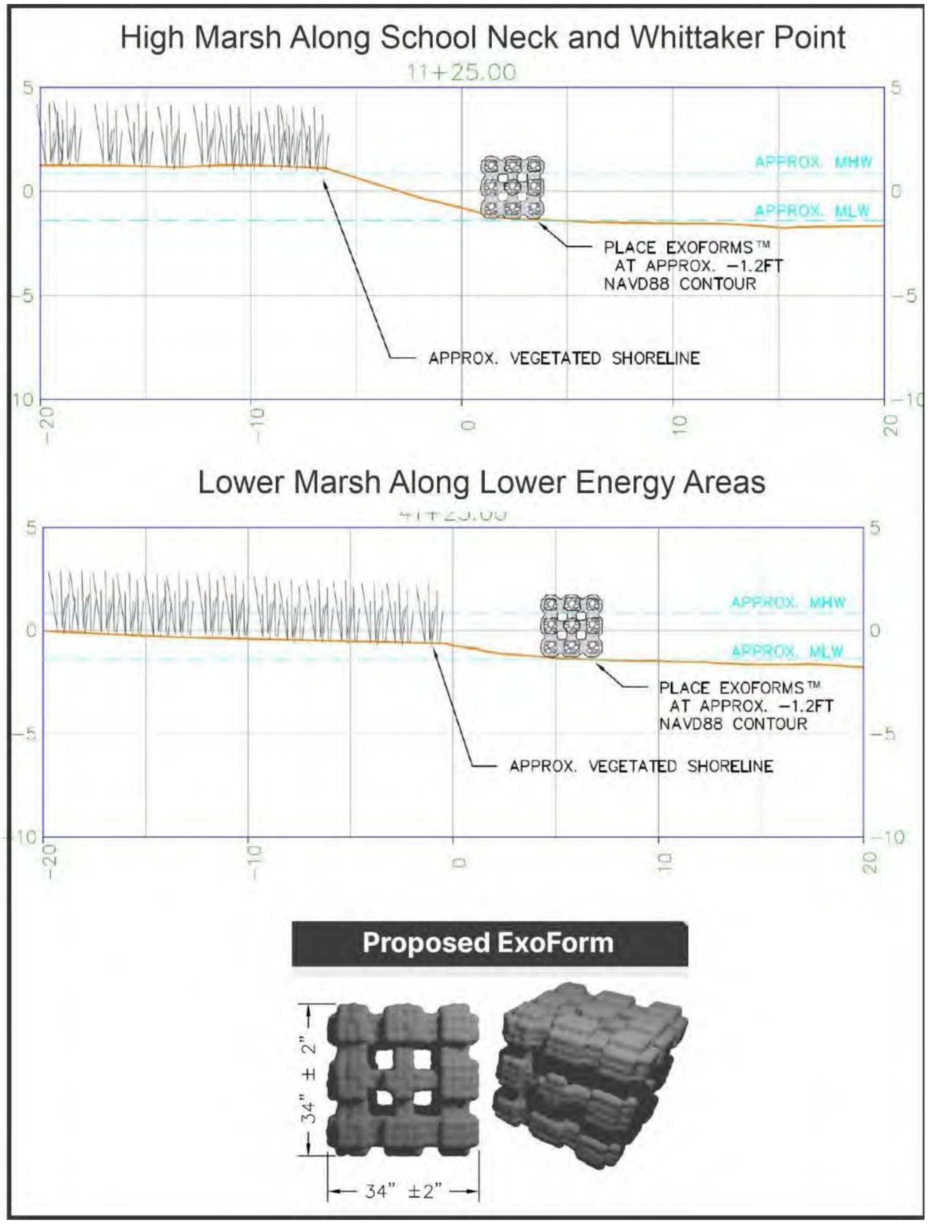


*Figure 4-5. Natrx design for concrete intertidal oyster reef units for CSRA-W.*

- Quickreefs (nativeshorelines.com) are concrete slabs that are placed at an angle in the nearshore (Figure 4-6). QuickReef provided a design option for this site which consists of concrete sills spread along the shoreline of the site, each being 24 ft tall and measuring no longer than 100 ft. Each sill is composed of individual upper segments spaced 5 ft apart and placed upon a continuous base layer, which itself is placed upon a layer of 3/8 inch untreated plywood to evenly distribute the weight of the structures and help to combat sinking due to the site's soft nearshore sediment. Quickreefs can also be installed with or without sand and plants adjacent to the west shoreline in place of the hybrid rock marsh sills. However, they would need to be designed to be as high as the rock sills and hold the sand behind them.

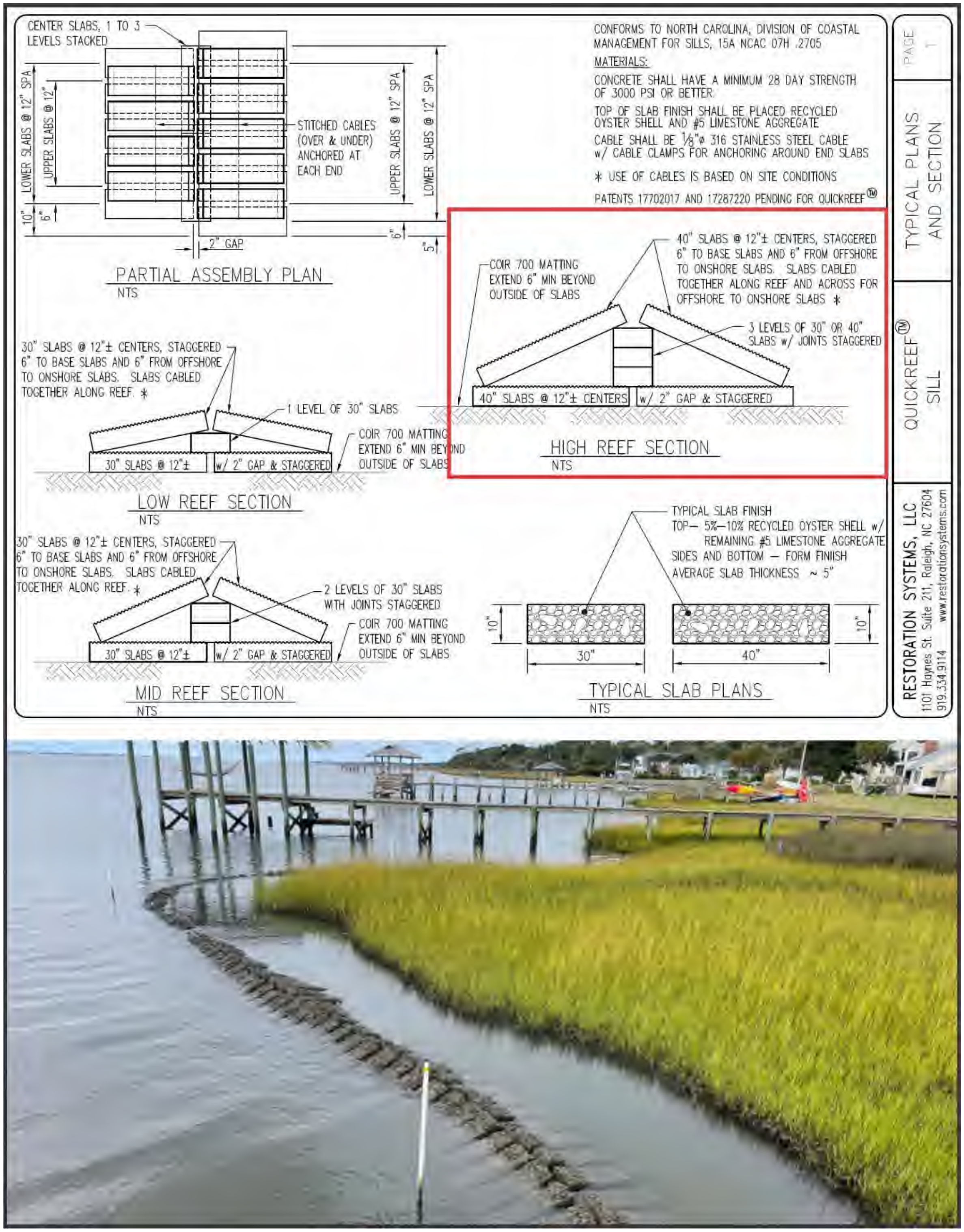


*Figure 4-6. Schematics by Restoration Systems, LLC and photo showing Quickreef installation. https://nativeshorelines.com/quickreef-living-shorelines/*

The intertidal oyster reefs are recommended along the south and east facing shorelines of CSRA-W. At School Neck Point and Whittaker Point, a larger, concrete structure is recommended because of the potential wave climate and the need to hold these headlands. Smaller, oyster bag sills or concrete forms are recommeded in the lower energy areas. Bottom stability is an issue in these areas and needs to be addressed for any structure larger than the oyster bag sills or oyster castles. These two types of intertidal oyster reefs are fairly light and can be placed right up against the scarp where the bottom is more stable.

The rock sills and intertidal oyster reefs have been permitted and installed in Chesapeake Bay. The rock sills have been extremely effective shore protection for 40 years and will provide a higher level of protection and more coastal resiliency than the intertidal oyster reefs. Other consideration when deciding on a strategy may be that a larger rock structure may impact the viewshed as they will be visible along the shoreline. The oyster reefs will generally provide shore erosion mitigation at the site for a lower cost. Oyster bags and oyster castles are units that can be installed by volunteers ensuring that the cost is minimal. Diamond and X reefs and Natrx units must be stockpiled and installed using heavy construction equipment. Therefore, their cost will vary per site due to site-specific conditions including access and construction considerations and may, in fact, cost more than a hybrid rock marsh sill.

#### *4.1.3 Thin-Layer Placement*

Thin layer placement (TLP), or thin-layer sediment addition, is a process in which sediment removed from navigation channels during dredging 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 (VIMS, 2014). The main goal of TLP is to restore and maintain coastal wetlands by emulating the natural processes of gradual sediment deposition, slightly increasing their elevation to allow the marshes to continue to exist and thrive in the face of erosion and sea-level rise without limiting vegetation growth (Raposa et al., 2020). The amount of sediment deposited through thin-layering depends on its usage. The restoration and maintenance of an existing wetland requires approximately six inches of sediment deposition, while the creation of a new wetland requires at least a foot of sediment deposition (Welp et al., 2014). Adding too little sediment may not allow the marsh to withstand erosion and flooding, which can damage vegetation. However, adding too much sediment may limit natural plant growth and leave the marsh vulnerable to invasive species like *Phragmites australis*. Due to the Chesapeake Bay's conditions of rising water levels and land subsidence, in conjunction with its many channels and inlets in need of dredging, thin-layering techniques may prove to be extremely beneficial in creating, restoring, and maintaining coastal wetlands in the region (VIMS, 2014). Though done in other areas of the country, thin-layer placement (TLP) is only recently started being used in Virginia.

Many areas of the CSRA-W could be enhanced with TLP (Figure 4-7). If the area south of the trees was used as the TLP area, 49 acres could be enhanced. A typical TLP depth is 4-8 inches (10-20 cm) although it can range from 0.4 to 20 inches (1 cm to 50 cm). Research has shown that S. alterniflora can grow through an overburden of sediment up to 9 inches (23 cm) regardless of sediment type (Reimold *et al.*, 1978). Using an average depth of 0.5 ft, the volume

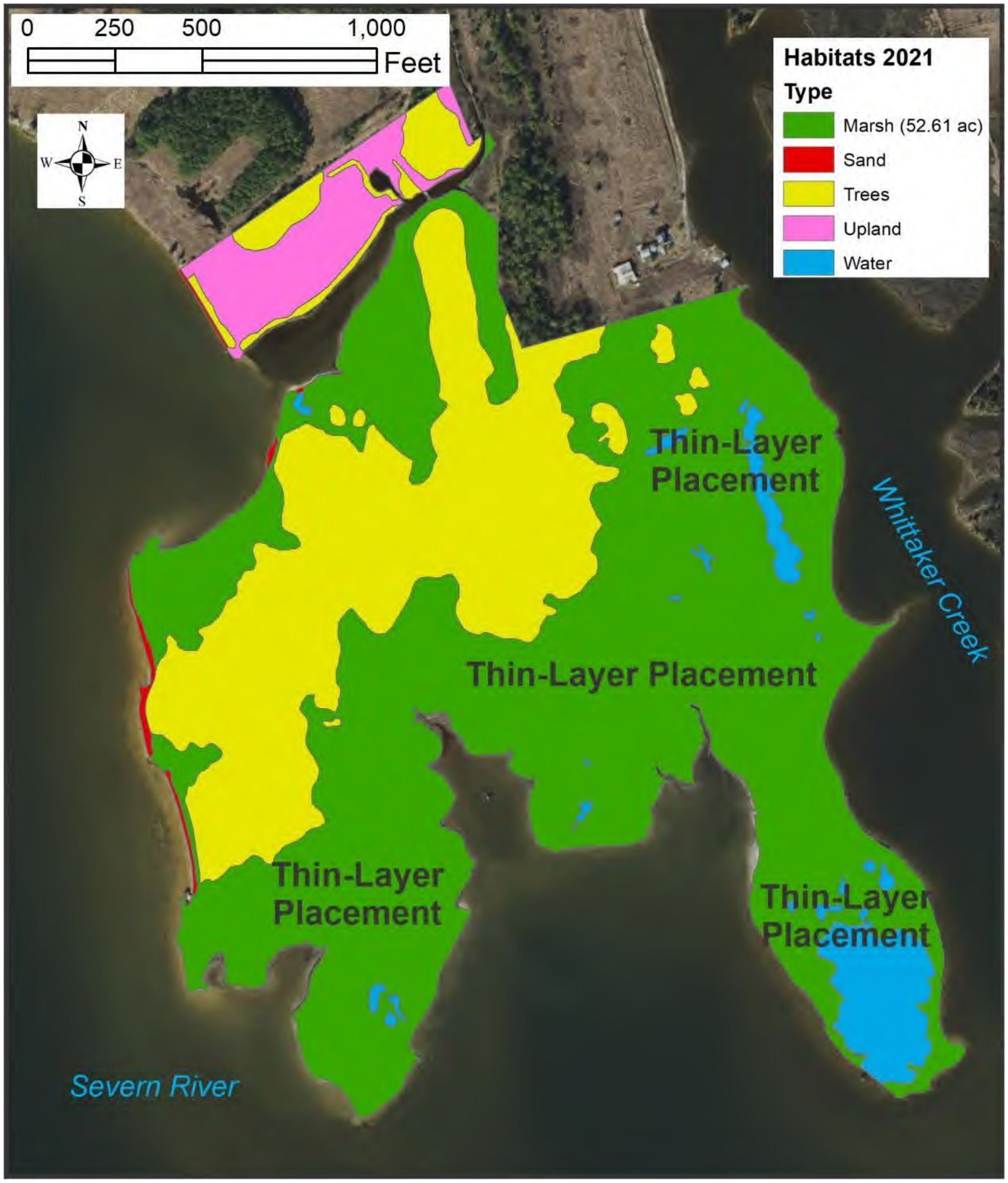


*Figure 4-7. Areas of CSRA-W that would be suitable for thin-layer placement of dredge material.*

of material that could be placed on the 49 acres of marsh and interior ponding is about 40,000 cubic yards (cy). If all the marsh area is included (52.6 acres), about 42,430 cy could be placed at CSRA-W.

Sediment grain size is variable but other locations have used 40-50% fine sand with 50-60% silt and clay (Raposa *et al.*, 2020). Recent surveys of sediment type within local creeks that need dredged revealed that though Free School Creek adjacent to CSRA-W is close by and has about 14,600 cy of material that could be dredged, the material is mostly silt and clay and likely would be too fine to be used for TLP (DiNapoli et al., 2021). However, Davis Creek which is across Mobjack Bay from the Severn River had about 24,150 cy of material that needed dredged. It was mostly sand, but with some of the material having 20-25% fines and the D50 (median grain size) being between 0.12 mm and 0.18 mm, it was not appropriate for shoreline beneficial use as that requires less than 10-15% fines and a recommended minimum D50 of 0.25 mm (Hardaway et al., 2020). However, this material would likely be appropriate for TLP. In addition, the sediment was tested for chemicals and neither sample locations had any of the contaminants in quantities larger than the limits of the tests used (Hardaway et al., 2020).

### 4.2 Reach Design Considerations

Using a reach approach for shoreline management was recommended by Hardaway & Byrne (1999). However, for many property owners, shore protection has the narrow focus of their own property. The next generation management planning needs to consider options outside of the property that will enhance the reach overall. By combining options, larger, more resilient options can be obtained than on a parcel by parcel level. Parcel boundary lines do not often coincide with a coastal reach, and projects constructed may not be as effective. However, the planning framework has not been in place to assist property owners to work on a multi-parcel or reach basis.

This site is large enough that it has reaches within the property rather than with adjacent property owners. However, at the northwest section of the property where Sills 1 and 2 are, the adjacent property owner could continue the sill to ensure protection of the entire shoreline. On Whittaker Creek, the adjacent property owner can be included in the discussions regarding the marsh edge protection using intertidal oyster reefs.

### 4.3 Final Design

The CSRA-W property is owned and managed by MP-PAA. In consultation with MP-PAA representatives, a multifaceted management plan that best aligned with available funding resources was selected. Considering that the MP-PAA does not currently have funding available to fund reach-based construction activities and the CSRA-W is publicly owned and eligible for many state and federal grant funding programs, designs selected for the management plan were selected by the MP-PAA representatives which best aligned with the priorities of available state and federal grant funding sources. The designs were also placed in different locations around the site based on unique, reach-specific factors identified by the site analysis and field work to minimize habitat impacts while providing shore erosion mitigation. As per the property owner, the structures will either consist of Quickreefs or Natrx modules. These are both proprietary products offered by only their respective companies who provided the design for this project. VIMS does not advocate for any particular product, but rather allows the property owner to make the final decision on their shore protection.

QuickReef sills will be placed along the western shore and stacked at an angle to reduce wave impacts at the shoreline and provide substrate for oyster settlement. The western shoreline has eroding uplands adjacent to the shore. Fifteen sills that are 5 ft wide will be constructed along the western shorelines at MLW to avoid impact to SAV. They will be 80 or 90 ft long with gaps 15 or 20 ft wide with several larger gaps to allow public access (Figure 4-8). Sand fill will be placed landward of the sills at about 1 ft thick to the edge of existing vegetation, base of shoreline scarp, or MHW to provide substrate for planted marsh. Quickreefs are placed by hand. The cost will depend on final site conditions and the project timeline, but presently, about $450/linear ft could be used to estimate overall cost.

Concrete, 3D printed Natrx exomodules will be placed adjacent to the marsh shoreline along the southern and eastern shorelines at MLW to avoid SAV impacts. These 34-inch square units will have holes and a rough surface to provide substrate for oyster settlement. Along the southern points, 15 segments of these units will be placed 100 ft long with 20 ft gaps (Figure 4-9). In slightly lower fetch areas,21 segments of the units will be placed in 80 segments with 35 ft gaps. Along the lowest fetch area of Whittaker Creek, 13 segments of smaller Natrx units or oyster bay sills will be placed in 50 long units with 30 ft gaps (Figure 4-10). All materials will be brought in by barge. No grading or tree cutting will occur.

Natrx modules will need to be placed with heavy machinery. These 1-ton blocks will sink into the substrate up to 1 ft in the soft bottom adjacent to the marsh in these areas, according to the Natrx designer. They are designed this way and though these modules would be stable, they could sink varying depths affecting the overall wave attenuation capabilities of the system and the amount of area available for oyster larvae settlement. It is suggested that the units are installed with filter cloth or a gabion mattress. An estimated cost to install just the units is about $650/linear foot.

The third part of the design consists on placing smaller intertidal oyster structures, such as oyster bags or oyster castles® within the softer remaining areas that occur between the two points, along the Whittaker Creek shoreline to the property boundary. The oyster bags or castles will be much cheaper to purchase and can be installed by hand, creating the option to use volunteers for installation. Smaller Natrx modules could be placed in these areas as well. They would be more expensive due to the need for heavy machinery to install them. Note, we are not recommending anything be placed along the shoreline at section 2 (Figure 3-2). The bottom is extremely soft and would likely not support any type of structure.

Due to the size of the project, phasing can be considered for the site. Depending on available funding and property owner priorities, installing intertidal oyster reefs at the southern tips of School Neck and Whittaker Points or the Quickreef sills should be priorities. The marsh points are eroding quickly, and the sooner structures are placed for shore erosion mitigation, lesser marsh area will be lost. In particular, if the marsh between the shoreline and the non-vegetated wetland on the interior of Whittaker Point (Area 8) erodes, nearly half of the marsh area of the Point will be lost. However, if public access is a priority, stabilizing the western shorelines will protect higher, upland areas as well as provide safe, sandy areas for usage. The smaller intertidal oyster reefs recommended between the points and along Whittaker Creek are in areas that have the lowest rates of change and could be considered a lower priority for shore protection.

Additionally, MP-PAA has expressed interest in pursuing thin layer placement and marsh enhancement in the future. This is needed to raise the elevation of the marsh, particularly in the areas that are being converted to open water within the interior of the marsh. The proposed oyster sills will protect the marsh edge from erosion, but without additional elevation, the low marsh will deteriorate as the high marsh migrates into the wooded areas.

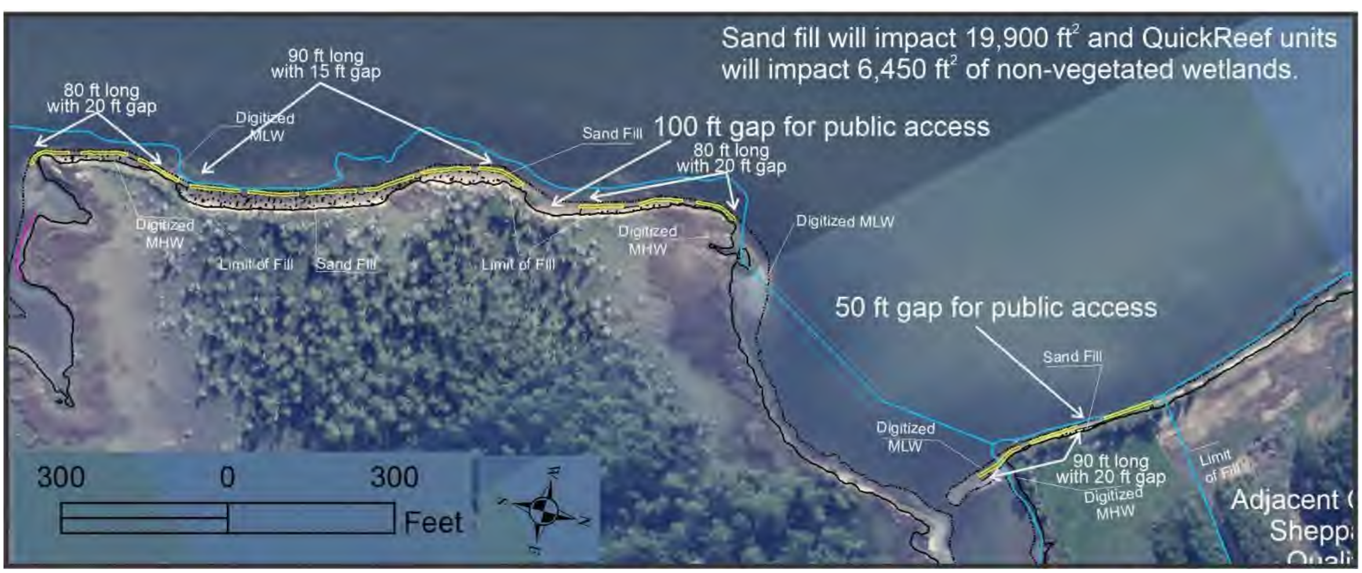


*Figure 4-8. Configuration of Quickreef sills along the western shore of CSRA-W.*

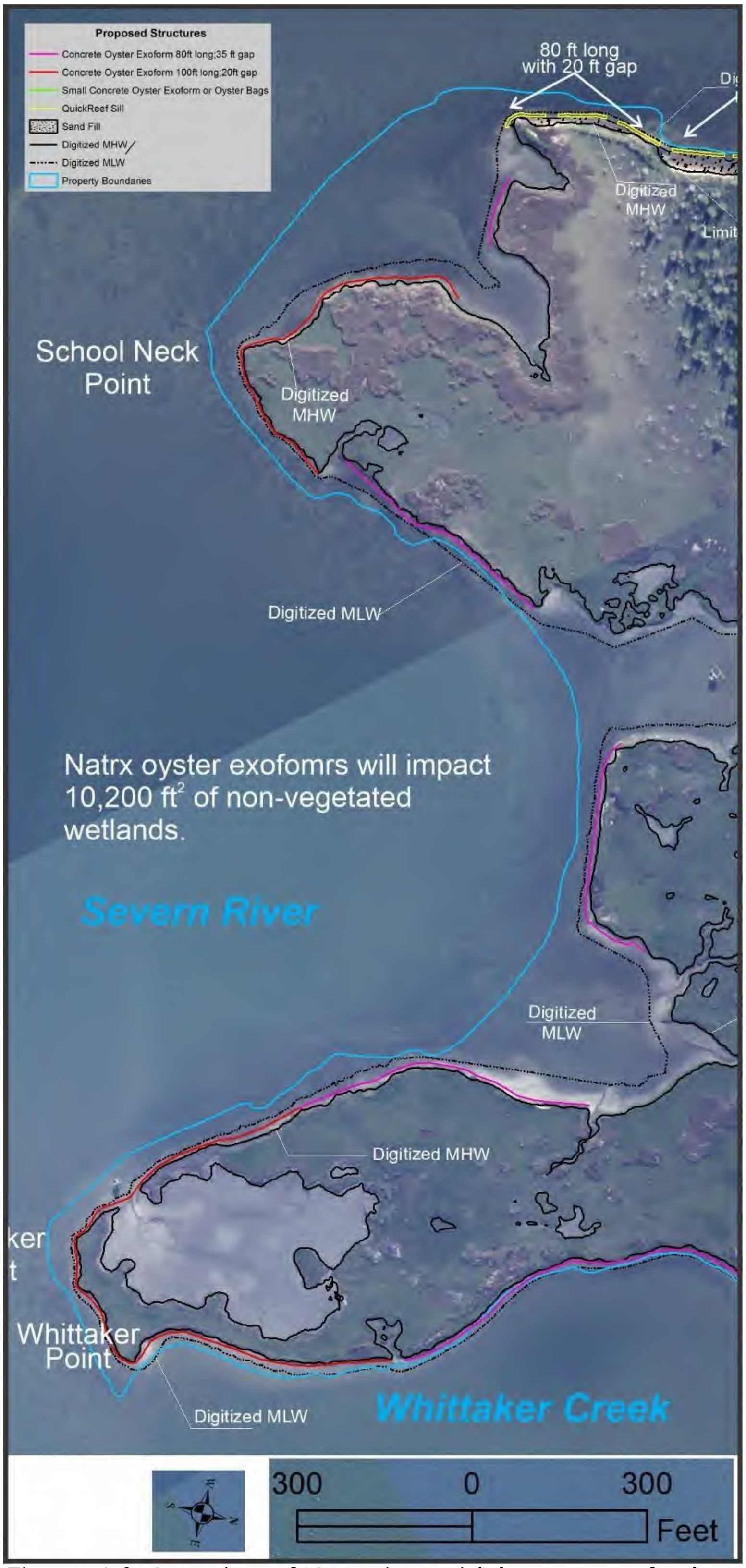


*Figure 4-9. Location of Natrx intertidal oyster reefs along the Severn River at CSRA-W.*


*Figure 4-10. Location of Natrx intertidal oyster reefs along Whittaker Creek at CSRA-W.*

# 5 Maintenance, Monitoring, & Resiliency

## 5.1 Maintenance

Maintenance for this project is recommended, though it is likely to be minimal. For the hybrid marsh sills, some maintenance may be required. Generally, if trees begin to shade the marsh, they should be trimmed. If large debris washes up on the marsh, it should be removed. After a very large storm, the system may require additional sand and/or plants to restore the marsh.

For the intertidal oyster reef installation. The goal of the project is for a thriving reef to develop in the nearshore. This should not require any maintenance. Once the reef units are installed, they should have spat settlement on them and other faunal use. It will take several years to see appreciable size oysters at the reefs.

## 5.2 Monitoring

Monitoring of the site is recommended. It is not required by the permitting authorities, though it may be required by grant funding. Generally, monitoring is looking to assess the strategy's condition over time to answer the general question of how they are functioning for shoreline protection. This can be done using very low-cost items by non-technical staff or volunteers. At the minimum, occasional ground photography of the units along the shoreline over time should be taken over time to see how the marsh is growing and if the intertidal reefs have oyster settlement.

Metrics for the hybrid rock marsh sills include identifying areas of rapid sand loss and large areas of plant mortality should they occur. If they do, they would need to be addressed. Using permanent meter square plots can be used to determine change in vegetation. They should be surveyed once a year for percent cover, tallest stem length, and the number of flowering shoots (Milligan, Priest, & Hardaway, 2019). Tidal inundation can be qualitatively monitored by observing wrack lines in the marsh. This is important to ensure that the plants receive enough inundation without being flooded more regularly.

Measuring changes in elevation is best done with a topographic survey. Surveying for elevation at certain cross-sections would also show how the structure is affecting the shoreline. Surveying at least once a year is recommended. Because it can be difficult to measure small changes in elevation, setting up high resolution benchmarks is suggested. However, this can be costly. An alternative is to use strategically placed stakes with measurements from the top of the stake to the substrate surface. Periodically re-measuring the exposed height of the stake can show where sand is being lost or where it is accreting (Milligan, Priest, & Hardaway, 2019).

For the intertidal oyster reefs, it can take several years to see the affect along the shoreline. Drone imagery of the site would show the effectiveness of the shore protection mitigating erosion. The goal is to have the scarp erode into a gentler coastal profile that grasses can grow on. As the profile gentles landward of the reef, the marsh may expand riverward. Documenting growth of grasses in the intertidal zone is recommended as is determining how well oyster larvae are settling on the reef structures.

Costs for monitoring can vary depending on which strategies are chosen; however, ground photography and vegetation documentation can be done by volunteers and does not take much time nor does it cost much.

### 5.3 Coastal Resiliency

The goal of a marsh sill and the intertidal oyster reefs is to protect the edge of the marsh from erosion and help break storm waves before they impact the site. The marsh will still flood during storms, and SLR will continue to impact the site. However, the reef itself can adapt to SLR by continuing to grow in elevation.

Overall, the site has gentle slopes along the interior of the marsh. Over time, the low and high marsh have migrated into the wooded areas. This will continue through time as the marsh adapts to rising sea-levels. The lower elevations will continue to convert to interior water reducing the overall amount of vegetated marsh. The only option to stop this is to raise the elevation of the marsh through TLP.

# 6 Summary

Captain Sinclair's Recreational Area (CSRA) is located on the Severn River and Whittaker Creek in Gloucester County, Virginia.  In 2016, a shoreline management plan was developed for CRSA, and a hybrid gapped stone sill living shoreline system and oyster bag sills were installed on the site in 2016 and 2017, respectively. Recently, the 100-acre western peninsula, CRSA-W, with 2 miles of shoreline across Whittaker Creek from the original shoreline management area was acquired by the Middle Peninsula Public Access Authority (MP-PAA) and assimilated into CRSA. The goal of this project is to determine how erosion can be managed CSRA-W in coordination with MP-PAA's goals.

A remote site assessment of the property was done in order to analyze the physical characteristics, habitat shifts, and shoreline changes rates of the site over time. The site has both low and medium-energy wave environments. The overall elevation is low, with an average marsh elevation of 3.25 ft MLW and a maximum upland elevation of 5 ft MLW. As such, the area is especially threatened by flooding from storm surge and sea level rise. Using historical aerial and satellite imagery in combination with the Digital Shoreline Analysis System (DSAS) extension in ArcGIS, it was determined that the western and southern shorelines are experiencing the highest rates of erosion, which has been increasing in recent years.

An on-site elevation survey using real-time kinematic global positioning system (RTK-GPS) technology was conducted in addition to nearshore sediment sampling and GPS-tagged photography. Using the results of the on-site surveys and the remote assessment, four design options were created for the MP-PAA. The first option presented is to do nothing and allow the marsh to retreat naturally. The second option is to construct hybrid stone sill living shoreline systems along the site. The third option is to construct intertidal oyster reefs along the site, and a variety of proprietary and non-proprietary design examples were presented. The final option is to incorporate the use of thin layer placement (TLP) to restore and build the marsh habitat with dredged sediment.

The MP-PAA regularly utilizes its public properties to help facilitate and test shoreline protection products which are both innovative and new to the Commonwealth. One such product, Quickreef, offered to donate units to demonstrate technology at a low to moderate energy shoreline location on an MP-PAA owned property. Since the effectiveness of the Quickreef units will be evaluated and better understood by the time construction occurs at the CSRA-W property, Middle Peninsula Planning District Commission staff on behalf of the MP-PAA selected to design Quickreef sill living shoreline systems as a first possible targeted location solution amongst the proposed concepts along the western shore with firmer nearshore sediment and higher elevation uplands. The construction of both larger concrete oyster reef structures at the southern points has been selected as well as smaller intertidal oyster reefs in the softer nearshore areas along the eastern shoreline and the southern shoreline between the two points. They have also expressed interest in pursuing TLP and marsh enhancement in the future. The shoreline management plan has factored in strategies best aligned with MP-PAA's preferences, priorities, and ability to fund the project, and is focused on the implementation of this project.

This report provides an overall summary of the site assessment, shore survey, data analysis, and management planning undertaken for the site, and presents the information so that an effective shoreline management strategy can be selected to mitigate erosion at this site and create a stable tidal marsh that can be resilient in the face of ongoing and future sea level rise and storm activity.

# 7 References

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# Appendix A

Auger Logs and Sediment Analysis

## Sediment Analysis of Auger Sediment Samples

| SAMPLE ID | V COARSE SAN | COARSE SAND | MEDIUM SAN | % FINE SAND: | % V FINE SAND | % SAND: | % SILT: | % CLAY: | % MU |
|---|---|---|---|---|---|---|---|---|---|
| Auger 1-1 | 0 | 0.7 | 7.3 | 39.9 | 22.8 | **70.7** | 19.8 | 9.5 | |
| Auger 1-2 | 0 | 0.6 | 5.1 | 38.8 | 22.9 | **67.4** | 21.4 | | |
| Auger 2-1 | 1.0 | 4.0 | 11.6 | 25.4 | 14.8 | **56.9** | 28.3 | | |
| Auger 2-2 | 1.5 | 4.4 | 12.0 | 25.4 | 15.5 | **58.8** | | | |
| Auger 3-1 | 1.3 | 6.6 | 17.6 | 31.1 | 14.9 | | | | |
| Auger 3-2 | 1.5 | 5.0 | 16.2 | 33.9 | 16 | | | | |

| SAMPLE ID | MEAN (mm) | MEDIAN (mm) | SORTING | S |
|---|---|---|---|---|
| Auger 1-1 | 131.3 | 129.6 | 107. | |
| Auger 1-2 | 120.9 | 122.9 | | |
| Auger 2-1 | 151.8 | | | |
| Auger 2-2 | 163.0 | | | |
| Auger 3-1 | | | | |
| Au | | | | |

## Logs

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| CLIENT: Middle Peninsula Public Access Authority | | | | DATE: 14 April 2023 | | | |
| SUBJECT: Captain Sinclair's Recreational Area West | | | | | | | |
| BORING #: A-1 | Total Depth | | Elev: | Location: | | | |
| Type of Boring: | | Started: | Completed: | Driller: CSH | | | |
| Elevation MLW | Depth | | Description of Materials (classification) | Sample Blows | Sample Depth (ft) | Moisture Content (%) | Remarks |
| | 0 | | | | | | |
| | -1 | | Gray v. soft, v. fine silty sand (SM) little silt, trace clay | | | | A1-1 |
| | -2 | | Gray to tan stiff v. fine silty sand (SM) some silt, little clay | | | | A1-2 |
| | -3 | | | | | | |
| | -4 | | | | | | |
| | -5 | | | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| CLIENT: Middle Peninsula Public Access Authority | | | | DATE: 14 April 2023 | | | | |
| SUBJECT: Captain Sinclair's Recreational Area West | | | | | | | | |
| BORING #: A-2 | | Total Depth | Elev: | Location: | | | | |
| Type of Boring: | | | Started: | Completed: | | Driller: CSH | | |
| Elevation MLW | Depth | | Description of Materials (classification) | Sample Blows | Sample Depth (ft) | Moisture Content (%) | Remarks | |
| | 0 | | | | | | | |
| | -1 | | Olive gray v. soft silty sand (SC), some silt, little clay | | | | A2-1 | |
| | -2 | | Dark gray v. soft silty sand (SC), some silt, little clay | | | | A2-2 | |
| | -3 | | | | | | | |
| | -4 | | | | | | | |
| | -5 | | | | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| CLIENT: Middle Peninsula Public Access Authority | | | | DATE: 14 April 2023 | | | | |
| SUBJECT: Captain Sinclair's Recreational Area West | | | | | | | | |
| BORING #: A-3 | | Total Depth | Elev: | Location: | | | | |
| Type of Boring: | | | Started: | Completed: | | Driller: CSH | | |
| Elevation MLW | Depth | | Description of Materials (classification) | Sample Blows | Sample Depth (ft) | Moisture Content (%) | Remarks | |
| | 0 | | | | | | | |
| | -1 | | Gray to yellowish orange med. stiff fine silty sand (SM) little silt, little clay | | | | A3-1 | |
| | -2 | | Gray to yellowish orange med. stiff fine silty sand (SM) little silt, trace clay | | | | A3-2 | |
| | -3 | | | | | | | |
| | -4 | | | | | | | |
| | -5 | | | | | | | |

# Appendix B

Draft Joint Permit Application

# Regulatory Agency Contact Information

**Virginia Marine Resources Commission (VMRC)**
Habitat Management Division
380 Fenwick Road, Building 96
Fort Monroe, VA 23651
Phone: (757) 247-2200, Fax: (757) 247-8062
Website: http://www.mrc.virginia.gov/hmac/hmoverview.shtm

**United States Army Corps of Engineers (USACE)**
Norfolk District
803 Front Street, ATTN: CENAO-WR-R
Norfolk, Virginia 23510-1011
Phone: (757) 201-7652, Fax: (757) 201-7678
Website: http://www.nao.usace.army.mil/Missions/Regulatory.aspx

**Virginia Department of Environmental Quality (DEQ)**
Virginia Water Protection Permit Program
Post Office Box 1105
Richmond, Virginia 23218
Phone: (804) 698-4000
Website: http://www.deq.virginia.gov/

**LOCAL WETLANDS BOARD (LWB) CONTACT INFORMATION:**
Links to LWB information on the Web can be found at
http://ccrm.vims.edu/permits_web/guidance/local_wetlands_boards.html
In addition, the phone numbers listed below can be used to contact the LWB. Please be advised that these phone numbers are subject to change at any time.

**Accomack County (757) 787-5721, Cape Charles (757) 331-3259, Charles City County (804) 829-9296, Chesapeake (757) 382-6248, Colonial Heights (804) 520-9275, Essex County (804) 443-4951, Fairfax County (703) 324-1364, Fredericksburg (540) 372-1179, Gloucester County (804) 693-2744, Hampton (757) 727-6140, Hopewell (804) 541-2267, Isle of Wight County (757) 365-6211, James City County (757) 253-6673, King and Queen County (804) 769-4978, King George County (540) 775-7111, King William County (804) 769-4927, Lancaster County (804) 462-5220, Mathews County (804) 725-5025, Middlesex County (804) 758-0500, New Kent County (804) 966-9690, Newport News (757) 247-8437, Norfolk (757) 664-4368, Northampton County (757) 678-0442, Northumberland County (804) 580-8910, Poquoson (757) 868-3040, Portsmouth (757) 393-8836, Prince William County (703) 792-6984, Richmond County (804) 333-3415, Stafford County (540) 658-8668, Suffolk (757) 923-3650, Virginia Beach (757) 427-8246, Westmoreland County (804) 493-0120, West Point (804) 843-3330, Williamsburg (757) 220-6130, York County (757) 890-3538**

# Tidewater Joint Permit Application (JPA)
# For Projects Involving Tidal Waters, Tidal Wetlands and/or Dunes and Beaches in Virginia

This application may be used for most commercial and noncommercial projects involving **tidal waters, tidal wetlands and/or dunes and beaches in Virginia** which require review and/or authorization by Local Wetlands Boards (LWB), the Virginia Marine Resources Commission (VMRC), the Department of Environmental Quality (DEQ), and/or the U. S. Army Corps of Engineers (USACE). This application can be used for:

- **Access-related activities**, including piers, boathouses, boat ramps (without associated dredging or excavation*), moorings, marinas.
- **Shoreline stabilization projects** including living shorelines, riprap revetments, marsh toe stabilization, bulkheads, breakwaters, beach nourishment, groins, and jetties. It is the policy of the Commonwealth that living shorelines are the preferred alternative for stabilizing tidal shorelines (Va. Code § 28.2-104.1).
- **Crossings** over or under tidal waters and wetlands including bridges and utility lines (water, sewer, electric).
- **Aquaculture structures**, including cages and floats except "oyster gardening"**

***Note:** for all dredging, excavation, or surface water withdrawal projects you **MUST** use the Standard JPA form; for noncommercial, riparian shellfish aquaculture projects (i.e., "oyster gardening") you must use the abbreviated JPA found at https://mrc.virginia.gov/forms/2019/VGP3_Aquaculture_form_2019.pdf or call VMRC for a form.

The DEQ and the USACE use this form to determine whether projects qualify for certain General, Regional, and/or Nationwide permits. If your project does not qualify for these permits and you need a DEQ Virginia Water Protection permit or an individual USACE permit, you must submit the Standard Joint Permit application form. You can find this application at http://www.nao.usace.army.mil/Missions/Regulatory/JPA.aspx. Please note that some health departments and local agencies, such as local building officials and erosion and sediment control authorities, do not use the Joint Permit Application process or forms and may have different informational requirements. The applicant is responsible for contacting these agencies for information regarding those permitting requirements.

## HOW TO APPLY

**Submit one (1) completed copy of the Tidewater JPA to VMRC:**

1. If by mail or courier, use the VMRC address provided on page 1.
2. If by electronic mail, address the package to: **JPA.permits@mrc.virginia.gov.** The application must be provided in the .pdf format and should not exceed 10 MB. If larger than 10 MB you may provide a file transfer protocol (ftp) site for download purposes.

**The Tidewater JPA should include the following:**

1. **Part 1 –** General Information
2. **Part 2 –** Signatures
3. **Part 3** - Appendices (A, B, C, and/or D as applicable to your project)
4. **Part 4 –** Project Drawings.
   The drawings shall include the following for **ALL** projects:
   - Vicinity Map (USGS topographic map, road map or similar showing project location)
   - Plan View Drawing (overhead, to scale or with dimensions clearly marked)
   - Section View Drawing (side-view, to scale or with dimensions clearly marked)

Sample drawings are included at the end of Part 4 of this application to show examples of the information needed to consider your application complete and allow for the timely processing.

When completing this form, use the legal name of the applicant, agent, and/or property owner. For DEQ application purposes, *legal name* means the full legal name of an individual, business, or other organization. For an individual, the legal name is the first name, middle initial, last name, and suffix. For an entity authorized to do business in Virginia, the legal name is the exact name set forth in the entity's articles of incorporation, organization or trust, or formation agreement, as applicable. Also provide the name registered with the State Corporation Commission, if required to register. DEQ issues a permit or grants coverage to the so-named individual or business, who becomes the 'permittee'. Correspondence from some agencies, including permits, authorizations, and/or coverage, may be provided via electronic mail. If the applicant and/or agent wishes to receive their permit via electronic mail, please remember to include an e-mail address at the requested place in the application.

In order for projects requiring LWB authorization to be considered complete (Virginia Code § 28.2-1302); "The permit application shall include the following: the name and address of the applicant; a detailed description of the proposed activities; a map, drawn to an appropriate and uniform scale, showing the area of wetlands directly affected, the location of the proposed work thereon, the area of existing and proposed fill and excavation, the location, width, depth and length of any proposed channel and disposal area, and the location of all existing and proposed structures, sewage collection and treatment facilities, utility installations, roadways, and other related appurtenances of facilities, including those on the adjacent uplands; a description of the type of equipment to be used and the means of access to the activity site; the names and addresses of record of adjacent land and known claimants of water rights in or adjacent to the wetland of whom the applicant has notice; an estimate of cost; the primary purpose of the project; and secondary purpose of the proposed project; a complete description of measures to be taken during and after alteration to reduce detrimental offsite effects; the completion date of the proposed work, project, or structure; and such additional materials and documentation as the wetlands board may require."

You may include signed Adjacent Property Owner (APO) Acknowledgement Forms found at the end of this Short Form. You must provide these addresses in Part 1 whether or not you use the APO forms. VMRC will request comments from APOs for projects that require permits for encroachment over state-owned submerged lands. VMRC or your local wetlands board must notify all APO's of public hearings required for all proposals involving tidal wetlands and dunes/beaches that are not authorized by statute. This information will not be used by DEQ to meet the requirements of notifying riparian land owners.

~~Regional Permit 17 (RP-17), authorizes the installation and/or construction of open-pile piers, mooring structures/devices, fender piles, covered boathouses/boatslips, boatlifts, osprey pilings/platforms, accessory pier structures, and certain devices associated with shellfish gardening, for private use, subject to strict compliance with all conditions and limitations further set out in the RP-17 enclosure located at http://www.nao.usace.army.mil/Missions/Regulatory/RBregional/. In addition to the information required in this JPA, prospective permittees seeking authorization under RP-17 must complete and submit the 'Regional Permit 17 Checklist' with their JPA. A copy of the 'Regional Permit 17 Checklist' is found on pages 13 and 14 of this application package. If the prospective permittee answers "yes" (or "N/A", where applicable) to all of the questions on the 'Regional Permit 17 Checklist', the permittee is in compliance with RP-17 and will not receive any other written authorization from the Corps but may not proceed with construction until they have obtained all necessary state and local permits.~~ ***~~Note: If the prospective permittee answers "no" to any of the questions on the 'Regional Permit 17 Checklist' then their proposed structure(s) does not meet the terms and conditions of RP-17 and written authorization from the Corps is required before commencement of any work.~~***

**Note: Land disturbance (grading, filling, etc.) or removal of vegetation associated with projects located in Chesapeake Bay Preservation Areas will require approval from local governments. Certain localities utilize this application during their Bay Act review. Part 5 of this application is included to provide assistance for the applicant to comply with Bay Act /or Erosion and Sediment Control requirements concurrent with this application.**

## WHAT HAPPENS NEXT

Upon receipt of an application, VMRC will assign a permit application number to the JPA and will then distribute a copy of the application and any original plan copies submitted to the other regulatory agencies that are involved in the JPA process. All agencies will conduct separate but concurrent reviews of your project. Please be aware that each agency must issue a separate permit (or a notification that no permit is required). Note that in some cases, DEQ may be taking an action on behalf of the USACE, such as when the State Program General Permit (SPGP) applies. Make sure that you have received all necessary authorizations, or documentation that no permit is required, from each agency prior to beginning the proposed work.

During the JPA review process, site inspections may be necessary to evaluate a proposed project. Failure to allow an authorized representative of a regulatory agency to enter the property, or to take photographs of conditions at the project site, may result in either the withdrawal or denial of your permit application.

For certain federal and state permit applications, a public notice is published in a newspaper having circulation in the project area, is mailed to adjacent and/or riparian property owners, and/or is posted on the agency's web page. The public may comment on the project during a designated comment period, if applicable, which varies depending upon the type of permit being applied for and the issuing agency. In certain circumstances, the project may be heard by a governing board, such as a Local Wetlands Board, the State Water Control Board, or VMRC in cases where a locality does not have a wetlands board and with certain subaqueous cases. You may be responsible for bearing the costs for advertisement of public notices.

Public hearings that are held by VMRC occur at their regularly scheduled monthly commission meetings under the following situations: Protested applications for VMRC permits which cannot be resolved; projects costing over $500,000 involving encroachment over state-owned subaqueous land; and all projects affecting tidal wetlands and dunes/beaches in localities without a LWB. All interested parties will be officially notified regarding the date and time of the hearing and Commission meeting procedures. The Commission will usually make a decision on the project at the meeting unless a decision for continuance is made. If a proposed project is approved, a permit or similar agency correspondence is sent to the applicant. In some cases, notarized signatures, as well as processing fees and royalties, are required before the permit is validated. If the project is denied, the applicant will be notified in writing.

## PERMIT APPLICATION OR OTHER FEES

***Do not send any fees with the JPA***. VMRC is not responsible for accounting for fees required by other agencies. Please consult agency websites or contact agencies directly for current fee information and submittal instructions.

- USACE: Permit application fees are required for USACE Individual (Standard) permits. A USACE project manager will contact you regarding the proper fee and submittal requirements.

- DEQ: Permit application fees required for Virginia Water Protection permits – while detailed in 9VAC25-20 – are conveyed to the applicant by the applicable DEQ office (http://www.deq.virginia.gov/Locations.aspx). Complete the Permit Application Fee Form and submit it per the instructions to the address listed on the form. Instructions for submitting any other fees will be provided to the applicant by DEQ staff.
- VMRC: An application fee of $300 may be required for projects impacting tidal wetlands, beaches and/or dunes when VMRC acts as the LWB. VMRC will notify the applicant in writing if the fee is required. Permit fees involving subaqueous lands are $25.00 for projects costing $10,000 or less and $100 for projects costing more than $10,000. Royalties may also be required for some projects. The proper permit fee and any required royalty is paid at the time of permit issuance by VMRC. VMRC staff will send the permittee a letter notifying him/her of the proper permit fees and submittal requirements.
- LWB: Permit fees vary by locality. Contact the LWB for your project area or their website for fee information and submittal requirements. Contact information for LWBs may be found at http://ccrm.vims.edu/permits_web/guidance/local_wetlands_boards.html.

| **FOR AGENCY USE ONLY** | |
|---|---|
| | Notes: |
| | JPA # |

# APPLICANTS
## Part 1 – General Information

**PLEASE PRINT OR TYPE ALL ANSWERS:** If a question does not apply to your project, please print N/A (not applicable) in the space provided. If additional space is needed, attach 8-1/2 x 11 inch sheets of paper.

| ***Check all that apply*** | | |
|---|---|---|
| Pre-Construction Notification (PCN) ☐<br>NWP # ____________________<br>(*For Nationwide Permits ONLY - No DEQ-VWP permit writer will be assigned*) | PASDO – PGP Self Verification ☒<br>*(Replaces Regional Permit 17 (RP-17) checklist)* | |

**County or City in which the project is located:** Gloucester County

**Waterway at project site:** Severn River

***PREVIOUS ACTIONS RELATED TO THE PROPOSED WORK (Include all federal, state, and local pre application coordination, site visits, previous permits, or applications whether issued, withdrawn, or denied)***

Historical information for past permit submittals can be found online with VMRC - https://webapps.mrc.virginia.gov/public/habitat/ - or VIMS - http://ccrm.vims.edu/perms/newpermits.html

| Agency | Action / Activity | Permit/Project number, including any non-reporting Nationwide permits previously used (e.g., NWP 13) | Date of Action | If denied, give reason for denial |
|---|---|---|---|---|
| | | | | |
| | | | | |

# Part 1 - General Information (continued)

1. Applicant's legal name* and complete mailing address:
   Middle Peninsula Chesapeake Bay Public Access Authority

   Contact Information:
   Home (____)______________
   Work (____)______________
   Fax (____)______________
   Cell (____)______________
   e-mail ____________________

   State Corporation Commission Name and ID Number (if applicable) ______________

2. Property owner(s) legal name* and complete address, if different from applicant: Contact Information:
   Home (____)______________
   Work (____)______________
   Fax (____)______________
   Cell (____)______________
   e-mail ____________________

   State Corporation Commission Name and ID Number (if applicable) ______________

3. Authorized agent name* and complete mailing address (if applicable):

   Contact Information:
   Home (____)______________
   Work (____)______________
   Fax (____)______________
   Cell (____)______________
   e-mail ____________________

   State Corporation Commission Name and ID Number (if applicable) ______________

*** If multiple applicants, property owners, and/or agents, each must be listed and each must sign the applicant signature page.**

4. Provide a detailed description of the project in the space below, including the type of project, its dimensions, materials, and method of construction. Be sure to include how the construction site will be accessed and whether tree clearing and/or grading will be required, including the total acreage. If the project requires pilings, please be sure to include the total number, type (e.g. wood, steel, etc), diameter, and method of installation (e.g. hammer, vibratory, jetted, etc). If additional space is needed, provide a separate sheet of paper with the project description.

   Captain Sinclair's Recreational Area West is a large marsh peninsula on the Severn River extending into Whittaker Creek. The 100-acre property is especially threatened by flooding from storm surge and sea level rise. The western shoreline is a low energy environment, and the eastern shore along Whittaker Creek has very low energy. The southern points (School Neck and Whittaker Points) are exposed to medium energy, but the shoreline between them is low energy. The site has a low elevation, with an average marsh elevation of +3.3 ft MLW and a maximum upland elevation of +5 ft MLW. Overall, it was determined that the western and southern shorelines are experiencing the highest rates of erosion, which has been increasing in recent years. In addition, with the recent upgrades to the boat ramp in Whittaker Creek, the marsh shoreline along the creek could become exposed to boat wake. The western shoreline is sandy and has a firm to semi-firm bottom. The rest of the shoreline is marsh and has a soft bottom. In addition, SAV is prevalent at the site extending to MLW in most areas. Two types of products will be used to mitigate erosion and enhance the marsh at the site. QuickReef sills are rough concrete slabs (40 in x 12 in) placed along the western shore and stacked at an angle to reduce wave impacts at the shoreline and provide substrate for oyster settlement. The western shoreline has eroding uplands adjacent to the shore. Fifteen sills that are 5 ft wide will be constructed along the western shorelines at MLW to avoid impact to SAV. They will be 80 or 90 ft long with gaps 15 or 20 ft wide with several larger gaps to allow public access (as shown in drawings). Sand fill will be placed landward of the sills at about 1 ft thick to the edge of existing vegetation, base of shoreline scarp, or MHW to provide substrate for planted marsh. Concrete, 3D printed Natrx exomodules will be placed adjacent to the marsh shoreline along the southern and eastern shorelines at MLW to avoid SAV impacts. These 34 inch square units will have holes and a rough surface to provide substrate for oyster settlement. Along the southern points, these units will be placed 100 ft long with 20 ft gaps. In slightly lower fetch areas, the units will be placed in 80 segments with 35 ft gaps. Along the lowest fetch area of Whittaker Creek, smaller Natrx units or oyster bay sills will be placed in 50 long units with 30 ft gaps. All materials will be brought in by barge. No grading or tree cutting will occur.

# Part 1 - General Information (continued)

5. Have you obtained a contractor for the project? ___ Yes* ___ No. *If your answer is "Yes" complete the remainder of this question and submit the Applicant's and Contractor's Acknowledgment Form (enclosed)

   Contractor's name* and complete mailing address:

   Contact Information:
   Home (____)____________
   Work (____)____________
   Fax (____)____________
   Cell (____)____________
   email ________________

   State Corporation Commission Name and ID Number (if applicable) ____________________

**<u>* If multiple contractors, each must be listed and each must sign the applicant signature page.</u>**

6. List the name, address and telephone number of the newspaper having general circulation in the area of the project. Failure to complete this question may delay local and State processing.

   Name and complete mailing address:
   Gloucester-Mathews Gazette-Journal
   P.O. Box 2060
   Gloucester, Va. 23061

   Telephone number
   (804) 693-3101

7. Give the following project location information:
   Street Address (911 address if available)________________________
   Lot/Block/Parcel# 27949, 12282
   Subdivision________________________
   City / County Gloucester ZIP Code____________
   Latitude and Longitude at Center Point of Project Site (Decimal Degrees):
   37.324574 / -76.436155 (Example: 36.41600/-76.30733)

   If the project is located in a rural area, please provide driving directions giving distances from the best and nearest visible landmarks or major intersections. *Note: if the project is in an undeveloped subdivision or property, clearly stake and identify property lines and location of the proposed project. A supplemental map showing how the property is to be subdivided should also be provided.*

   Head north on 17 into Gloucester County, turn right onto Rt. 614, continue on to School Hose Rd., turn right onto Captain Sinclair Recreational Area - West.

8. What are the *primary and secondary purposes of and the need for* the project? For example, the primary purpose <u>may</u> be "to protect property from erosion due to boat wakes" and the secondary purpose <u>may</u> be "to provide safer access to a pier."

   Primary purpose is to abate shore erosion and loss of the marsh from the eroding edge as well as to protect the small amount of wooded upland that the site has from erosion. The secondary purpose is to stabilize the shoreline for public access.

# Part 1 - General Information (continued)

9. Proposed use (check one):
   ___ Single user (private, non-commercial, residential)
   _X_ Multi-user (community, commercial, industrial, government)

10. Describe alternatives considered and the measures that will be taken to avoid and minimize impacts, to the maximum extent practicable, to wetlands, surface waters, submerged lands, and buffer areas associated with any disturbance (clearing, grading, excavating) during and after project construction. *Please be advised that unavoidable losses of tidal wetlands and/or aquatic resources may require compensatory mitigation.*

    Rock sills with sand and plants were considered for the western shoreline, but access and SAV impacts make them more difficult to construct. No grading will occur.

11. Is this application being submitted for after-the-fact authorization for work which has already begun or been completed? ___Yes _X_No. If yes, be sure to clearly depict the portions of the project which are already complete in the project drawings.

12. Approximate cost of the entire project (materials, labor, etc.): $ QuickReefs $650,000; Natrx $2.5 million
    Approximate cost of that portion of the project that is channelward of mean low water:
    $ 0

13. Completion date of the proposed work: Not known at this time - ______

14. Adjacent Property Owner Information: List the name and complete **mailing address**, including zip code, of each adjacent property owner to the project. (NOTE: If you own the adjacent lot, provide the requested information for the first adjacent parcel beyond your property line.) Failure to provide this information may result in a delay in the processing of your application by VMRC.

    Charles S. Jackson Trust
    P.O. Box 611
    White Marsh, VA 23183

    Sheppard Quality Homes
    2509 South Military Hwy, Suite A
    Chesapeake, VA 23320

# Part 2 - Signatures

**1. Applicants and property owners (if different from applicant).**
**NOTE: REQUIRED FOR ALL PROJECTS**

| |
|---|
| **<u>PRIVACY ACT STATEMENT</u>: The Department of the Army permit program is authorized by Section 10 of the Rivers and Harbors Act of 1899, Section 404 of the Clean Water Act, and Section 103 of the Marine Protection Research and Sanctuaries Act of 1972. These laws require that individuals obtain permits that authorize structures and work in or affecting navigable waters of the United States, the discharge of dredged or fill material into waters of the United States, and the transportation of dredged material for the purpose of dumping it into ocean waters prior to undertaking the activity. Information provided in the Joint Permit Application will be used in the permit review process and is a matter of public record once the application is filed. Disclosure of the requested information is voluntary, but it may not be possible to evaluate the permit application or to issue a permit if the information requested is not provided.** |
| **CERTIFICATION: I am hereby applying for all permits typically issued by the DEQ, VMRC, USACE, and/or Local Wetlands Boards for the activities I have described herein. I agree to allow the duly authorized representatives of any regulatory or advisory agency to enter upon the premises of the project site at reasonable times to inspect and photograph site conditions, both in reviewing a proposal to issue a permit and after permit issuance to determine compliance with the permit.**<br>**In addition, I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations.** |

______________________________ ______________________________
Applicant's Legal Name (printed/typed) (Use if more than one applicant)

______________________________ ______________________________
Applicant's Signature (Use if more than one applicant)

______________________________
Date

______________________________ ______________________________
Property Owner's Legal Name (printed/typed) (Use if more than one owner)
(If different from Applicant)

______________________________ ______________________________
Property Owner's Signature (Use if more than one owner)

______________________________
Date

# Part 2 – Signatures (continued)

***2. Applicants having agents (if applicable)***

**CERTIFICATION OF AUTHORIZATION**

I (we),____________________, hereby certify that I (we) have authorized ___________________________
(Applicant's legal name(s)) (Agent's name(s))
to act on my behalf and take all actions necessary to the processing, issuance and acceptance of this permit and any and all standard and special conditions attached.

We hereby certify that the information submitted in this application is true and accurate to the best of our knowledge.

____________________________________ ____________________________________
(Agent's Signature) (Use if more than one agent)

____________________________________
(Date)

____________________________________ ____________________________________
(Applicant's Signature) (Use if more than one applicant)

____________________________________
(Date)

***3. Applicant's having contractors (if applicable)***

**CONTRACTOR ACKNOWLEDGEMENT**

I (we), ______________________, have contracted_____________________________________________
(Applicant's legal name(s)) (Contractor's name(s))
to perform the work described in this Joint Permit Application, signed and dated________________________.

We will read and abide by all conditions set forth in all Federal, State and Local permits as required for this project. We understand that failure to follow the conditions of the permits may constitute a violation of applicable Federal, state and local statutes and that we will be liable for any civil and/or criminal penalties imposed by these statutes. In addition, we agree to make available a copy of any permit to any regulatory representative visiting the project to ensure permit compliance. If we fail to provide the applicable permit upon request, we understand that the representative will have the option of stopping our operation until it has been determined that we have a properly signed and executed permit and are in full compliance with all terms and conditions.

________________________________
Contractor's name or name of firm

____________________________________
Contractor's or firms address

________________________________ ____________________________________
Contractor's signature and title Contractor's License Number

________________________________ ____________________________________
Applicant's signature (use if more than one applicant)

________________________________
Date

# Part 2 – Signatures (continued)

## ADJACENT PROPERTY OWNER'S ACKNOWLEDGEMENT FORM

I (we), ______________________________________, own land next to (across the water
(Print adjacent/nearby property owner's name)

from/on the same cove as) the land of________________________________________.
(Print applicant's name(s))

I have reviewed the applicant's project drawings dated __________________________
(Date)

to be submitted for all necessary federal, state and local permits.

I HAVE NO COMMENT_______ ABOUT THE PROJECT.

I DO NOT OBJECT ______ TO THE PROJECT.

I OBJECT ______ TO THE PROJECT.

**The applicant has agreed to contact me for additional comments if the proposal changes prior to construction of the project.**

(Before signing this form be sure you have checked the appropriate option above).

______________________________________
Adjacent/nearby property owner's signature(s)

_____________________________________
Date

**Note: If you object to the proposal, the reason(s) you oppose the project must be submitted in writing to VMRC. An objection will not necessarily result in denial of the project; however, valid complaints will be given full consideration during the permit review process.**

# Part 2 – Signatures (continued)

## ADJACENT PROPERTY OWNER'S ACKNOWLEDGEMENT FORM

I (we), ______________________________________, own land next to (across the water
(Print adjacent/nearby property owner's name)

from/on the same cove as) the land of_________________________________________.
(Print applicant's name(s))

I have reviewed the applicant's project drawings dated ___________________________
(Date)

to be submitted for all necessary federal, state and local permits.

I HAVE NO COMMENT_______ ABOUT THE PROJECT.

I DO NOT OBJECT ______ TO THE PROJECT.

I OBJECT ______ TO THE PROJECT.

**The applicant has agreed to contact me for additional comments if the proposal changes prior to construction of the project.**

(Before signing this form, be sure you have checked the appropriate option above).

______________________________________
Adjacent/nearby property owner's signature(s)

_____________________________________
Date

**Note: If you object to the proposal, the reason(s) you oppose the project must be submitted in writing to VMRC. An objection will not necessarily result in denial of the project; however, valid complaints will be given full consideration during the permit review process.**

# Part 3 – Appendices (continued)

**Appendix B: Projects for Shoreline Stabilization** in tidal wetlands, tidal waters and dunes/beaches including riprap revetments and associated backfill, marsh toe stabilization, bulkheads and associated backfill, breakwaters, beach nourishment, groins, jetties, and living shoreline projects. Answer all questions that apply. Please provide any reports provided from the Shoreline Erosion Advisory Service or VIMS**.**

**NOTE:** It is the policy of the Commonwealth that living shorelines are the preferred alternative for stabilizing tidal shorelines (Va. Code § 28.2-104.1). **Information on non-structural, vegetative alternatives (i.e., Living Shoreline) for shoreline stabilization is available at http://ccrm.vims.edu/coastal_zone/living_shorelines/index.html.**

1. Describe each **revetment, bulkhead, marsh toe, breakwater, groin, jetty, other structure, or living shoreline project** separately in the space below. Include the overall length in linear feet, the amount of impacts in acres, and volume of associated backfill below mean high water and/or ordinary high water in cubic yards, as applicable:

   Two types of units will be installed along the property. QuickReef sills with sand and marsh plantings and Natrx exoform modules. The QuickReef sills are 5 ft wide and consist of 40 in x 12 in concrete slabs that are stacked at an angle and provide substrate for an intertidal oyster reef sill. Fifteen reefs will be placed on coir mat just landward of MLW along the shoreline in 80-90 ft sections (total 1,290 linear ft) with 15-20 ft gaps except where noted on the plan for public access. A thin layer of sand (750 cy), about 1 ft deep, will be placed landward of the sill to existing vegetation/shoreline scarp/MHW and planted with Spartina alterniflora. No grading will occur. Concrete reef material and sand will impact about 0.6 acres of non-vegetated wetlands of which 0.5 acres will be planted with marsh vegetation.

   Natrx modules will be placed at MLW adjacent to the eroding marsh scarp along the southern and eastern shorelines to create substrate for intertidal oyster reefs. These 34 inch square modules will be 3D printed with holes to allow more area for oyster settlement. There will be 15 segments placed in 100 ft sections with 20 ft gaps along the southern points, 21 segments of 80 ft long units with 35 ft gaps along the lower fetch areas, and along the lowest energy area on Whittaker Creek, 13 segments of smaller Natrx units or oyster bags will be 50 ft long with 30 ft gaps (total impact 3,830 linear ft, 0.2 acres of non-vegetated wetlands). All materials for both projects will be brought in by barge.

2. What is the maximum encroachment channelward of mean high water? 25______feet.
   Channelward of mean low water? 0______feet.
   Channelward of the back edge of the dune or beach?_____feet.

3. Please calculate the square footage of encroachment over:
   - Vegetated wetlands 0_________square feet
   - Non-vegetated wetlands 36,550______square feet
   - Subaqueous bottom 0_________square feet
   - Dune and/or beach 0_________square feet

4. For bulkheads, is any part of the project maintenance or replacement of a previously authorized, currently serviceable, existing structure? ____ Yes____ No.

   If yes, will the construction of the new bulkhead be no further than two (2) feet channelward of the existing bulkhead? _____Yes ____No.

   If no, please provide an explanation for the purpose and need for the additional encroachment.

# Part 3 – Appendices (continued)

5. Describe the type of construction and **all** materials to be used, including source of backfill material, if applicable (e.g., vinyl sheet-pile bulkhead, timber stringers and butt piles, 100% sand backfill from upland source; broken concrete core material with Class II quarry stone armor over filter cloth).
   **NOTE**: **Drawings must include construction details, including dimensions, design and all materials, including fittings if used**.

   Construction materials used will be concrete QuickReef units, concrete Natrx exoform modules, oyster bags, coir mat, sand fill from upland source.

6. If using stone, broken concrete, etc. for your structure(s), what is the average weight of the:
   Core (inner layer) material__________ pounds per stone Class size ________
   Armor (outer layer) material __________ pounds per stone Class size ________

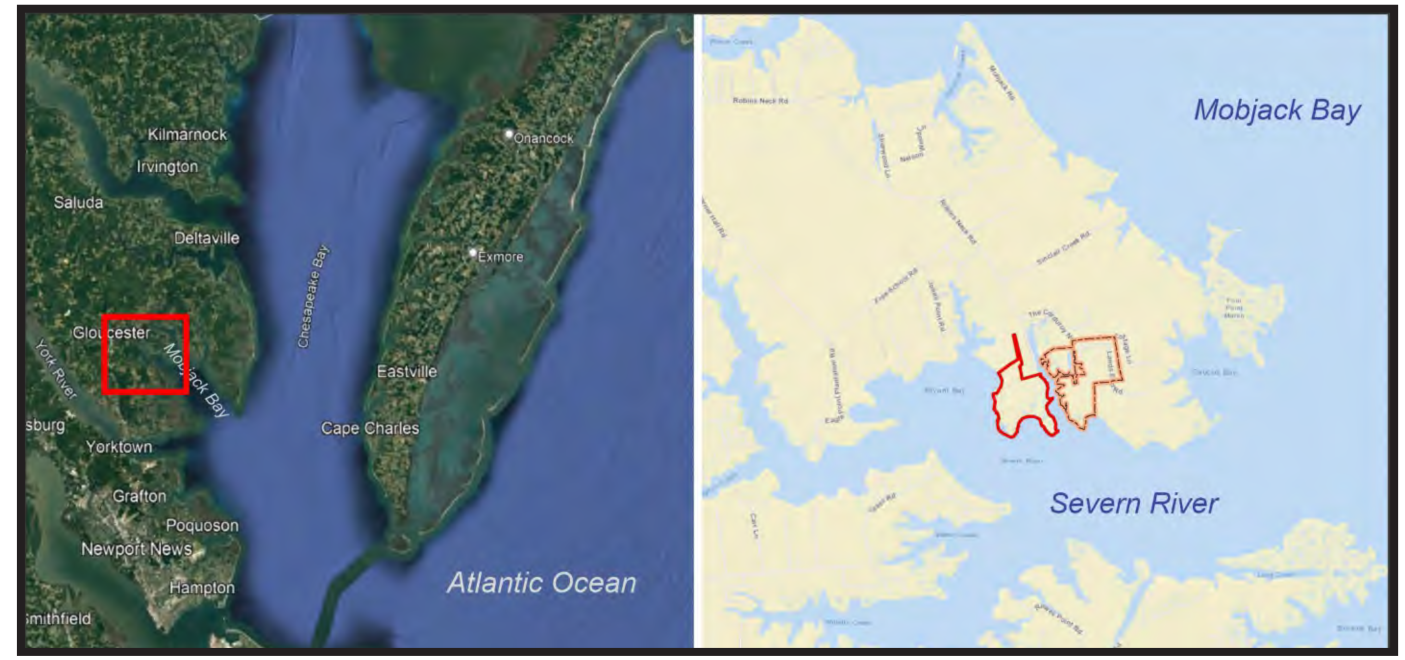
7. For **beach nourishment**, including that associated with breakwaters, groins or other structures, provide the following:

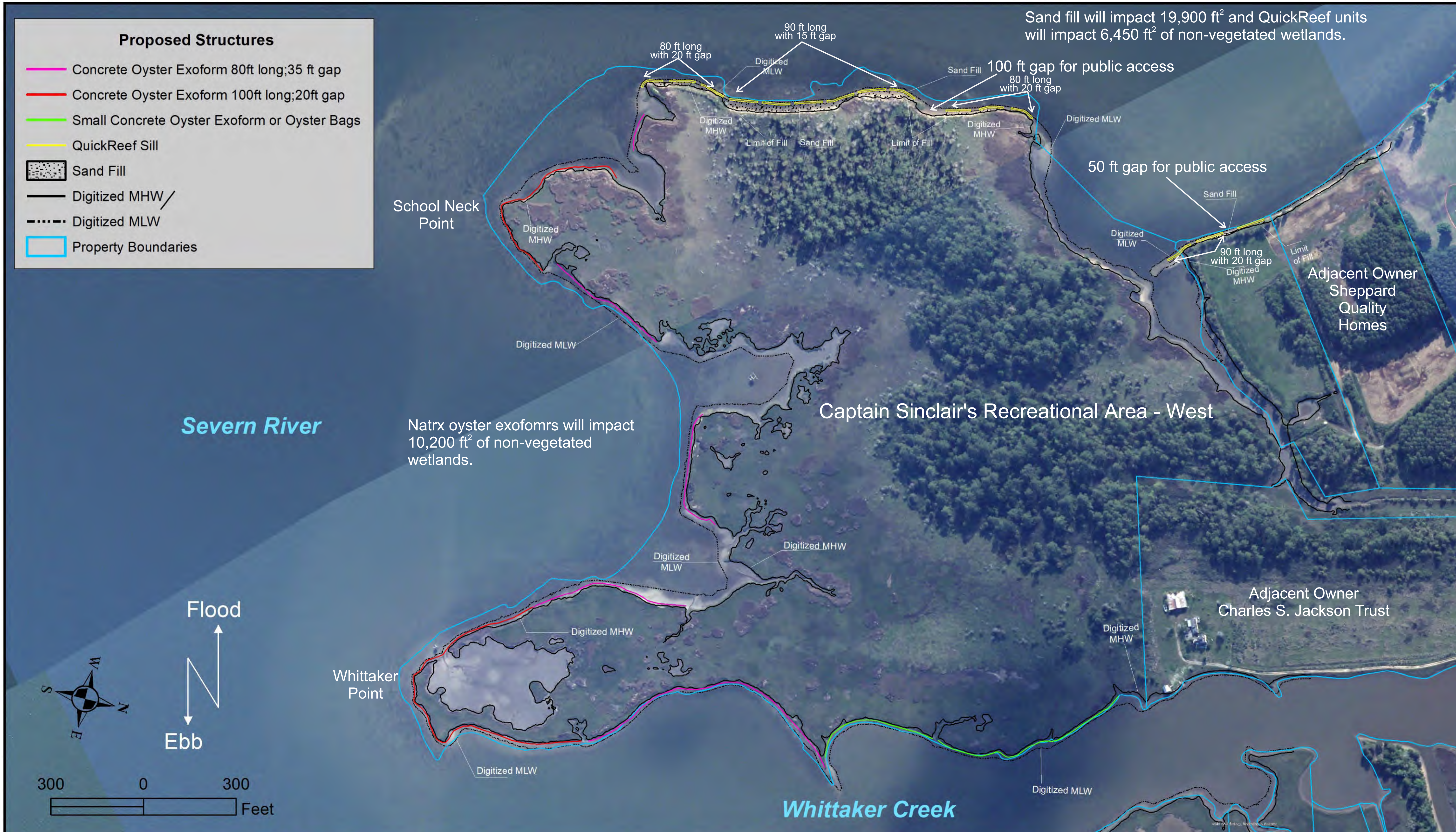
   - Volume of material
     0 cubic yards channelward of mean low water
     750 cubic yards landward of mean low water
     750 cubic yards channelward of mean high water
     0 cubic yards landward of mean high water
   - Area to be covered
     0 square feet channelward of mean low water
     19,900 square feet landward of mean low water
     19,900 square feet channelward of mean high water
     0 square feet landward of mean high water
   - Source of material, composition (e.g. 90% sand, 10% clay): local borrow pit
   - Method of transportation and placement:

     Sand will be brought in by barge.
   - Describe any proposed vegetative stabilization measures to be used, including planting schedule, spacing, monitoring, etc. Additional guidance is available at http://www.vims.edu/about/search/index.php?q=planting+guidelines:

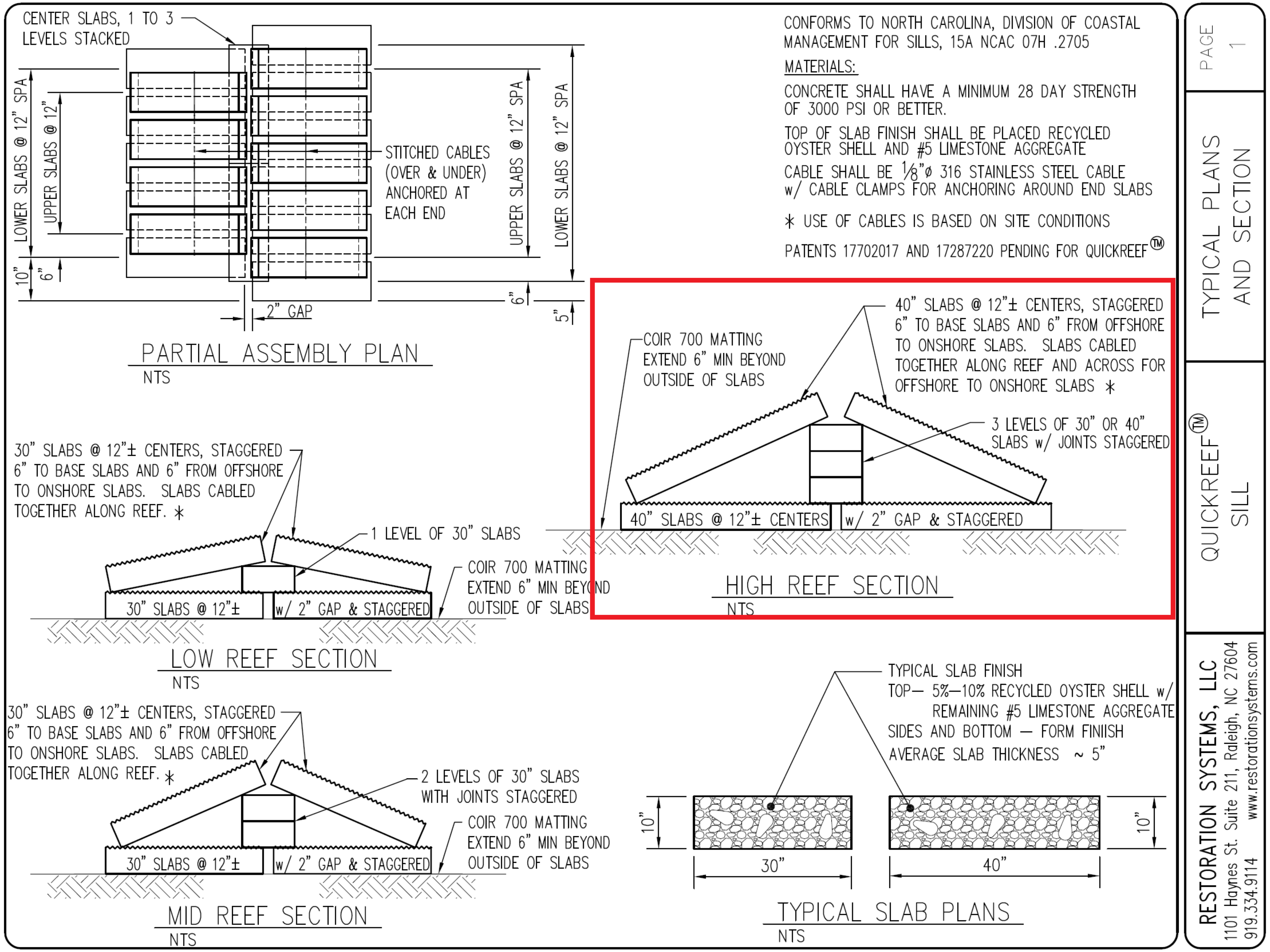
     Vegetative stabilization of the sand substrate will be with Spartina alterniflora. It will be planted on a 1.5' x 1.5' grid spacing with 0.5 oz of slow release fertilizer per plant. Survival of 80% of the planting is required for one year.

# Captain Sinclair's Recreational Area - West Living Shoreline and Oyster Restoration Project


| Adjacent Propert Owner: | **Captain Sinclair**<br>**Living Shoreline Project** | | Application By: |
|---|---|---|---|
| | | | Date: |
| Datum: | At:<br>In: | Purpose: | Sheet No.: |



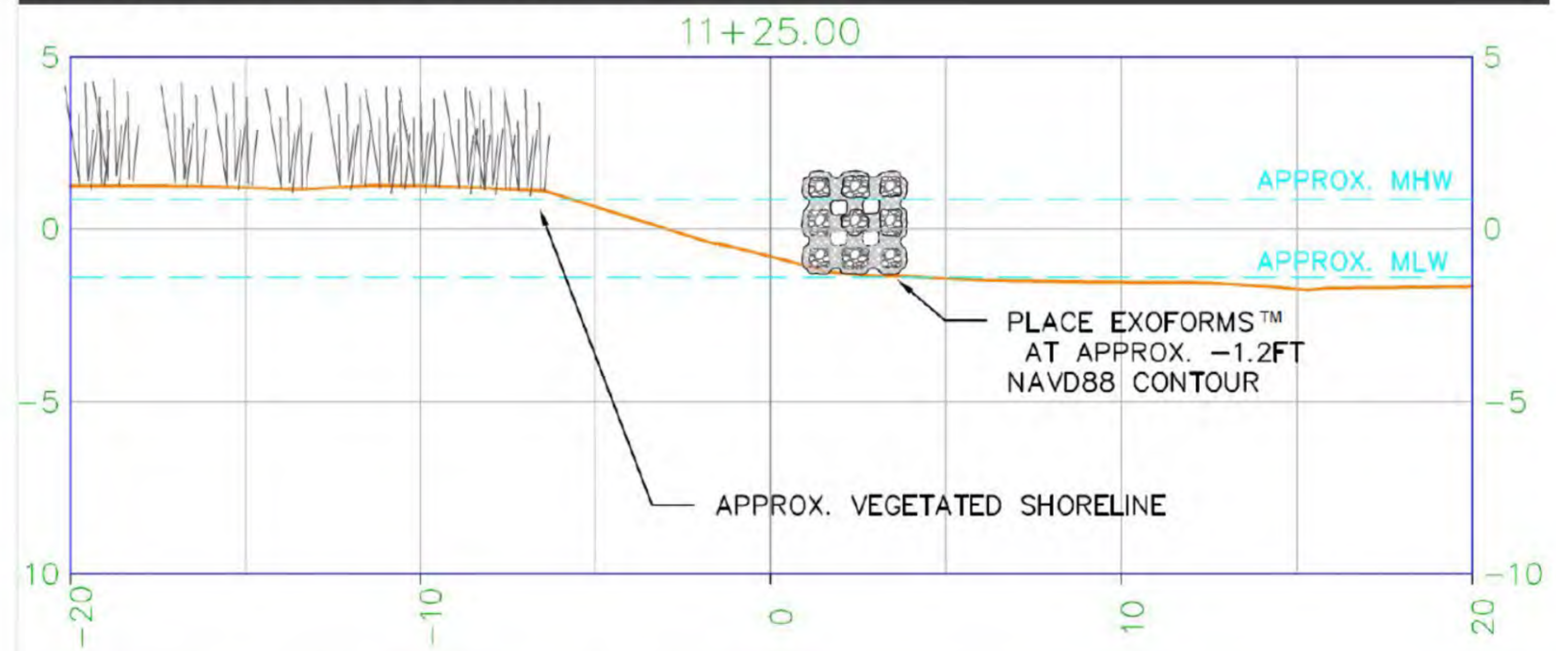

The high reef section will be used in 100 ft sections with 5 ft gaps. except where noted on the plan for public access.

The reefs will be placed at MLW to avoid impacting SAV.

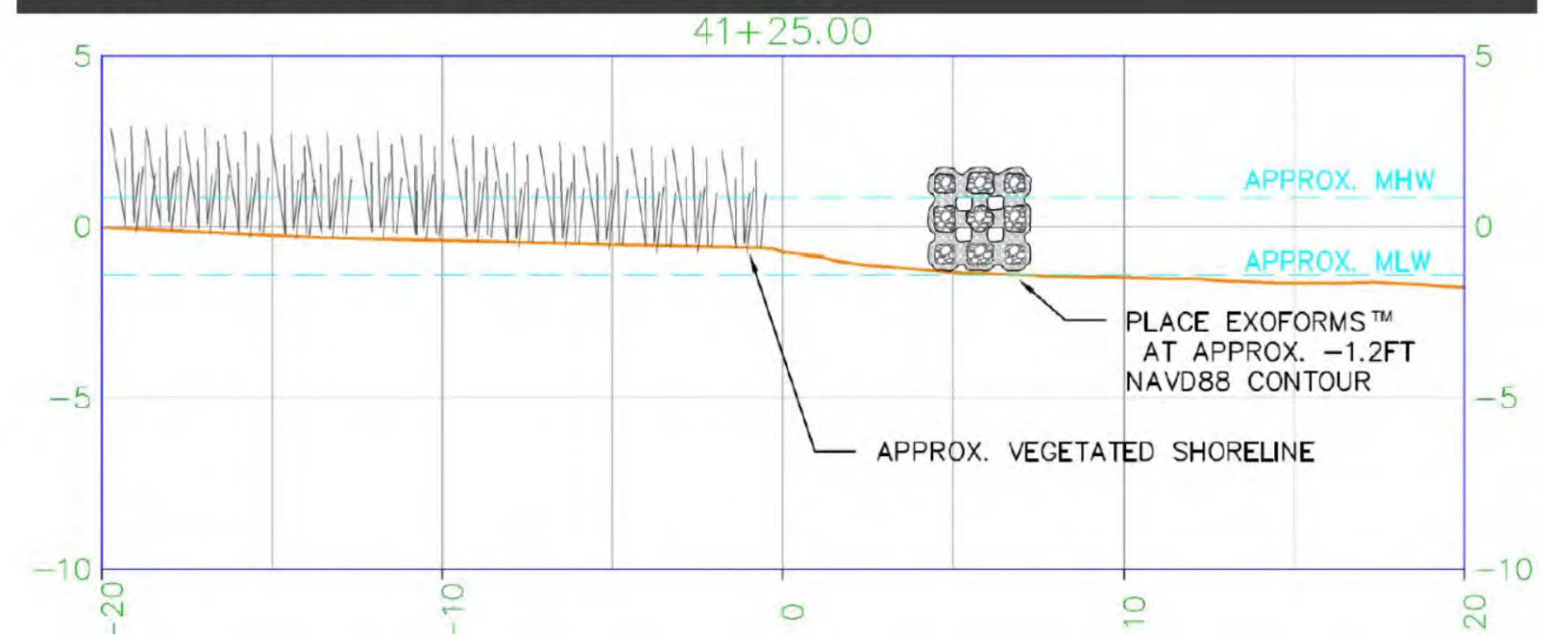
https://nativeshorelines.com/quickreef-living-shorelines/

QuickReef Sill

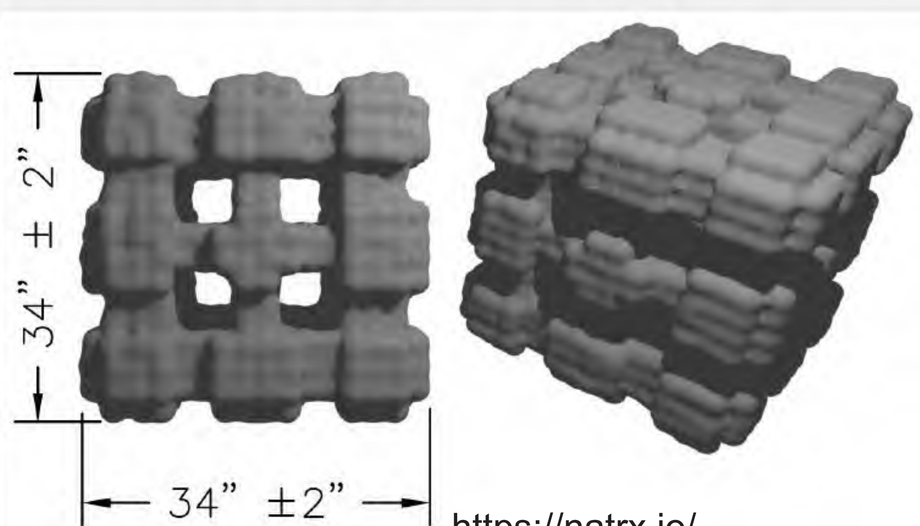

## High Marsh Section - A




## Low Marsh Section - B




## Proposed ExoForm




https://natrx.io/

Oyster modules will be placed at MLW to avoid impacting SAV along the southern points and Whittaker Creek.

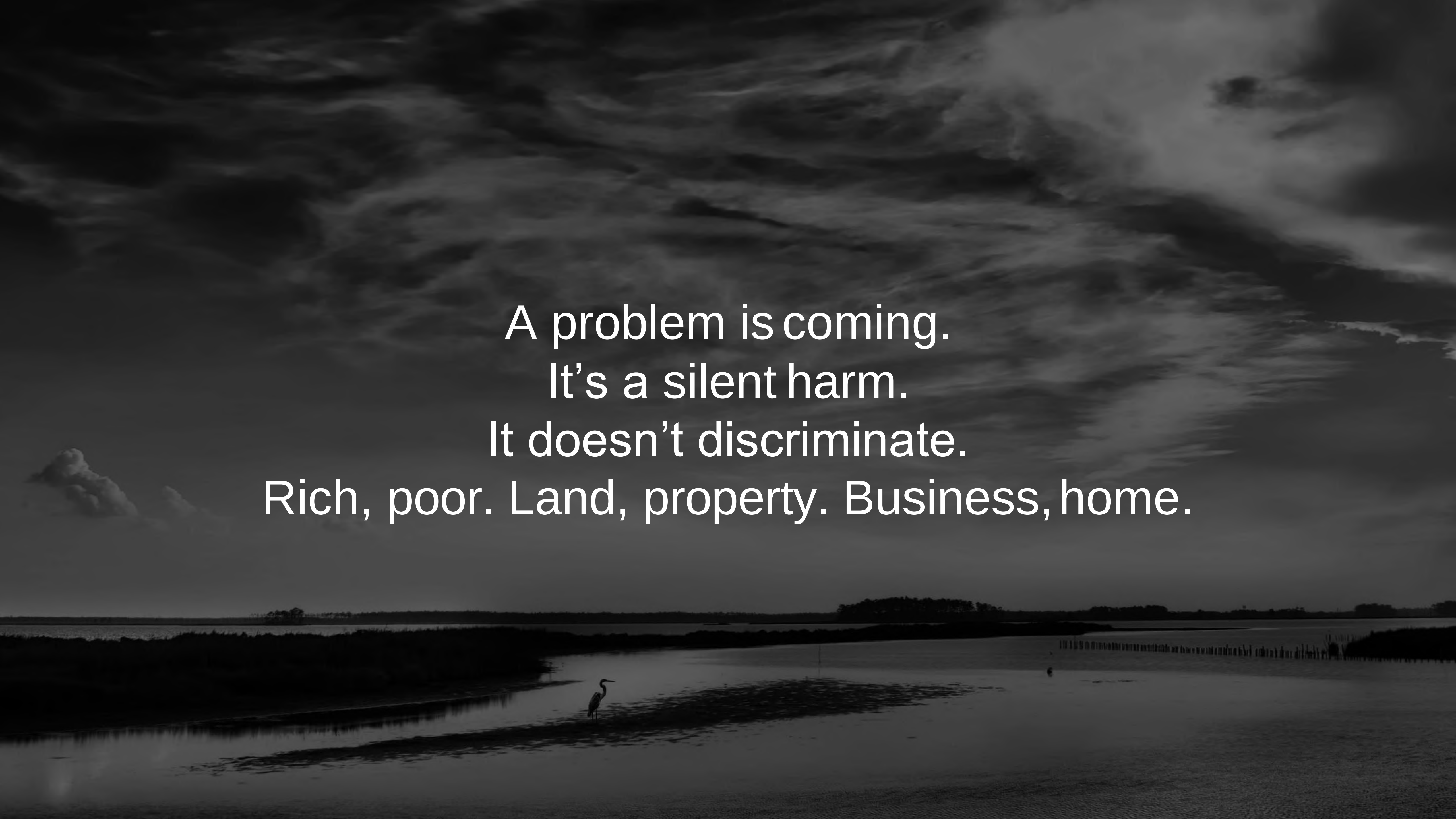
Natrx Concrete Oyster Exoform

# Appendix C: Next Generation Shoreline Management Planning Summary Presentation

# can·cer

/ˈkansər/

a practice or phenomenon perceived to be evil or destructive and hard to contain or eradicate.


A problem is coming.
It’s a silent harm.
It doesn’t discriminate.
Rich, poor. Land, property. Business, home.


COASTAL CANCER

To best understand where we are


you must understand where we were.

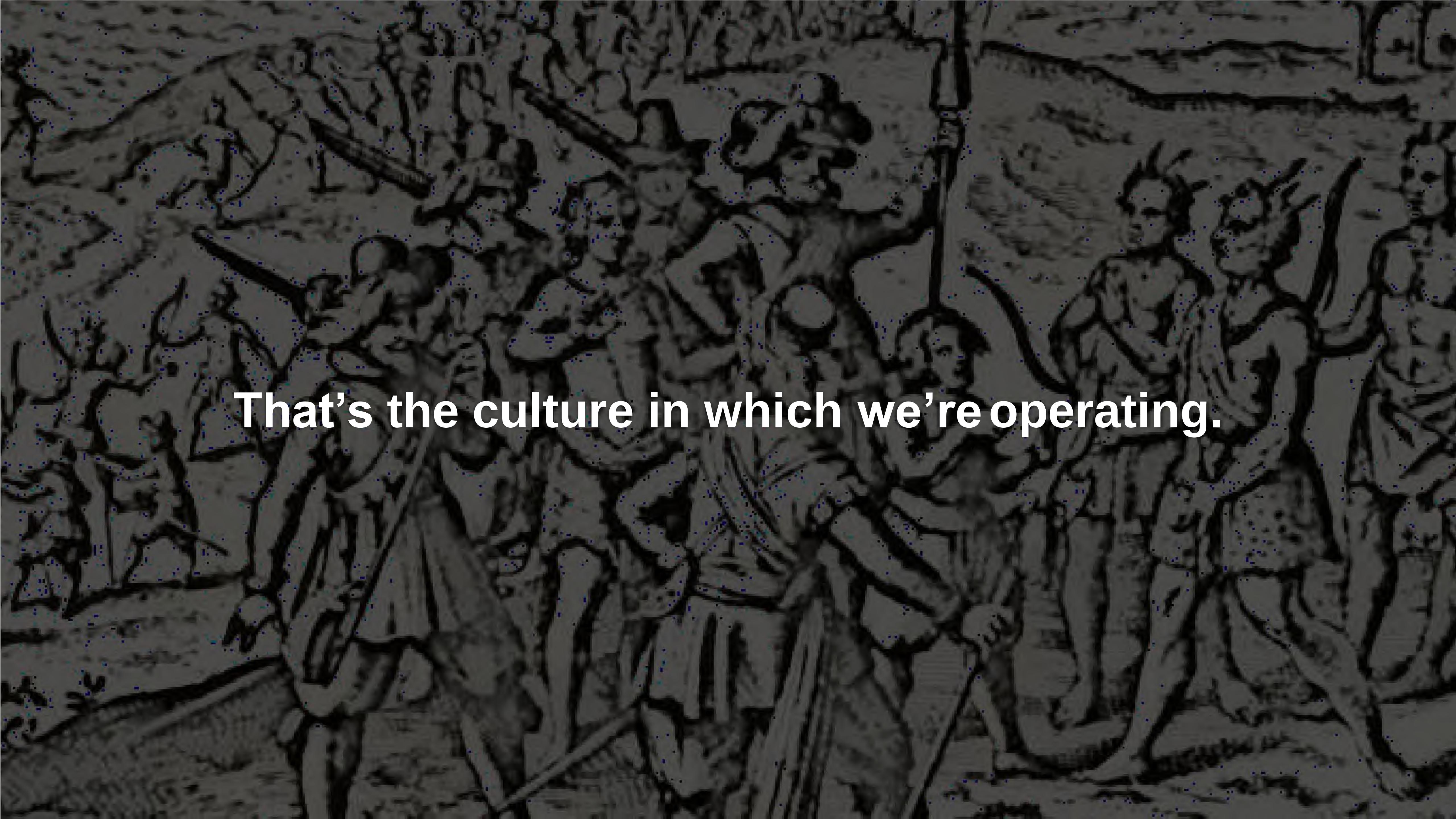
Before the colonization of the Americas, when the population was Native American residents, people lived and moved with nature.

When the water came, they moved.

**But then colonists came and English property law came into being. Humans put stakes in the ground for property rights and ownership.**

**If the water came, it didn't matter. They weren't leaving because they owned the land.**

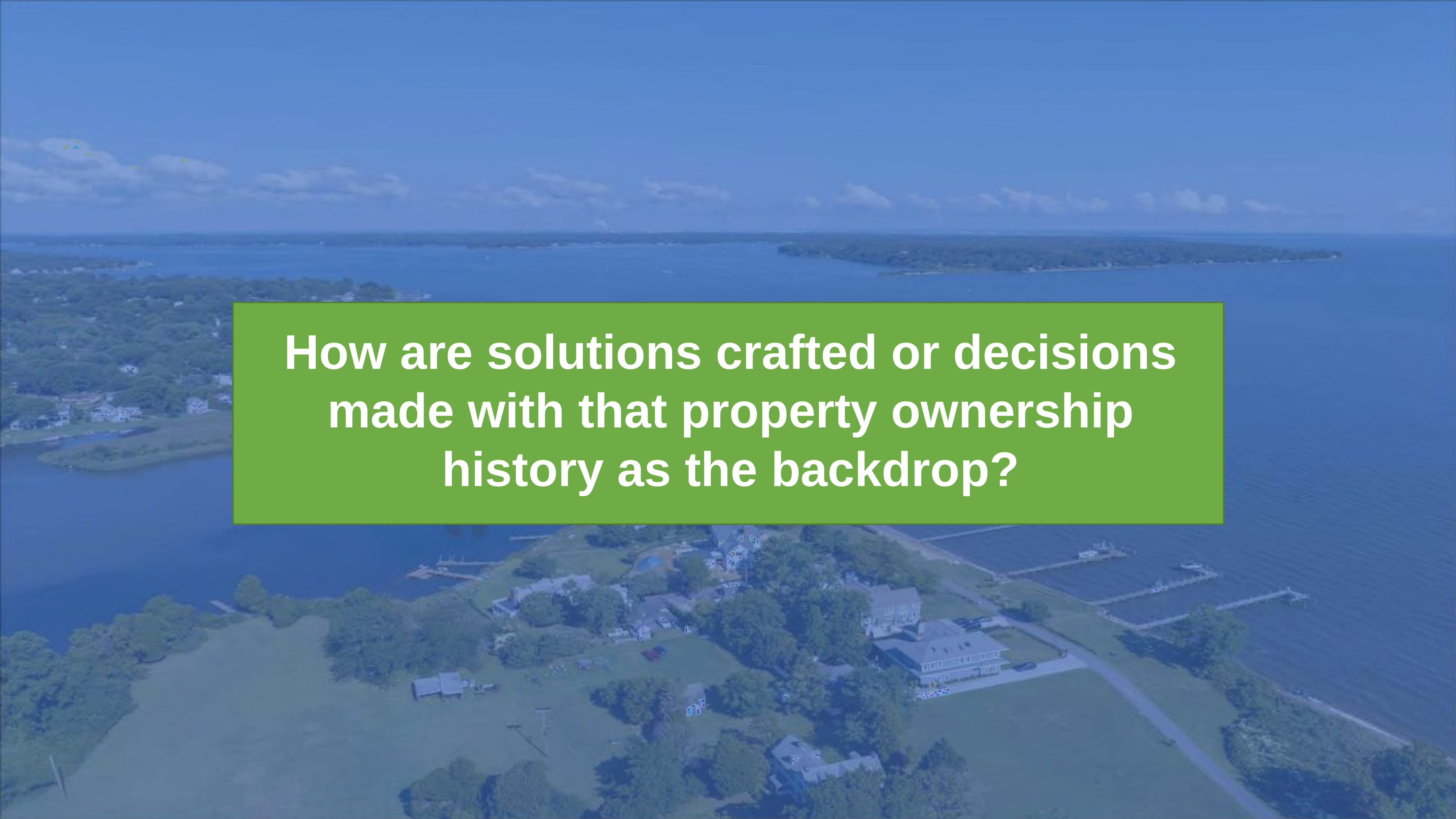
**But then colonists came and English**



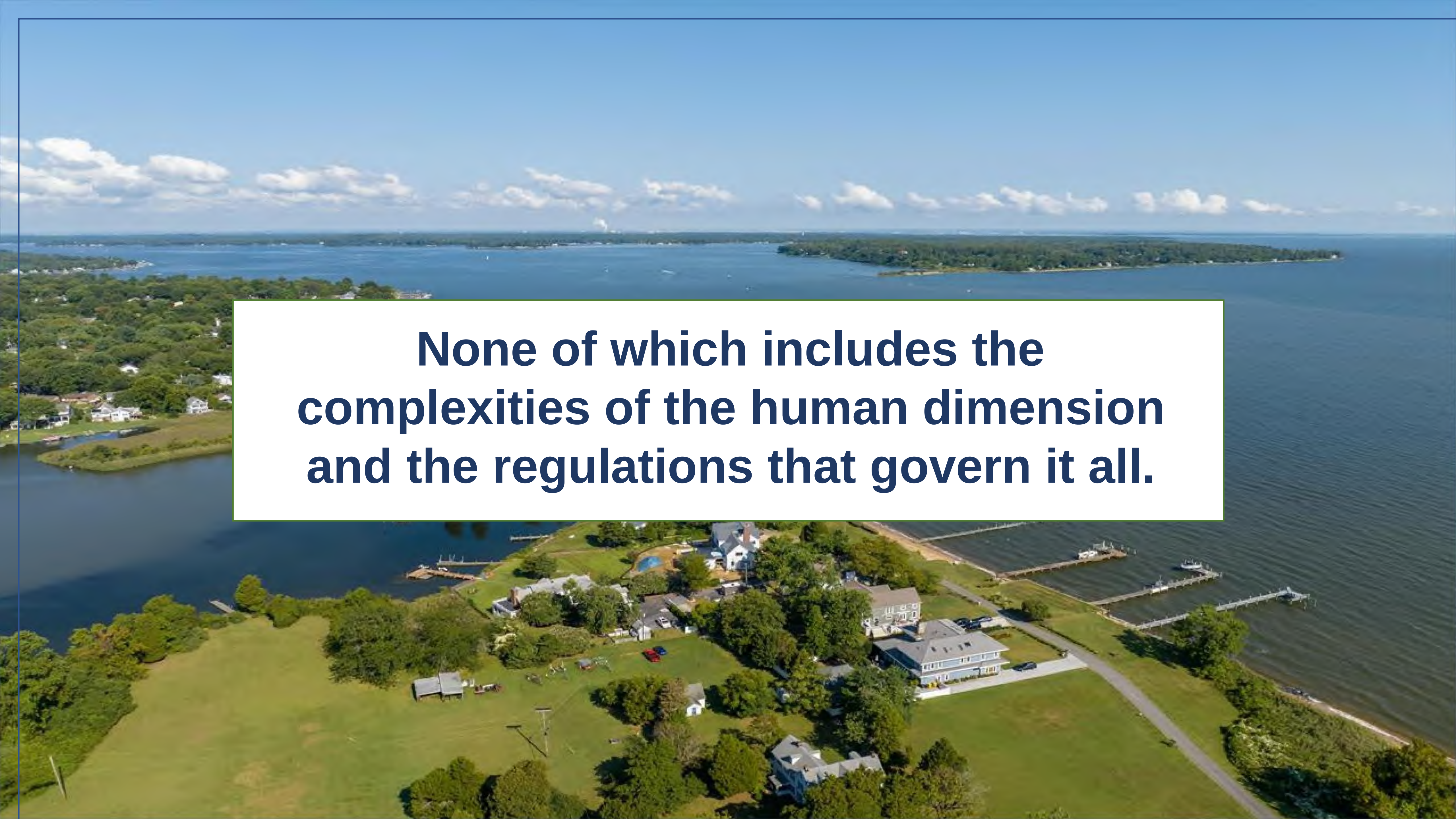
**That’s the culture in which we’re operating.**


Landowners want to hold in place
what Mother Nature wants to move.
PIER CLOSED
Temporarily
No Trespassing

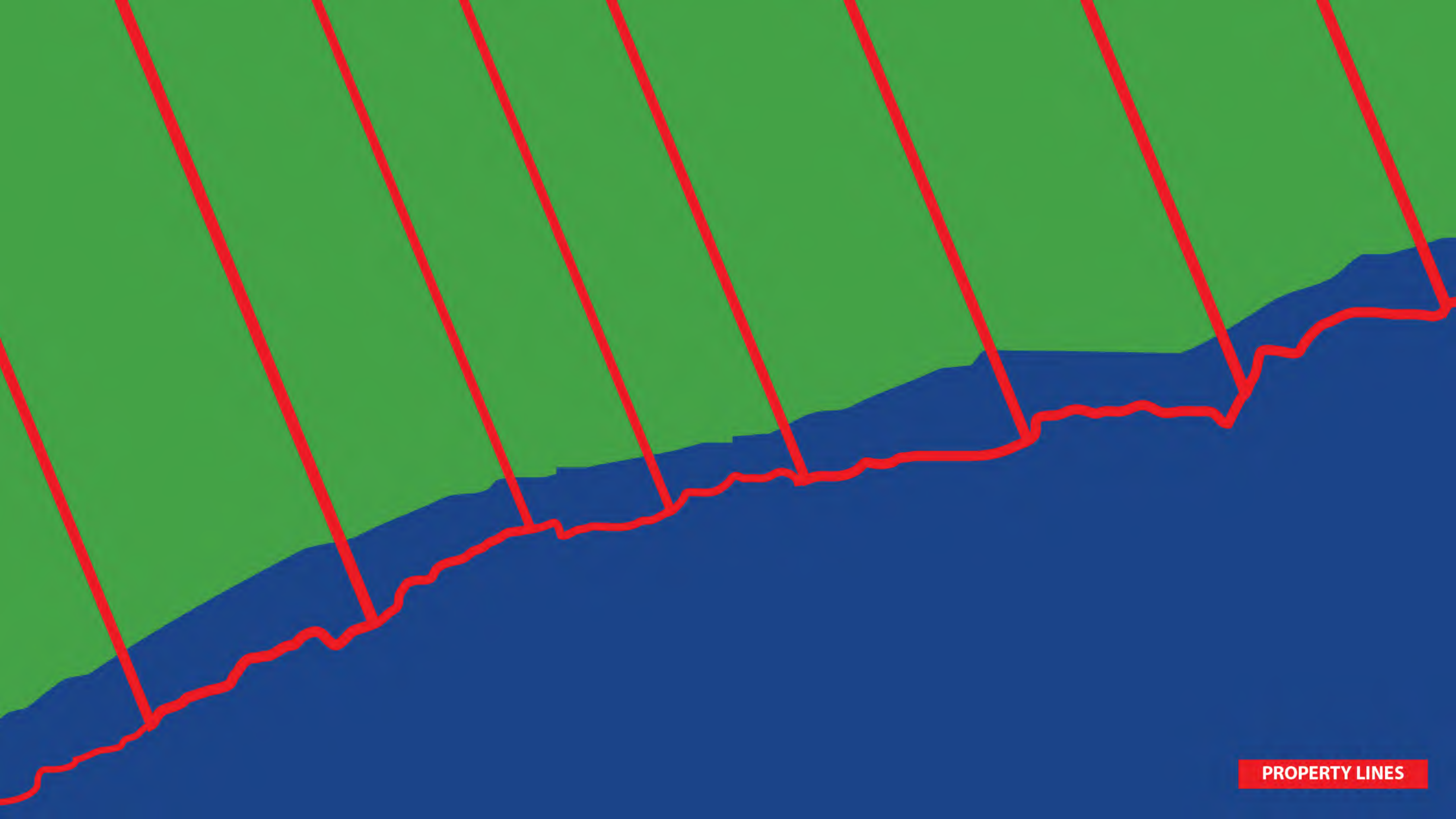

their land.



**How are solutions crafted or decisions made with that property ownership history as the backdrop?**



**None of which includes the complexities of the human dimension and the regulations that govern it all.**


PROPERTY LINES


PEOPLE
PROPERTY LINES


POLITICS
PEOPLE
PROPERTY LINES


FINANCIAL MEANS
POLITICS
PEOPLE
PROPERTY LINES


FINANCIAL MEANS
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PEOPLE
RPA BUFFER
PROPERTY LINES


FINANCIAL MEANS
POLITICS
VMRC
PEOPLE
RPA BUFFER
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FINANCIAL MEANS
ARMY CORPS
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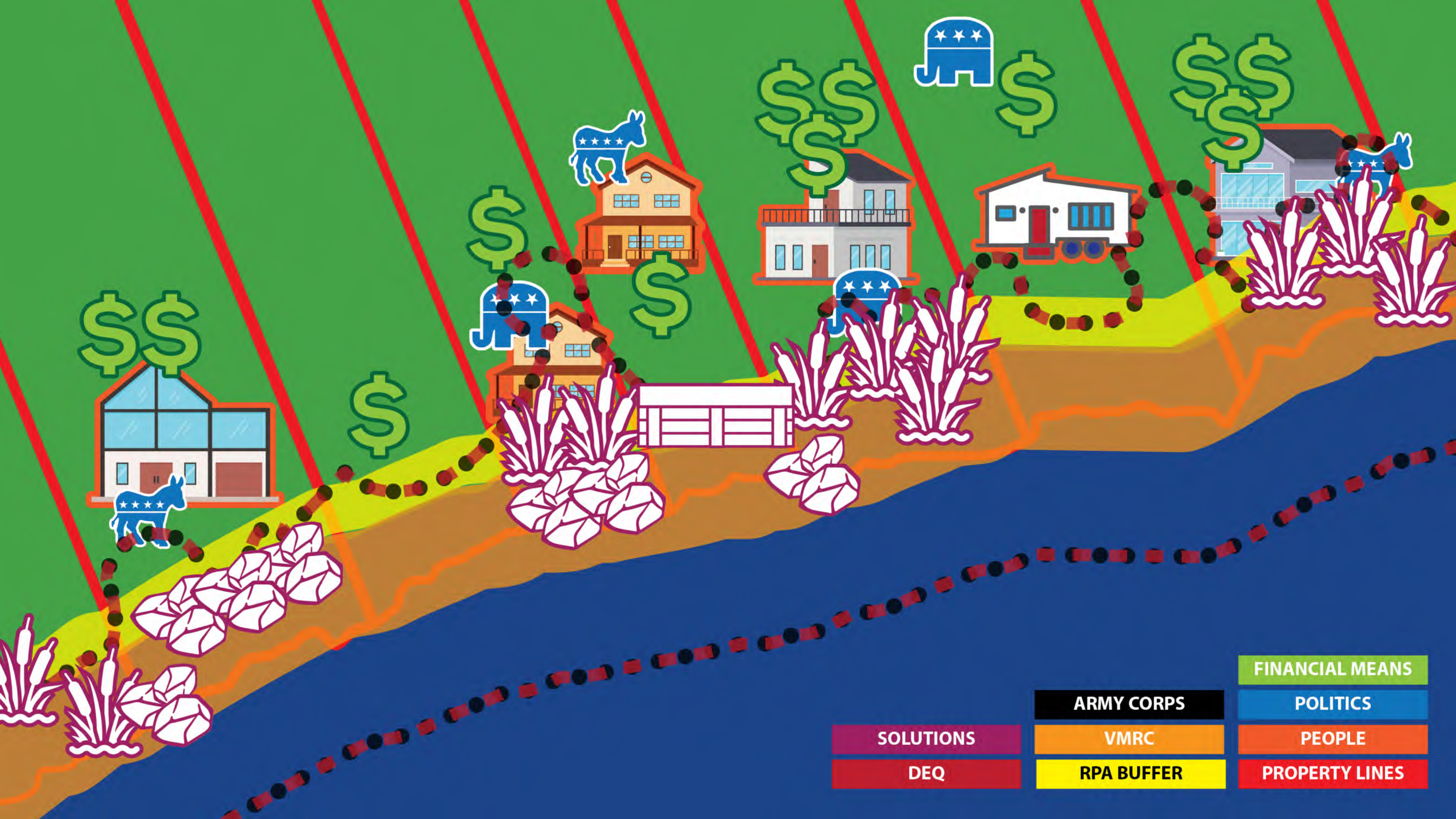

FINANCIAL MEANS
ARMY CORPS
POLITICS
SOLUTIONS
VMRC
PEOPLE
DEQ
RPA BUFFER
PROPERTY LINES

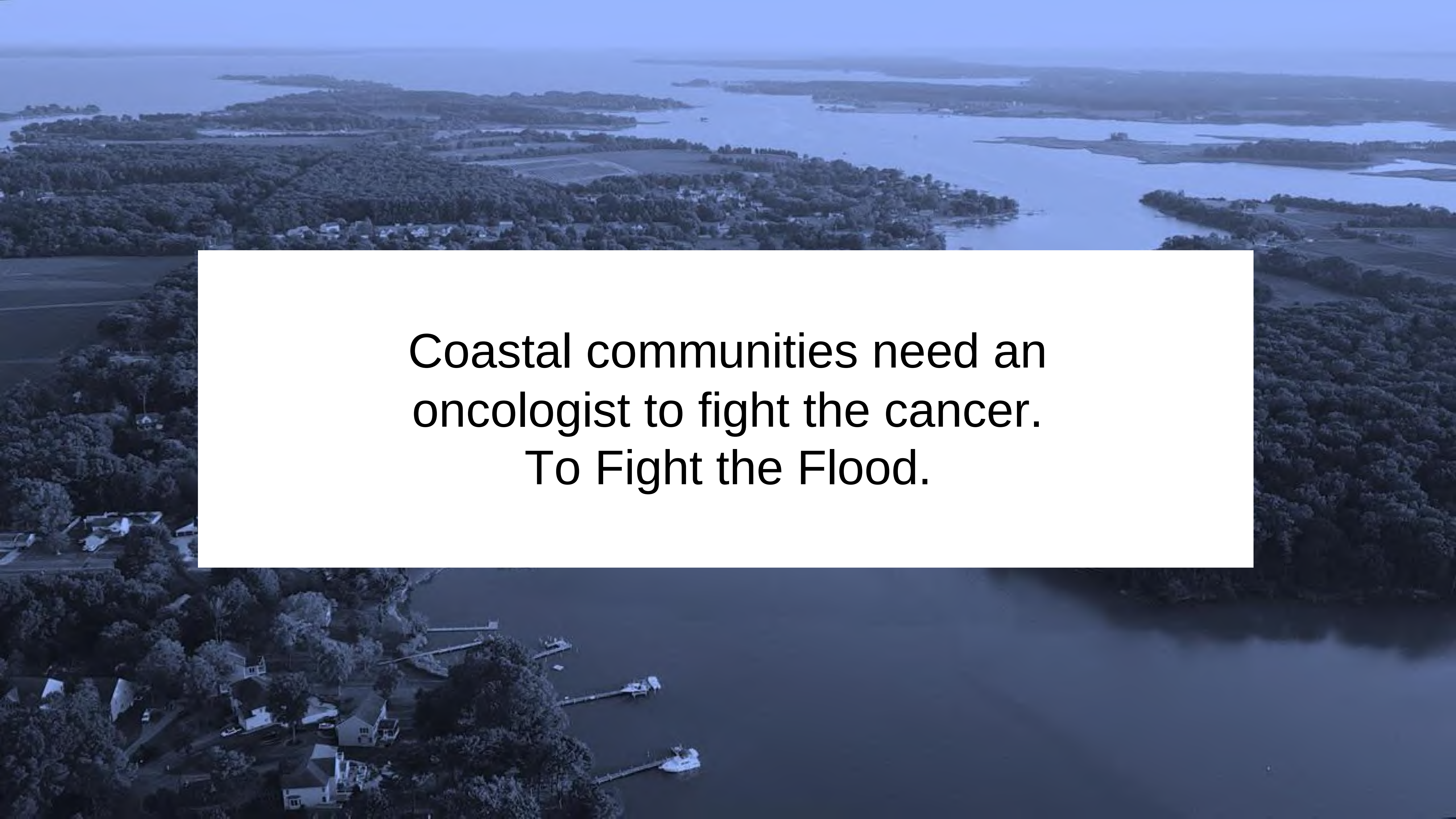

Expansion of the Groundwater Management Area
Modification to the Virginia Floodplain Ordinances
Homeowners Flood Insurance Affordability Act
Integration Bill – integrating elements of the Erosion & Sediment Control Law, Stormwater Management Act & Ches. Bay Preservation Act
Biggert-Waters Flood Insurance Reform Act
Regulations for Alternative Onsite Sewage Systems
Chesapeake Bay TMDL issued
Regulations Governing Application fees for Construction permits for Onsite Sewage Disposal Systems and Private Wells
Virginia Watershed Implementation Plan
Sewage Handling and Disposal Regulations amended
Chesapeake 2000 Agreement
Alternative Discharging Sewage Treatment Regulations for individual Single Family Dwellings
Federal Non-Tidal Wetlands Regulations
Private Well Regulations
Sanitary Regulations for Marinas and Boat Moorings
Virginia Stormwater Management Act
Chesapeake Bay Preservation Area Designation and Management Regulations
Chesapeake Bay Preservation Act
Sewage Handling and Disposal Regulations
Virginia Waste Management Act
Flood Disaster Protection Act
Virginia Erosion and Sediment Control Law
Tidal Wetlands Act
Clean Water Act
FINANCIAL MEANS
REGULATIONS
ARMY CORPS
POLITICS
SOLUTIONS
VMRC
PEOPLE
DEQ
RPA BUFFER
PROPERTY LINES

**Up until now, coastal managers have planned and attempted to implement solutions without taking into consideration the realities of property ownership and the human dimension.**

What makes the Next Generation Shoreline management process innovative isn't some new engineering solution.

It's the mindset shift.

It's the understanding of this complex environment.



Coastal communities need an oncologist to fight the cancer.
To Fight the Flood.

The Middle Peninsula, a rural coastal Virginia community, has started that fight by taking a nod from how physicians fight cancer.

One property at a time with a custom solution that fits the needs of each owner.

This is how we cure the cancer. This is how we use the innovative solutions available to make our shorelines more resilient.

Because no one size fits all.

**This project was funded by the Virginia Coastal Zone Management Program at the Department of Environmental Quality through Grant #NA21NOS4190152 and #NA22NOS4190187, Task 73 of the U.S. Department of Commerce, National Oceanic and Atmospheric Administration, under the Coastal Zone Management Act of 1972, as amended. The views expressed herein are those of the authors and do not necessarily reflect the views of the U.S. Department of Commerce, NOAA, or any of its subagencies.**

# Appendix D: VIMS Shoreline Studies Program Shoreline Management Plan Summary Presentation

# Determining Elements of a Next Iteration Shoreline Management Plan in the Commonwealth of Virginia

Shoreline Studies Program
Virginia Institute of Marine Science

This project was funded by the Virginia Coastal Zone Management Program at the Department of Environmental Quality through Grant # NA22NOS4190187 Task 73 of the U.S. Department of Commerce, National Oceanic and Atmospheric Administration, under the Coastal Zone Management Act of 1972, as amended. The views expressed herein are those of the authors and do not necessarily reflect the views of the U.S. Department of Commerce, NOAA, or any of its subagencies.

# Shoreline Management Plans

Factors that should be accounted for when developing a shoreline management plan (SMP)

- Federal, state, and local government policies and priorities
- Socio-economic needs
- Environmental factors and protection
- Resiliency in the face of storm surge and sea level rise


NOAA shoreline graphic

# What is a Living Shoreline?

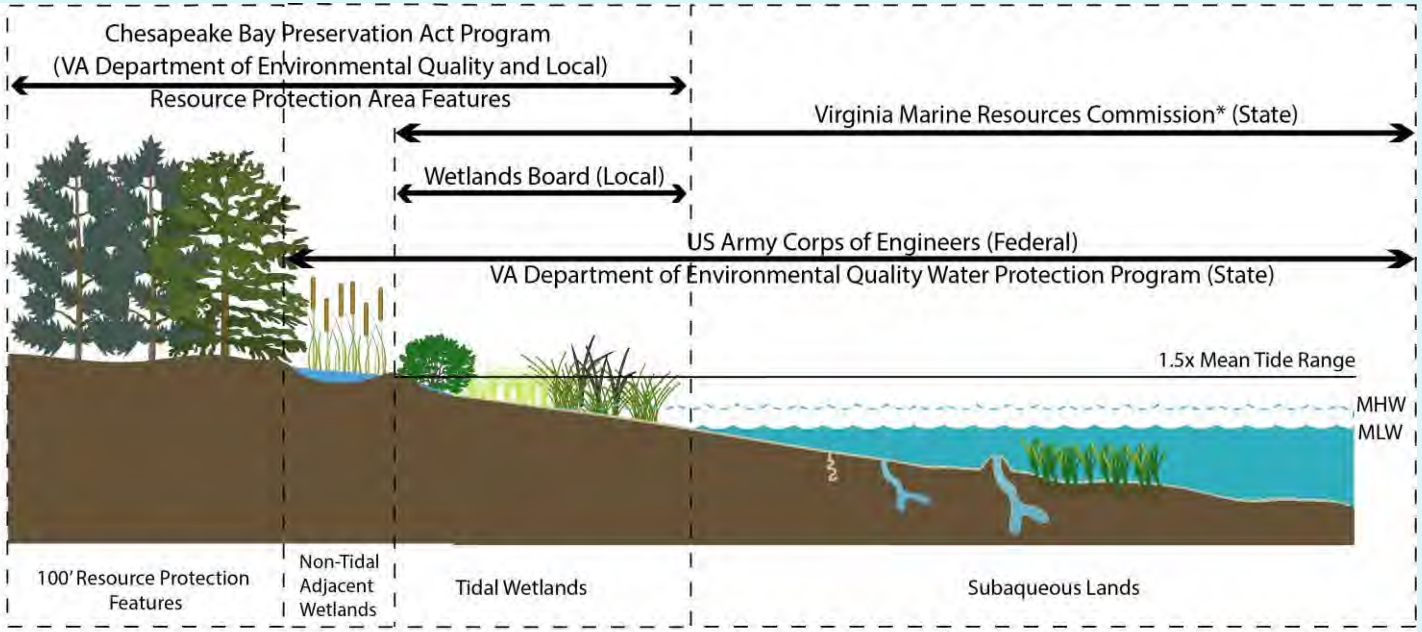
- A living shoreline is a protected, stabilized coastal edge made of natural materials such as plants, sand, rock or other natural material. Natural infrastructure solutions like living shorelines provide wildlife habitat, as well as natural resilience to communities near the waterfront.
- Living shorelines are sometimes referred to as nature-based, green, or soft shorelines. They are an innovative and cost-effective technique for coastal management.
  - Hybrid: planted marsh and fill is fronted by some type of structure (i.e. sills or breakwaters) that protects the shoreline from wave action while enhancing the marsh/beach habitat. Intertidal oyster reef structures are typically placed at about mean low water to allow oysters to settle over time creating an intertidal reef.
  - Soft: sediment and vegetation only.

# Living Shorelines in Virginia

- Under the Code of Virginia, a living shoreline is defined as a shoreline management practice that provides erosion control and water quality benefits; protects, restores, or enhances natural shoreline habitat; and maintains coastal processes through the strategic placement of plants, stone, sand fill, and other structural and organic materials. When practicable, a living shoreline may enhance coastal resilience and attenuation of wave energy and storm surge.
- In Virginia, living shorelines are the required shoreline management strategy for all new shoreline protection construction whenever the best available science determines they are suitable.

# Living Shorelines in Virginia

- Unlike some coastal states, Virginia allows for shoreline structures to be placed on state bottom below mean low water (MLW).
- The area between MLW and 1.5x the mean tide range is in the jurisdiction of the local wetlands board or, in absence of one, the Virginia Marine Resources Commission (VMRC).
- This has led to conflict between permitting authorities, scientific and environmental groups, and property owners.




* VMRC has oversight authority for the Tidal Wetlands Act and administers the Act in localities without a wetlands zoning ordinance and local wetlands board.

Virginia Shorezone Jurisdictions: legally defined shoreline resources and the relevant local, state and federal authorities. Note that some authorities cross resource boundaries and most resources have at least two responsible regulatory authorities. Symbols courtesy of the Integration and Application Network (ian.umces.edu/symbols/), University of Maryland Center for Environmental Science.

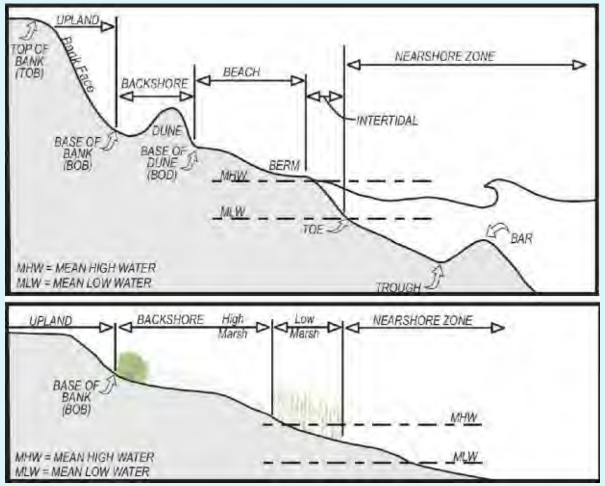
# What Does “Next Iteration” Mean?

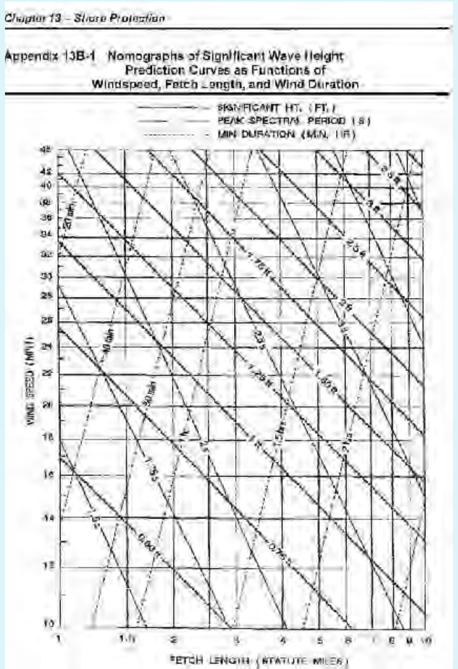
- Shoreline management in the past has been focused on property-by-property designs.
- This leads to ineffective management strategies and clashes with neighboring property owners, as only a small portion of the shoreline is protected, and adjacent areas can be negatively impacted.
- Next iteration shoreline management refers to the idea that SMP designs should shift focus to community and reach-based designs to create a holistic approach.
- This approach creates more effective SMPs that protect larger areas of shorelines and facilitates cooperation between property owners rather than conflict.

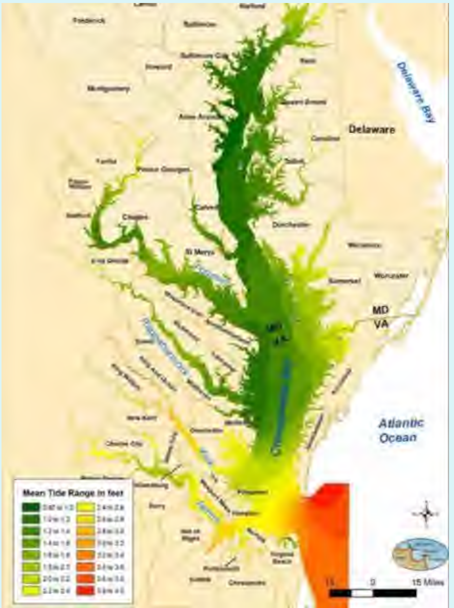

# Assessing the Problem

To create an effective SMP for an area, all of the following factors should be considered

- Physical Characteristics
  - Coastal geomorphology
  - Nearshore bathymetry
  - Shore zone habitats
  - Bank/dune size
  - Bank composition
  - Land use
  - Archaeology
  - Existing structures on property and adjacent
- Energy Environment
  - Shore change rates
  - Fetch
  - Design wave energy
  - Bank/dune condition
  - Critical areas
- Hydrodynamic Setting
  - Tide range
  - Storm surge
  - Sea level rise
  - Direction of face
  - Direction of storm impact
- Marine Resources
  - Submerged aquatic vegetation (SAV)
  - Vegetated and non-vegetated wetlands
  - Private and public shellfish harvesting grounds
  - Presence of oysters and other bivalves along the shoreline
  - VDH health advisories
  - Salinity
  - Endangered species

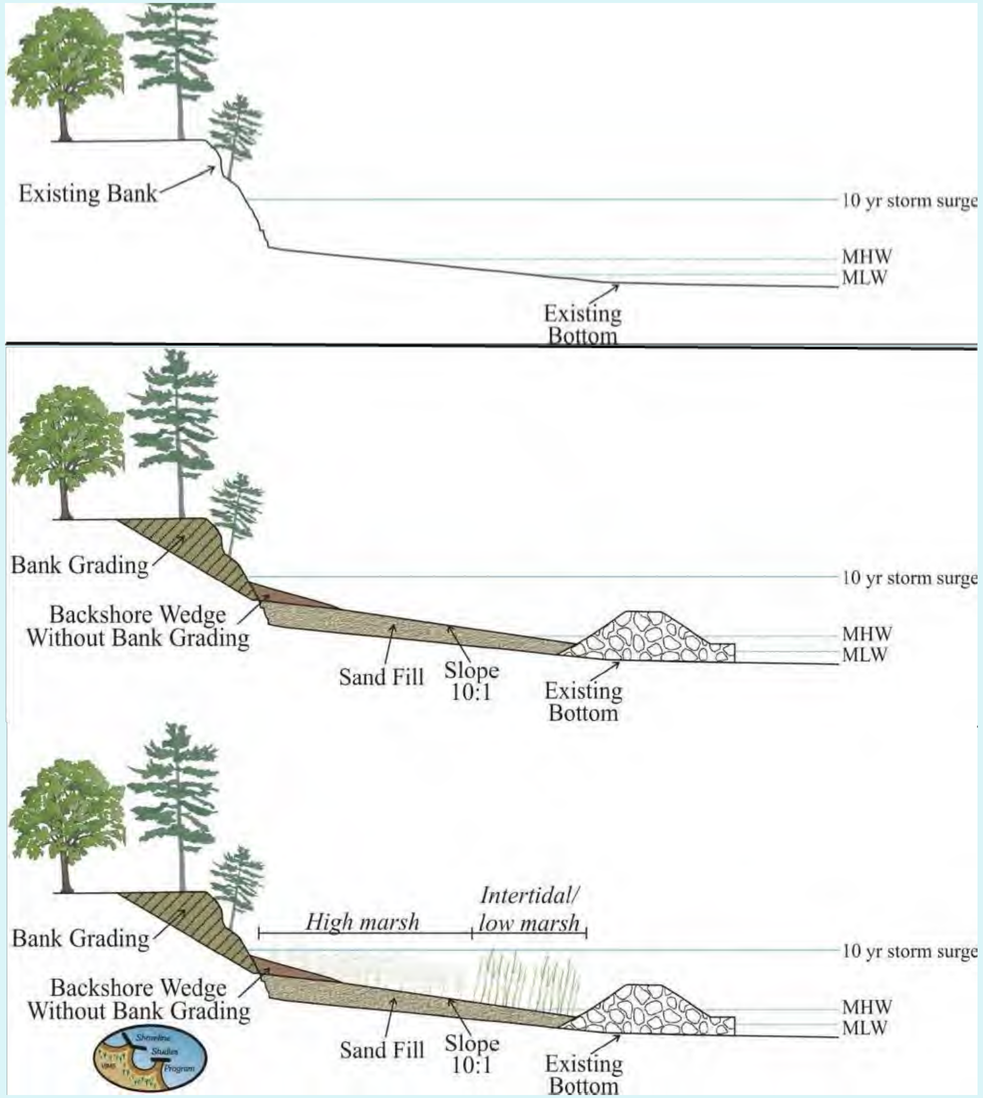


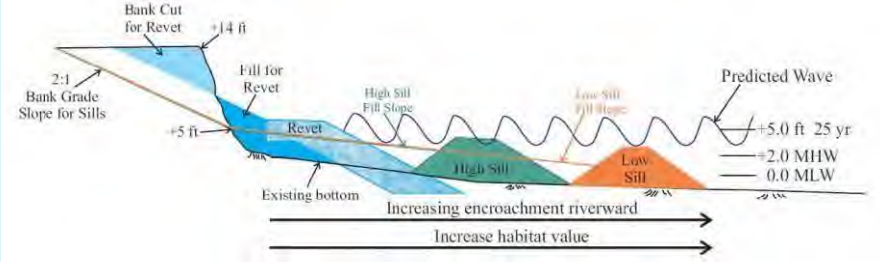



# Shoreline Management Plan Elements

- A next iteration SMP should combine all of the following along with a holistic, community–based focus
  - A location-specific design that accounts for the focus area's unique conditions
  - A resilient design that accounts for both storm surge and rising sea levels
  - A design that acknowledges all property rights associated with the area and avoids conflict with all concerned parties



# System Assessment

A SMP can be assessed on 3 levels

### Parcel Level

- Based on property boundaries
- Focused primarily on the 4 categories studied in the site assessment
- Considers downdrift impacts and impacts to neighboring parcels
- Usually not concurrent with the coastal geomorphology

### Community/Reach Level

- Focused on all waterfront parcels within a given reach/area
- Usually the most efficient, effective, and economical way to conduct a SMP
- Addresses an entire area and all of its subreaches to work more holistically with the coastal environment
- Can become complicated with the different needs, wants, and financial capabilities of all concerned property owners

### Larger System Level

- Varies depending on the site
- Focuses on the coastal environment and ecosystem rather than manmade parcels
- Looks at factors such as affecting adjacent habitats and marsh loss

# Creating Alternatives

Alternatives should provide varying and affordable options that still meet the goals of the project for both the shoreline and upland. Questions that should be asked are:

- What will be effective? Use the parameters from the site assessment to determine the needs of the area.
    - Some designs may not be suitable for the project.
    - Designs will likely not address every issue and should focus on the primary concerns.
    - Reach designs for multiple parcels should be beneficial to each property.
- What is permittable? Virginia law states living shorelines must be used where science shows they are suitable.
    - Designs should minimally and effectively encroach upon shallow water habitat.
    - Novel designs using proprietary units should be confirmed as permittable before used in a SMP.
    - Designs such as detached breakwaters and subtidal reefs may not considered living shorelines and should confirmed as permittable before use in a SMP.
- What about property rights? Land ownership framework is an important consideration in long-term planning.
    - Designs should respect the rights of all owners – ideally, property owners will work together to choose a holistic approach, but each property owner has the right to choose what design is built on their parcel as long as it is permittable and affordable.
    - The Virginia private/public property line is at MLW, which is constantly shifting due to sea level rise – this could affect current living shorelines on private land as well as future decisions of property owners

# Management Strategies for the SMP

1. Do Nothing: leave the area as it is and allow erosion to continue.

2. Managed Retreat: move infrastructure back from the shoreline and allow erosion to continue and the marsh to migrate naturally. This can also include enhancing the marsh by planting existing substrate with marsh grasses possibly using coir logs to protect them; trimming trees to allow sunlight to reach the marsh; and small, intertidal oyster reefs using such materials as oyster bags, oyster castles, or other concrete structures.

3. Living Shorelines: hybrid gray/green living shorelines placed in the nearshore. These sills or attached breakwater systems include sand and plants to create marsh/beach habitat for shore protection. A rock or other natural material structure is built to hold the sand/marsh.


3

# Management Strategies for the SMP

4. Living Shorelines Headland Control: strategically placed stone sills/breakwaters with sand fill and planted vegetation that hold strategic headlands but allow for erosion between structures (cost-effective strategy for larger reaches). Eventually, a stable embayment will develop.

5. Living Shorelines with Edging: Coir logs, intertidal oyster reefs or other habitat-based designs are placed along the shoreline to help attenuate waves. Sand and plantings may or may not be included. Though they often do not stop erosion, they do mitigate it so that eventually the coastal profile may reach equilibrium.

All designs should include upland considerations for runoff and habitat migration.

Though not shown, rock revetments and other hard structures can be considered if the site conditions require it. If an existing bulkhead fails, rather than replacing it, a living shoreline should be considered.

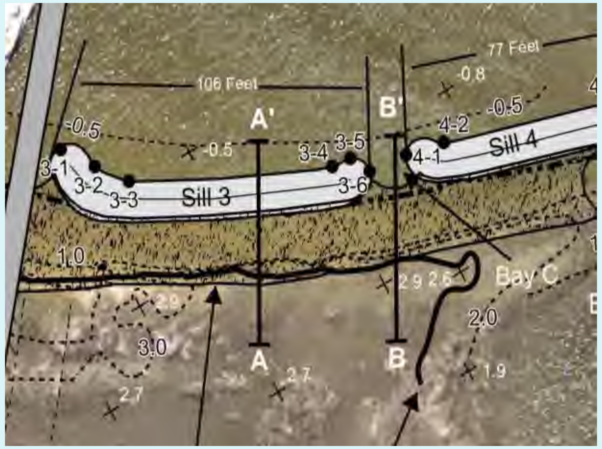

# Funding

- Providing different levels of conceptual plans creates alternatives for what works for a property owner within their budget, as well as what the shore protection could look like if it was done on a reach-basis.
- Determining cost estimates can be difficult and may require additional on-site assessments.
- Costs of novel and proprietary structures may also be difficult to estimate.
- Reach-based systems could be incentivized to implement the goals of the project through grants, loans, and tax breaks.
- Ultimately, the design chosen will depend on the site itself and the budget of the property owner.

# Finalizing a Plan

- Creating an understanding of both the short-term and long-term performance is important to a next iteration plan.
  - All conceptual options should be presented to and discussed with the property owner
  - Funding discussions should also be included in the final plan

- Designing shore protection structures for specific return storm surge frequencies provides a metric by which the proposed system can expect to perform during that event.
  - Erosion may still occur during severe storms, but the sediment will be retained in the marsh
  - Over time, the bank will stabilize as it evolves into an equilibrized slope

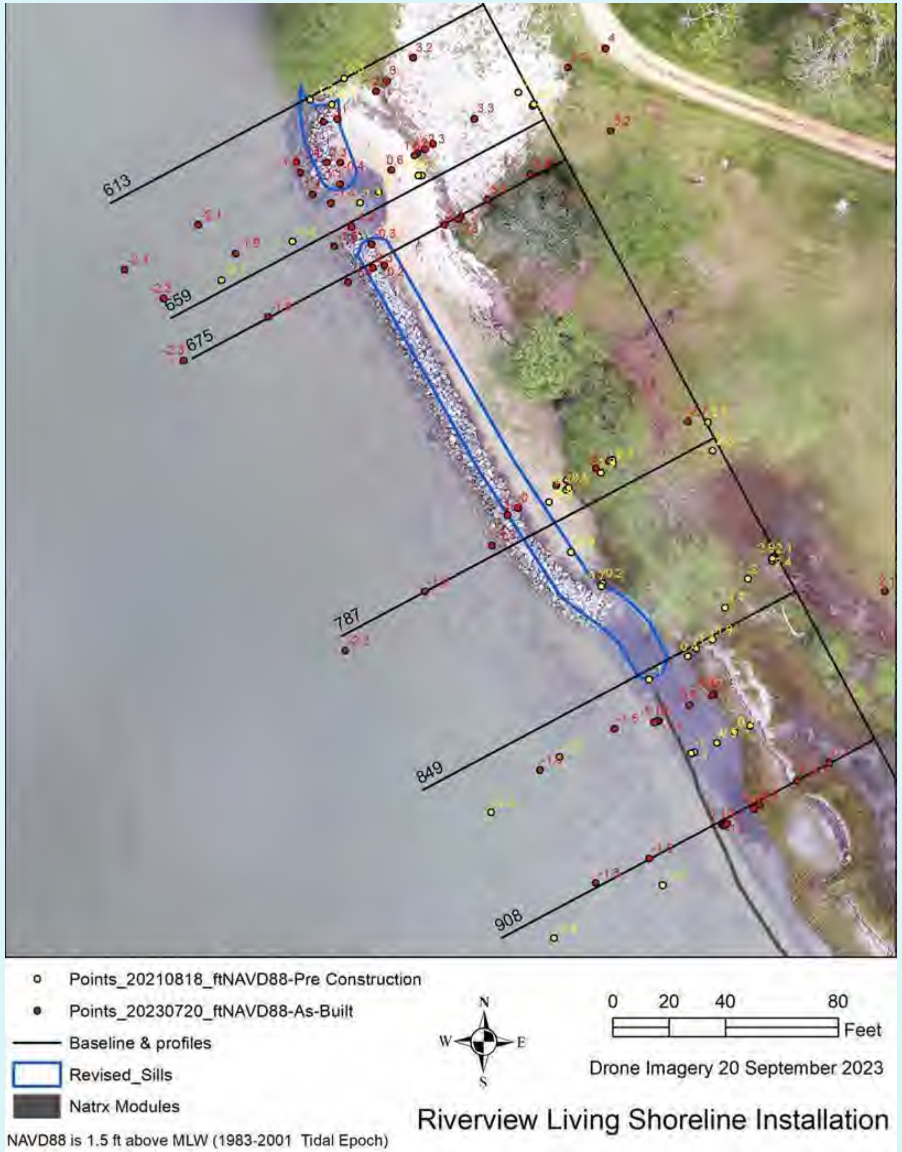




# Monitoring

- Minimum Monitoring
  - Visually inspect the site to ensure vegetation and oysters/other bivalves are healthy
  - Photograph the site to document its progress over time.

- Suggested Monitoring
  - Survey the site after completion to ensure construction was done at the correct elevation and distances.
  - Perform periodic surveys to ensure the system is maintaining elevation and protecting the shoreline from erosion.





# Maintenance

It is important to ensure that the property owner understands that maintenance may be needed for living shorelines. Each site will have different maintenance components, but generally include these:

Tree-trimming/removal: Trimming limbs that overhang and shade the marsh as well as removing small trees from the marsh before they grow too large (less than 1 in diameter) and shade the marsh.
Debris removal: Large amounts of debris whether natural, such as wrack or downed trees, or any human-made debris that washes up on the marsh should be removed before the marsh grass underneath dies.
Grass replanting: Sometimes marsh grass does not grow. The reason should be determined, rectified, and replanted. The reason can be planted at the wrong elevation, sand elevation, run-off, etc.
Sand replacement: After a large storm, some sand and plants may need to be replaced.
Invasive Species Removal: *Phragmites australis* is an invasive plant that will outperform native species and should be removed.


# Case Study: New Point Comfort SMP

- New Point Comfort Natural Area Preserve is a 105-acre site located in Mathews County, VA and managed by The Nature Conservancy (TNC).
- SSP created a next iteration SMP that uses a holistic approach for reach-based protection and enhancing habitat and coastal resiliency.
- The property had unique characteristics with a high energy shoreline on the Chesapeake Bay side of the peninsula and medium energy shorelines on the Mobjack Bay side.
- The Chesapeake Bay side of the property has a sandy beach that overwashes into the marsh. It is highly erosional.
- The northern section of the Mobjack Bay side is an eroding marsh with peat scarp (A). The southern portion inside Mobjack is an accreting beach (B). An observation pier occurs on the site as well (C).

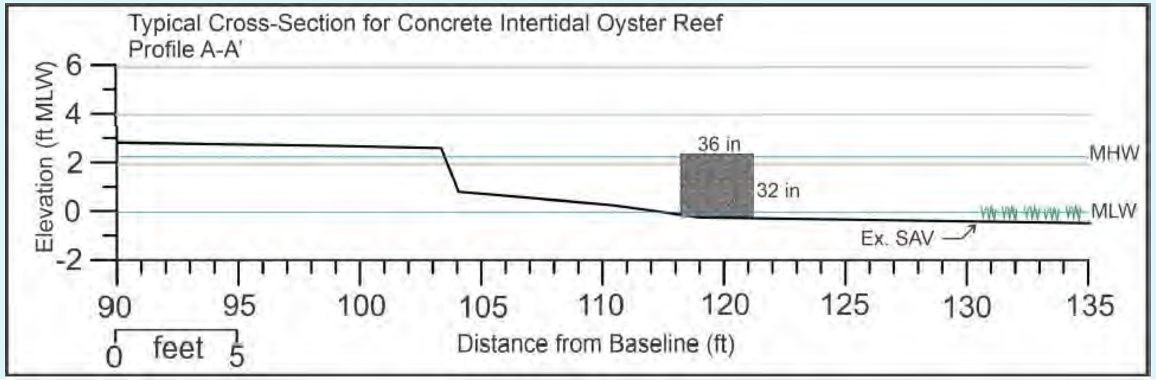

# Case Study: New Point Comfort SMP

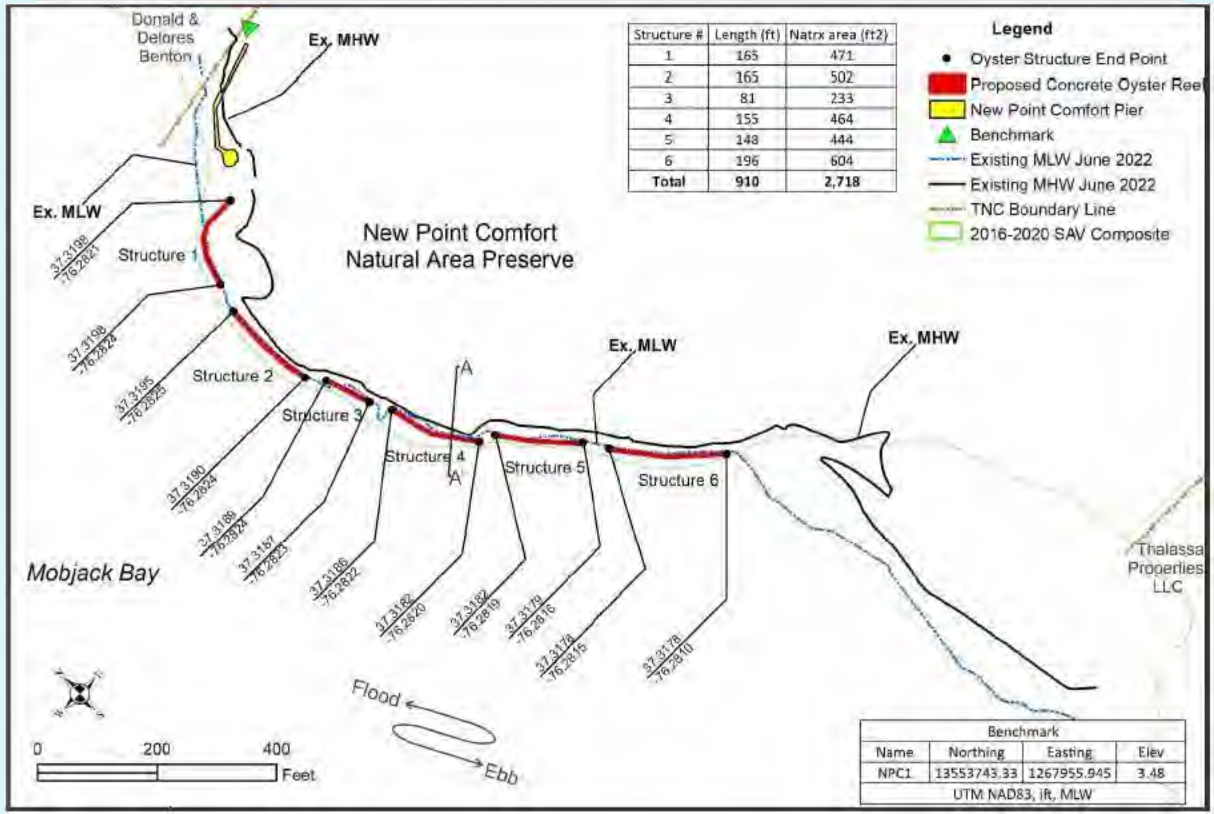
- Recommendations were made for the entire peninsula. On the Chesapeake Bay side of the property to extend the existing attached headland breakwater system south to preserve the marsh from continued erosion. Analysis also showed that ponding within the marsh is occurring threatening the integrity of the marsh. Thin-layer placement (TLP) of dredge material was recommended to enhance the existing marsh, create new marsh, and further stabilize the peninsula. It is recommended to include TLP on adjacent properties to be both cost-effective and promote resiliency for the entire area.
- The southern sandy shoreline on the property was found to be accreting, and it was determined that no action is needed at this time.
- Several design options were created to address shoreline erosion along the northern marsh and presented to TNC. They ultimately chose 3D-printed intertidal oyster reef structures (Natrx) as the management strategy that best suited their goals.


# Case Study: New Point Comfort SMP

- Six intertidal oyster reefs ranging from 81 to 196 ft in length will reduce erosion of the marsh edge.
- TNC chose this option because creating oyster habitat is advantageous for recent funding opportunities with NOAA and other agencies that are targeting habitat restoration on the Middle Peninsula.
- The reach-based SMP for New Point Comfort Natural Area Preserve will reduce erosion and allow the marsh to become a resilient and stable shoreline.
- This, in turn, will protect and create essential habitat for migratory bird species and fish and invertebrate species culturally and economically important to Chesapeake Bay.

An example of a 3D-printed Natrx living shoreline implemented at another site in Chesapeake Bay.



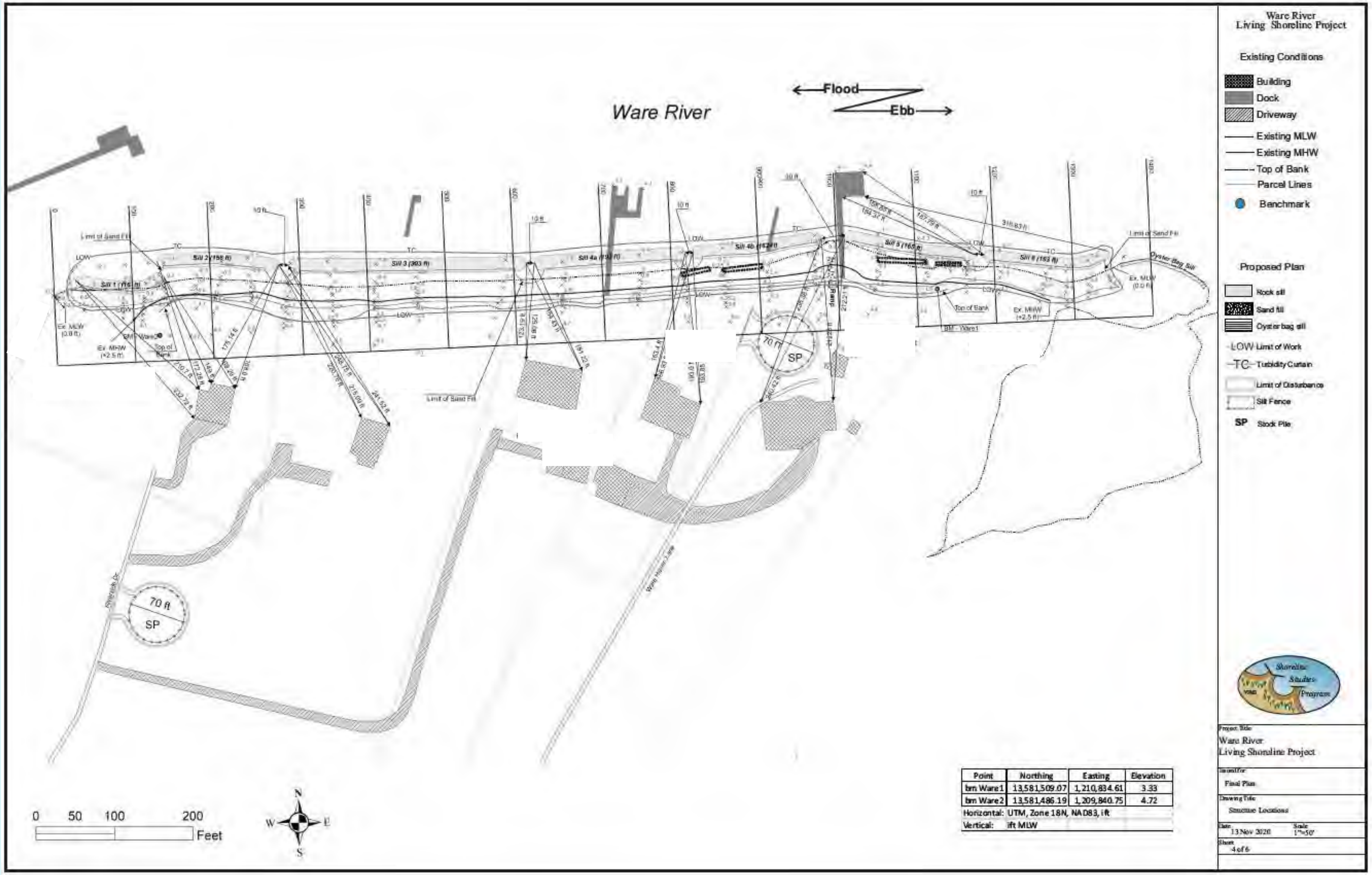




# Case Study: Ware River SMP

- The Ware River Living Shoreline SMP was created for a 1,400-ft long section of shoreline along the Ware River in Gloucester County, VA.
- The section of shoreline consists of 6 individual parcels owned by 6 different property owners.
- Using the next iteration reach-based strategy, one, cohesive SMP was created for the entire shoreline that fulfilled each property owner's needs.
- The design consisted of 7 hybrid gray/green marsh and rock sills placed along the shoreline fronting each property.

# Case Study: Ware River SMP

Structures and prices were considered on a per parcel basis and determined by the amount of material needed within each property boundary.



# Case Study: Ware River SMP

- So far, only one property owner decided to build the section of design along their parcel.

- However, the design remains in place and will create an easier process should any of the remaining property owners decide to build or seek funding in the future.

# Useful Shoreline Management Links

- Shoreline Studies Program Living Shorelines Hub: https://www.vims.edu/research/units/programs/ssp/shoreline_management/living_shorelines/index.php
- Living Shoreline Design Guidance: https://www.vims.edu/research/units/programs/ssp/shoreline_management/living_shorelines/class_info/index.php
- Living Shoreline Design Manual: https://scholarworks.wm.edu/reports/2863/
- Site Assessment Training Presentation: https://www.vims.edu/research/units/programs/ssp/_docs/site_eval_tools_presentation2022-2lr1.pdf
- Shoreline Change Viewer: https://vims-wm.maps.arcgis.com/apps/webappviewer/index.html?id=cd5cf9b788d0407fb9ba5ffb494e9bae
- SAV Interactive Mapping Tool: https://www.vims.edu/research/units/programs/sav/access/maps/index.php
- VMRC Shellfish Grounds Mapping Tool: https://webapps.mrc.virginia.gov/public/maps/chesapeakebay_map.php

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