Final

TNC MARYLAND BLUE CARBON RESILIENCE CREDIT FEASIBILITY STUDY

Prepared for
The Nature Conservancy
Maryland Department of Natural Resources

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819 SE Morrison Street
Suite 310
Portland, OR 97214
503.274.2010
esassoc.com

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EXECUTIVE SUMMARY

Our natural coastal and marine environments not only offer protection from the rising seas and stronger storms brought on by anthropogenic climate change, but also draw down atmospheric greenhouse gases (GHGs). While the protective ability of these habitats has long been understood, the latter benefit, so-called “blue carbon,” has increasingly attracted attention in recent years from scientists, policymakers, and land managers. Peer-reviewed scientific literature has demonstrated the great significance of wetlands, especially salt marsh, mangroves, and seagrass, in exhibiting high carbon uptake and storage per unit area. This process involves the capture of carbon dioxide from the atmosphere and its retention over time within plant materials and sediments as demonstrated in studies like Pendleton et al. (2012).

Globally, these coastal ecosystems are being lost or degraded at an alarming rate, and the diminishing carbon sequestration capacities and resilience associated with such losses has been the focus of many studies. In Maryland, for instance, the state has lost 45-65 percent of its original wetlands, even though 10 percent of the land is still classified as wetland (Clearwater et al. 2000). These systems have been drained for agricultural purposes and have been impacted by water quality issues. Furthermore, the Chesapeake Bay region is experiencing one of the highest rates of sea-level rise in the United States due to land subsidence which is further threatening wetland resiliency (Warren Pinnacle Consulting 2021). Given these trends, it is essential to understand, protect, restore, and value the blue carbon habitats in this region.

Blue Carbon Credits

One way to incentivize and support activities that protect these valuable habitats is developing blue carbon credits to sell on the market. Blue carbon credits allow businesses and individuals to offset their own carbon emissions by investing in projects that capture or store an equivalent amount of carbon elsewhere. This is crucial for entities seeking to achieve carbon neutrality or reduce their overall carbon footprint. By assigning a financial value to the carbon sequestered and stored in blue carbon habitats, credits provide a way to monetize the environmental services provided by these ecosystems. This financial incentive encourages the conservation and restoration of coastal areas. The credit system provides a standardized and verifiable method for quantifying and accounting for the carbon sequestration achieved by blue carbon projects. This ensures transparency and trust in the effectiveness of these projects. In essence, the use of blue carbon credits is a practical and scalable way to integrate coastal and marine ecosystems into broader climate change mitigation efforts, leveraging market mechanisms to drive environmental conservation and sustainability.

While blue carbon credits are a specific mechanism for companies to offset emissions through the conservation and restoration of coastal ecosystems, the concept of blue carbon extends beyond offsetting. Countries, as part of global initiatives like the Paris Agreement, may include commitments to conserve and restore blue carbon habitats. These commitments contribute to broader climate resilience and biodiversity conservation goals, and do not require the development of blue carbon credits. Similarly, several states such as New Jersey and California are leveraging proceeds from carbon market revenues to fund grants for conserving and restoring blue carbon habitats. Beyond the carbon market, efforts to manage and leverage coastal ecosystems are part of a broader conservation strategy. This includes recognizing the multiple benefits of coastal ecosystems, such as supporting biodiversity, protecting against storm surges, and providing livelihoods for local communities.

Study Overview

This feasibility study seeks to progress the developing market of blue carbon and resilience credits by understanding the credit feasibility of different project types and the issues that should be considered in developing projects. One of the challenges of bringing blue carbon credits to market is the interdisciplinary nature of such projects. A feasible credit project should be:

- Technically feasible. For blue carbon:
  - The project would create blue carbon credits by increasing sequestration or reducing emissions compared to a baseline scenario where the project is not implemented.
  - The project would be permanent, i.e., the carbon benefits would last for 100 years.
  - The project would provide “additionality”, meaning the carbon benefit would not occur without the project. For example, areas used for mitigation could not be counted towards carbon credits and land identified for acquisition would have to be at risk of development to be counted as additional.
- OR for resilience credits, this means that the project would reduce the number of people or developed properties at risk of flooding during the 10-, 25-, 50-, and/or 100-year storm events under existing conditions (i.e., without sea-level rise).
- Financially feasible. This means the credits generated by the project could be sold for more than the cost of bringing the project to the market. This includes costs for validation, measuring, reporting, and verifying emissions that occur post-implementation.
- Legally feasible. This means the project proponents would have the appropriate property rights, comply with permitting and regulations, and have the legal authority to sell the credits.
- Organizationally feasible. This means the project has proponents and the funding to implement it.

This study evaluates the technical, financial, legal, and organizational feasibility of funding restoration and conservation projects via blue carbon and/or resilience credits, while also considering the social impacts of blue carbon restoration. Based on stakeholder feedback, five high priority projects have been identified for the Chesapeake and Coastal Bays.

Site Analysis

Blue Carbon Crediting Case Studies

This project considered four different case studies for blue carbon crediting: Deal Island Marsh Restoration, Maryland Coastal Bays Marsh Restoration, Blackwater Marsh Migration Space and Crisfield Barrier Island Restoration. The first three projects are discussed in this section below, while the Crisfield project is discussed under the Combined Blue Carbon and Resilience Crediting Section further below.

Deal Island Marsh Restoration

The U.S. Army Corps of Engineers (USACE) conducts regular dredging of the Wicomico River but has limited remaining opportunities for upland dredge placement. As a result, they have partnered with MD DNR and Wicomico County to identify a marsh site in need of dredge placement to restore and prevent further loss. The Deal Island Marsh Restoration project involves the placement of an 18-inch layer of dredge material in two areas just south of the Deal Island Wildlife Management Area to help the marsh keep up with sea-level rise. The 75-acre property is divided into two sites: a 12-acre pilot project and the remaining 63-acre marsh.

To analyze the permanence of the blue carbon in the system, habitat evolution modeling was conducted to evaluate how the initial 75-acre project site and the adjacent 595-acre marsh areas would evolve over time with sea-level rise. It was assumed that recurring fill placement would be conducted approximately every 7 years in coordination with the regular dredging conducted by USACE. The model results showed that with fill through 2065, the marsh would be resilient to sea-level rise for at least 100 years. However, the financial feasibility assessment showed that funding the Deal Island project through carbon credits would likely not be financially feasible for less than a 50-year timeframe and less than a credit cost of $41/tonne.

Maryland Coastal Bays Marsh Restoration

On the Eastern Shore, the Maryland Coastal Bays Marsh Restoration project aims to restore marsh habitat at nine sites primarily through fill placement, runneling (the excavation of small channels through informal berms), and planting. Driven and funded by a variety of public and private organizations, in partnership with local landowners, this project would potentially restore 1,314 acres. 174 acres are in the implementation phase while the remaining 1,140 acres are awaiting funding.

The initial analysis suggests that the Coastal Bays Marsh Restoration would be financially feasible (i.e., cover the cost of bringing the credits to the market within a 20-year timeframe) only with a carbon price of $107/tonne or greater. The project could cover the cost of operating expenses for blue carbon crediting in 21 years at a credit price of $50/tonne. However, the habitat evolution modeling showed that without recurring fill placements, the marshes would drown out before 2100, so the carbon credits would not be considered permanent (i.e., sustainable for 100 years post-construction).

Blackwater Marsh Migration Space

The Blackwater Migration Space project aims to conserve upland properties for marshes in the Blackwater National Wildlife Refuge to migrate into with sea-level rise. Parcels that will be affected by 1-4 ft of sea-level rise are already experiencing regular inundation, so this project focuses on conserving parcels projected to be affected by 4-6 ft of sea-level rise. However, this latter amount of sea-level rise is not expected to occur before 2100, even under the 95th-percentile projections. The long timeline for return on investment makes this site infeasible for carbon finance.

Resilience Crediting

The Baltimore Wetland Restoration project seeks to create a coastal wetland at Soller's Point north of the Interstate 695 bridge near Baltimore in order to create habitat and reduce wave energy to the shoreline during storm events. The three berm alignment alternatives under consideration would offer flood protection to the energy infrastructure for Baltimore Gas & Electric (BGE) and Exelon. The wave runup modeling results, which were used to evaluate the three design alternatives, suggest little difference in coastal flood depth between existing conditions and the three alternatives, though all alternatives reduced wave velocities to close to zero behind the berms. Since no properties or people are at risk of flooding during the 100-year or smaller storm events under the baseline conditions, the project would not provide any additional benefits as defined by the Coastal Resilience crediting methodology.

To feasibly develop resilience credits, project impact areas need to already be experiencing flooding of people or property under the baseline condition. FEMA's National Flood Hazard Layer (NFHL) viewer provides FIRM data and is a helpful tool for identifying locations already at risk of flooding. For example, the neighborhoods east and northeast of the BGE property show extensive flooding during the 100-year event, so the proposed Cattail Point project may provide some benefit. Additionally, the Stonehouse Cove project and the Fishing Point project could provide resilience benefits to the USALCO chemical plant and the Kinder Morgan Baltimore Transload Terminal.

Combined Blue Carbon and Resilience Crediting

The Crisfield Barrier Island project was evaluated to determine whether restoring the marshes on Janes Island and Cedar Island would provide wave attenuation benefits to the City of Crisfield, which is at the frontline of climate impacts. It is included in this study for its potential under both the blue carbon and resilience crediting methodologies. However, modeling results suggest maintaining the existing marshes will not provide additional flood reduction benefits to Crisfield because flood waters and waves continue to reach the city through a channel between the islands. Additionally, because neither Janes Island nor Cedar Island are expected to breach before 2100, a thin-layer placement project would not provide additional resilience benefits as defined by the crediting methodology.

Under the baseline condition, most of the irregularly flooded marsh will be lost and converted to regularly flooded marsh or open water by 2100. To maximize blue carbon credits, a restoration project in the Crisfield Barrier Islands should focus on areas that are regularly flooded marsh today and expected to convert to open water in the near term, such as the north end of Janes Island. Reducing conversion from irregularly flooded marsh to regularly flooded marsh does not provide as much carbon benefit, although this type of restoration is still valuable as habitat. For example, if the 1,056 acres of marsh that is lost to open water was maintained for 20 years, that project would avoid losing 10,030 tonnes CO_2 equivalent in biomass and sequester 32,520 tonnes of CO_2 equivalent for a total blue carbon benefit of 42,550 tonnes of CO_2 equivalent, which would be more than both the Deal Island and Coastal Bays projects.

Landscape Feasibility

A high-level analysis was conducted to identify regions and parcels that would be worth further investigation for blue carbon and resilience credit feasibility. To assess potential blue carbon projects, the following two types of blue carbon credit projects were considered:

- Conservation of marsh migration space through land or easement acquisition for areas that are uplands today but are expected to convert to wetlands in the near- to mid-term with 2 feet of sea-level rise.
- Conservation of present-day wetlands that may be at risk of conversion or drowning with 1 foot of sea-level rise (i.e., candidates for thin-layer placement or erosion control)

The analysis found much larger areal extents met the criteria for potential thin-layer placement projects than for conservation. More site-specific data is needed to accurately evaluate the potential blue carbon credits for beneficial reuse sites. However, the potential amount of blue carbon can be very roughly estimated by assuming that these sites (44,485 acres) would be maintained as wetland for 30 years longer than under baseline conditions. This would result in 7.8 million tonnes of CO_2 equivalent (1 million tonnes avoided biomass loss and 6.8 million tonnes sequestered), which indicates that beneficial reuse of sediment has significant potential for blue carbon projects.

To assess potential resilience credit projects, FEMA flood hazards were intersected with areas of development to find areas that may benefit from the storm attenuation effects of marsh creation or restoration. However, the feasibility of resilience credit projects is complex and dependent on several factors. For instance, Crisfield has some of the most extensive marshes surrounding it compared to other sites, but modeling showed that restoration of Janes and Cedar Island would not be sufficient to protect the City due to fetch direction, interaction of storm conditions with local topography, and existing low City topography, among other reasons. Thorough site characterization and modeling will be needed to advance future sites.

Conclusions and Next Steps

Tables ES-1 and **ES-2** provide a summary of the projects and feasibility considerations.

TABLE ES-1
SUMMARY OF ALL BLUE CARBON CASE STUDIES

Site	Project type	Project benefit	Approx size (ac)	Cost[1]	Project lifespan[2] (years)	Carbon benefit of project over baseline (tonnes)	Break-even price over 50-years[3] (per tonne)	Credit Feasibility
Deal Island	Beneficial use of dredged material	Maintains habitat; protects infrastructure	670	$35,307,000	~100	20,970	$84	Potential
Coastal Bays	Beneficial use of dredged material & runneling	Maintains habitat; soft transition for saltwater intrusion on farmlands	1,314	$32,903,000	~90	25,030	$26	Potential with recurring fill placements
Blackwater[4]	Land easement	Protects future habitat	n/a	n/a	Would not begin until end of century	n/a	n/a	No, technically infeasible at this time
Crisfield[5]	Beneficial use of dredged material	Maintains habitat; provides continued wave barrier	1,056	n/a	20	42,550	n/a	Potentially technically feasible with recurring fill placements

NOTES:

1. Project implementation cost only.
2. How long the habitat will last before it is drowned due to sea-level rise.
3. Price to cover the carbon market costs
4. Blackwater was determined to be technically infeasible, so a financial analysis was not performed.
5. Crisfield did not have a specific project to evaluate, so an example project was developed. A financial analysis was not performed.

TABLE ES-2
SUMMARY OF ALL COASTAL RESILIENCE CASE STUDIES

Site	Project type	Project benefit	Credit Feasibility
Baltimore Wetlands	Wetland creation	Habitat creation; shoreline protection	No, technically infeasible b/c no existing flooding
Crisfield	Beneficial use of dredged material	Maintains habitat; provides continued wave barrier	No, technically infeasible b/c would not reduce flooding

Beneficial reuse of dredged material at Deal Island and Coastal Bays provides an opportunity to examine how these types of projects may be applied for restoration and carbon crediting efforts. Both projects have a relatively high price tag for the amount of carbon they sequester. Deal Island would break even on the blue carbon costs within a 20-year timeframe at a carbon price point of $690/tonne, while Coastal Bays would break even at a price of $107/tonne. The Coastal Bays project could cover its blue carbon operating expenses over 21 years at a cost of $50/tonne.

Deal Island was assumed to receive regular fill placement through 2065, which is expected to maintain the marsh for 100 years after initial construction. Coastal Bays was assumed to receive a one-time fill placement, and as a result, the marshes drown out much faster. The increased fill at Deal Island outweighs the benefit of high salinity (and therefore less methane) at Coastal Bays.

The results indicate that recurring fill placement will be necessary to maintain project permanence.

There is a great need for beneficial reuse projects as 110,000 acres of existing marsh are vulnerable to 2 feet of sea-level rise. Finding cost effective ways to implement these projects will be key to maintaining habitat in the future and blue carbon financing may play a role in these efforts if credit prices or the scale of projects increase.

Conservation easements may be feasible, but only in areas that are both at risk of development, and likely to convert to wetland in the near-term. Considering a 20-year timeframe for financial returns, any site converting to marsh is likely to be at risk of flooding, so ideally, development should be a low risk. The landscape feasibility analysis showed the number of sites that are not currently marsh but likely to be marsh soon are minimal.

The results of the analysis of Crisfield and the Baltimore wetland restoration projects showed that feasible resilience credit projects need to be located in communities where the flood risk is already evident. The landscape feasibility showed that these locations do exist but are not necessarily adjacent to existing marsh or are constrained by other community needs (such as the navigation channels adjacent to Crisfield). Further analysis of the sites identified in the landscape feasibility analysis is needed to understand the potential opportunities for these types of projects.

It is important to remember that the case studies analyzed for this project have widely varied and unique combinations of habitats, environmental challenges, ownership situations, and restoration opportunities, making the results difficult to generalize. It is also important to note that all of the projects analyzed in this study provide benefits beyond blue carbon, including providing habitat for threatened species, protecting against storm surges, and providing livelihoods for local communities. The carbon benefit provided by these projects is still important, even if carbon credits are not going to pay for the projects. Quantifying carbon benefits can be used to help project proponents win grant funding and used towards state emissions reductions goals, which often require less rigorous assessment than crediting. So, while the sites analyzed in this study may not be feasible on the blue carbon market, they still provide numerous ecosystem, climate, and resilience benefits.

To further analyze developing feasible credit projects in Maryland, next steps could include:

- Analyzing how carbon credits can be considered permanent when habitats are faced with sea-level rise. This could include studying what happens to soil carbon when habitats become submerged or eroded and studying how seagrasses may be able to migrate into submerged habitats and maintain soil carbon.
- Working with USACE and others to identify ways to make beneficial reuse projects more cost effective.
- Monitoring Deal Island post-construction to understand where the standing biomass carbon goes and any changes in emissions between dredge material placement and settlement of the material. Documentation of any monitoring efforts is recommended so that Deal Island can be used as a blue carbon pilot project.

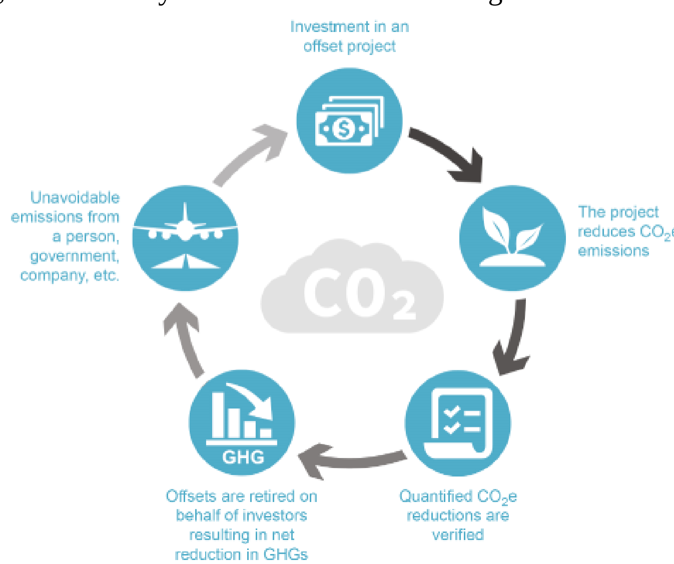
- Developing a finer scale habitat evolution model to be able to analyze changes in habitat types due to runneling. Continued monitoring of existing projects to determine how long it takes vegetation to reestablish and how elevations change post-runneling is recommended to inform any habitat evolution modeling.
- Analyzing construction emissions for proposed projects and/or developing innovative methods to reduce construction emissions for restoration.
- Identifying a feasible pilot project for developing resilience credits. Cattail Point, Stonehouse Cove, or Fishing Point projects in Baltimore should be considered.

SECTION 1
Introduction

As human-induced climate change continues to accelerate, our coastal and marine environments serve a dual purpose: they provide protection against rising sea levels and stronger storms, and they also play a crucial role in absorbing and storing atmospheric greenhouse gases (GHGs), a concept known as "blue carbon." While the protective aspect of these habitats has long been recognized, the blue carbon benefit has gained increasing attention from scientists, policymakers, and land managers in recent years. Peer-reviewed scientific literature has highlighted the significant role of wetlands, especially salt marshes, mangroves, and seagrass, in both capturing carbon dioxide from the atmosphere and storing it in plant materials and sediments (e.g., Pendleton et al. 2012).

Globally, these coastal ecosystems are disappearing at an alarming rate, and many studies have focused on the consequences of these losses for carbon sequestration capacity and resilience (Moritsch et al 2022, Nahlik and Fennessy 2016). In Maryland, for instance, the state has lost 45-65 percent of its original wetlands, even though 10 percent of the land is still classified as wetland (Clearwater et al. 2000). These systems have been drained for agricultural purposes and have been impacted by water quality issues. Furthermore, the Chesapeake Bay region is experiencing one of the highest rates of sea-level rise in the United States due to land subsidence which is further threatening wetland resiliency (Warren Pinnacle Consulting 2021). Given these trends, it is essential to understand, protect, restore, and value the blue carbon habitats in this region.

This feasibility study, prepared for The Nature Conservancy (TNC) and the Maryland Department of Natural Resources (MD DNR), aims not only to contribute to the existing knowledge about blue carbon but also to advance the emerging market of carbon and resilience credits by identifying feasible project types and addressing the key considerations in developing such projects. One of the challenges in bringing blue carbon credits to the market is the interdisciplinary nature of these projects. For instance, assessing the permanence of blue carbon credits involves considering physical factors like sea-level rise resilience, evolving legal frameworks, and changing carbon costs. Consequently, this study evaluates the technical, financial, legal, and organizational feasibility of



restoration and conservation projects while also taking into account the social impacts of project development.

1.1 The Voluntary Carbon Market

The voluntary carbon market provides individuals and corporations the opportunity to reduce their carbon footprint beyond internal reductions by offsetting their emissions through payments to projects elsewhere (see graphic on the previous page). However, carbon projects need to be verified to ensure that emissions reductions are actually occurring as a result of the project. Projects on the verified market follow standard approved methodologies and undergo third-party verification before developers can sell credits to individuals or companies to offset their emissions (Figure 1-1).

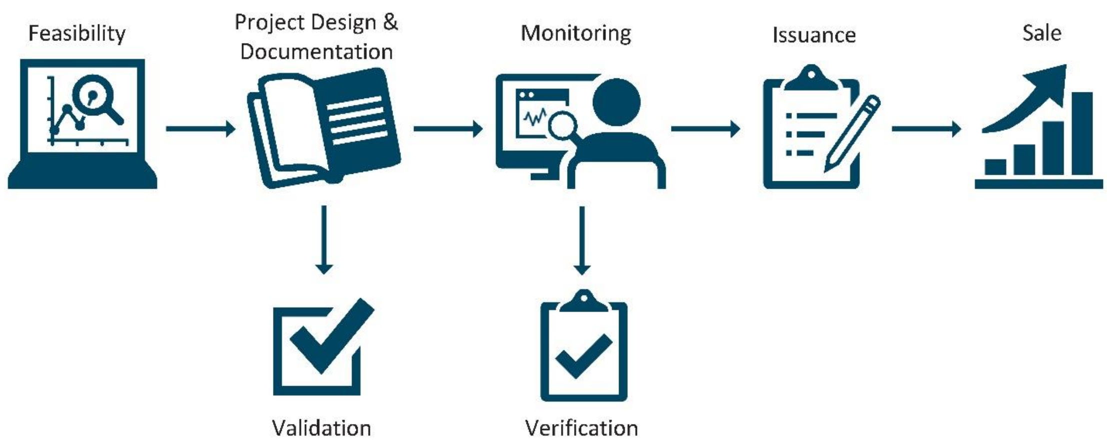


Figure 1-1. Market Project Development Process

Over the past few years, several blue carbon methodologies have been approved by standards such as Verra, and several pilot projects have been developed in mangrove forests throughout the world. Verra has issued a total of 970,000 blue carbon credits (i.e., 970,000 metric tonnes[1] of CO_2 equivalents) as of April 2021, but the rate of project development is increasing, with one mangrove reforestation project alone set to issue 1,000,000 credits (Jones 2021). Additionally, The Nature Conservancy's Virginia Coast Reserve Seagrass Restoration Project, the first blue carbon project in the U.S. focused solely on seagrass meadows, was recently registered by Verra in April 2022 (Oreska et al. 2020). The Taskforce on Scaling Voluntary Carbon Markets (2021) has estimated that the demand for carbon credits will increase to create a market worth $50 billion by 2030.

The Nature Conservancy (TNC) has developed an innovative methodology for quantifying coastal resilience, which could be used additively to blue carbon credits. This methodology uses an expected damage function modeling approach and is pending approval from Verra's Sustainable Development Verified Impact Standard (SDVISta) program. The coupling of blue

1 A metric tonne is 2,204.6 lbs and is a little bigger than the American ton's 2,000 lbs. Metric tonnes are typically used in carbon analyses.

carbon offsets and resilience credits and subsequent sale of these blue carbon resilience credits could provide an important and supplemental source of funding to restoration and conservation of these critical ecosystems. As new methodologies are accepted in the carbon market(s), “proof of concept” projects could lay the groundwork for broader acceptance of tidal wetland restoration and conservation activities in the regulated carbon markets where demand and prices are higher.

1.2 Study Outline

Based on stakeholder feedback, five high priority projects have been identified for the Chesapeake and Coastal Bays: Deal Island Restoration, Blackwater Marsh Migration Space, Maryland Coastal Bays Marsh Restoration, Baltimore Wetland Restoration, and Crisfield Barrier Island Restoration. While this study focuses on the blue carbon and resilience benefits of these projects, it is important to note that these projects provide other benefits, such as habitat for threatened species (e.g., Saltmarsh Sparrow) and water quality, as well, so even in the situation where a project may not be feasible as a blue carbon or resilience project, the project may move forward due to its other benefits. This study is organized around these different project types. An outline of the study is provided below.

- Section 1: Introduction
- Section 2: Methods
- Section 3: Blue Carbon Crediting Case Studies
- Section 4: Resilience Crediting Study
- Section 5: Combined Blue Carbon and Resilience Crediting Study
- Section 6: Landscape Feasibility
- Section 7: Conclusions and Next Steps

SECTION 2
Methods

2.1 Technical Feasibility (Carbon Standard and Methodology)

2.2.1 Methodology

As discussed in Section 1, crediting projects are assessed via standardized methodologies. This project uses the Verified Carbon Standards (VCS) issued by Verra for the voluntary carbon market. For the portfolio of projects in this study, the applicable VCS methodology is VM0033, "Methodology for Tidal Wetland and Seagrass Restoration" (VCS 2023). The specific details of the applicability of VM0033 for each of the project types are further discussed in Section 3 below.

The draft Coastal Resilience Methodology, currently in validation under the Sustainable Development Verified Impact Standard, was used for the projects that provide a resilience benefit. The details of applicability are discussed in Section 4.

2.2.2 Carbon Pools and Emissions Sources

The most fundamental aspect of a viable carbon crediting project is that the project scenario sequesters more carbon for the next 100 years than the baseline (without project) condition. The first step to determining whether a project is viable is to identify the carbon pools and emissions sources that are in play for a specific project. The Intergovernmental Panel on Climate Change (IPCC) Wetlands Supplement to the 2006 accounting guidelines (IPCC 2014) identifies three carbon pools important to calculating CO_2 removals in coastal wetlands (this also applies to other vegetated land cover types): biomass (aboveground and belowground), dead organic matter (wood from mangroves and litter pools), and soil carbon.

For emissions, methane (CH_4) and nitrous oxide (N_2O) are considered in the analysis. Methane emissions are produced when microorganisms in wet, poorly aerated soils, such as in freshwater or brackish marshes, decompose organic matter. High salinities reduce this methane production, so salt marsh (>18 ppt) is assumed to have negligible emissions (Poffenbarger et al. 2011). Methane has a 100-year Global Warming Potential (GWP) of 28-34 relative to CO_2, which means the effect of each tonne of CH_4 on the atmosphere in 100 years is 28—34 times greater than that of a tonne of CO2 (IPCC 2014). Natural wetlands can be, and often are, a source of N_2O. However, changes in emissions of N_2O are generally caused by anthropogenic N inputs (e.g., fertilizer) or the conversion of ammonia (contained in fish urea) to nitrate, generally associated with aquaculture. Since none of the project sites involve fertilizer or aquaculture, N_2O emissions were not included as part of this study.

2.2.3 Carbon Credits Accounting

The analysis then requires establishing spatial and temporal boundaries. Spatial boundaries were set by considering watershed divides (e.g., roads or natural features), property lines, site topography, and sea-level rise projections. Temporal boundaries were set based on project goals, the expected timing of project implementation, and model capabilities (see more in Section 2.2.4).

Given the project boundaries, the baseline and project scenarios must be defined. In the case where there is existing marsh, the baseline may involve carbon sequestration that is expected to decrease with time as sea levels rise and a loss of carbon as inundated soil is eroded. As part of the scenario analysis, determining whether the project would really provide additional sequestration (i.e., proving additionality) and whether the carbon benefits would last for 100 years (i.e., permanence) is key to developing a viable project.

Leakage is considered for each project where applicable and refers to the potential that a project, while reducing GHGs on site, may result in more emissions elsewhere.

2.2.4 Habitat Evolution

One important aspect of a blue carbon credit project is the permanence of the project. A project is not viable if it will not last and maintain the credits for a specified duration (e.g., Verra standard requires 100 years offset permanence). For the projects in this analysis, the biggest threat to permanence is sea-level rise, which is expected to drown coastal habitats over time. Using habitat mapping, topobathymetric data, project plans, and sea-level rise projections, the evolution of the coastal habitats was modeled over the established temporal extent using the Sea Levels Affecting Marshes Model (SLAMM). Coastal vegetation typically has a specific elevation related to the tides that is optimal for its establishment, so with rising water levels, each species would be expected to recruit upslope to maintain the inundation frequency that works best for it.

Under contract with The Nature Conservancy, Warren Pinnacle Consulting, Inc (WPC 2021) used SLAMM to model the habitat evolution of Maryland’s Chesapeake and Atlantic Coastal Bays to inform conservation and management as part of the National Oceanic and Atmospheric Administration’s (NOAA) National Centers for Coastal Ocean Science’s (NCCOS) Effects of Sea Level Rise (ESLR) program. The inputs and model from WPC 2021 were used to model baseline and project conditions.

SLAMM uses specific habitat categories derived from National Wetland Inventory (NWI) classification, such as “regularly flooded marsh”, “irregularly flooded marsh”, and “transitional salt marsh”, which do not translate exactly to habitats at the project site. For example, at Deal Island, the “irregularly flooded marsh” habitat includes *Spartina alterniflora*, *Juncus roemerianus*, and *Spartina patens* which establish (on average) from 0.98 -1.34 ft NAVD88 and which have varying methane emissions (Derby 2022).

The 2023 Maryland sea-level rise guidance (Boesch et al. 2023) recommends using the "best estimates" projections (i.e., the 50% probability projection) for managing/restoring natural infrastructure and the "Current Commitments" for the most likely emissions scenario, which results in 2.79 ft of sea-level rise by 2100 for the Cambridge gauge from a 2005 baseline. The closest scenario in the WPC report (2021) is the 50% Growing Emissions (RCP 8.5) projection, which was based on the 2018 Sea Level Projections for Maryland at the Cambridge tide gage from a 2010 baseline, as shown in **Table 2-1**. Adjusting the SLAMM 50% Growing Emissions scenario to a baseline of 2005, as used by Boesch et al. 2023, would change the projected sea-level rise to 3.05 feet.

TABLE 2-1
SEA-LEVEL RISE PROJECTIONS FOR CAMBRIDGE, MD

Year	Sea-Level Rise (ft)
2022	0.20
2030	0.43
2040	0.69
2050	1.02
2060	1.44
2070	1.80
2080	2.20
2090	2.59
2100	2.95

SOURCE: WPC 2021, The University of Maryland Center for Environmental Science 2018

2.2.5 Carbon Quantification

To determine the number of credits for each project, the difference in emissions and sequestration between the project and the baseline must be quantified. The IPCC 2006 GHG accounting framework is based on the following equation:

$$Emissions = -Sequestration = Activity\ Data * Emissions\ Factor$$

According to IPCC 2006, *activity data* are data on the magnitude of human activity resulting in GHG emissions and removals. For restoration projects, the relevant *activity data* are changes in land cover over time. *Emissions factors* are the rates of GHG emissions and removals[2] associated with a unit of activity data. A removal is a negative emission.

To calculate CO_2 removals, each habitat type is assigned a biomass density, a soil carbon sequestration factor, and a methane emissions rate. **Table 2-2** provides the sequestration and emissions rates used for each habitat type, which were parameterized by literature review that

2 The terms "sequestration" and "removal" are synonymous. "Sequestration" is used more often with wetland scientists while "removals" is more common with GHG accounting experts (and refers to a wider range of reductions in GHGs).

prioritized local data from similar ecologies and settings. **Appendix A** provides a detailed version of the table with literature references and assumptions.

Using habitat acreages, changing carbon stocks can be tracked through time as sea level rises and marshes migrate inland. For example, when land is covered with vegetation, there is a stock of carbon in the biomass and the soil, and the soil carbon increases according to the soil sequestration rate of the habitat, due to the incorporation of dead organic matter back into the soil. When a habitat converts to another habitat (e.g., from irregularly flooded marsh to regularly flooded marsh), aboveground biomass changes (may increase or decrease) due to the different type of vegetation, and soil sequestration continues, but at the rate of the new habitat type. All of sequestrations and emissions for each habitat type are then totaled for each scenario to determine the difference between the baseline and project scenario. The cumulative estimates were then used to assess the viability of each project from a carbon storage perspective.

TABLE 2-2
SEQUESTRATION AND EMISSION RATES BY HABITAT TYPE

Habitat	Aboveground carbon stock (MgC/ha)	Existing Soil Carbon (MgC/ha)	C Removal Rate (gC/m2/yr)	CH4 Emission Rate for salinity <18 ppt (MgCH4/ha/yr)	CH4 Emission Rate for salinity >18 ppt (MgCH4/ha/yr)
Forested Dry Land	-90	-78	0	0	0
Transitional Salt Marsh	-6.4	-201	-208	0.9	0.01
Regularly Flooded Marsh	-6.4	-201	-208	0.19	0.01
Non-Forested Dry Land	-26.1	-78	-23	0	0
Estuarine Beach	0	0	0	0.19	0.01
Tidal Flat	0	0	0	0.19	0.08
Estuarine Open Water	0	0	0	0.19	0.01
Irregularly Flooded Marsh	-6.4	-201	-208	0.2 – 0.9	0.01

Note: Negative numbers indicate removals while positive numbers represent emissions

2.2 Financial Feasibility

2.2.1 Methods

To analyze the financial feasibility of developing a blue carbon project, the net present value[3] (NPV) of the estimated cash flows was calculated over the first 20 years of the project. This timeframe was selected because it is the minimum duration stipulated by Verra. Additionally, financial investors generally prefer shorter time horizons such as 20 years. The analysis for each site is based on the estimates of carbon credits that could be generated by the project (adjusted to include a buffer), carbon credit prices, and project costs. The analysis was conducted twice: first (1) incorporating only the costs related to establishing the carbon credits to evaluate if bringing

[3] Net present value is a financial concept used to determine the value of money received or spent in the future in today's terms.

the project to the market would be financially feasible, and then (2) incorporating all the costs to determine how blue carbon revenues could contribute to project funding.

2.2.2 Overall and Carbon Revenue Assumptions

Table 2-3 summarizes key assumptions related to the carbon revenues and the discount rate. The cost assumptions are discussed separately in the case study sections. The initial assumption for **carbon pricing was \$20/tonnes of CO_2 equivalent (tCO_2e)**. However, simulations were also conducted for \$50 and \$100 per tCO2e, and a breakeven price was calculated for each site. Moreover, an **annual carbon price increase of 2.5%** was factored in. According to this trajectory, carbon prices that would begin at \$20/tCO2e in 2023, would rise to ~\$24/tCO2e by 2030, and ~\$30/tCO2e by 2040.

For context, the global weighted average carbon price across various project types in the voluntary carbon market stood at \$4/tCO_2e in 2021, as reported by respondents from Forest Trends' Ecosystem Marketplace (2022). In the same year, forestry and land use activities accounted for 46% of traded volumes and averaged slightly higher, around \$5.8/tCO_2e (ibid.). The compliance market where carbon offsets are legally mandated, have higher rates from \$8-84 tCO_2e (ESA 2022, Carbon Credits 2022). While the carbon credit price estimates used in this analysis may appear significantly higher than observed voluntary market prices, there is potential for price premiumization given the high demand and low supply of blue carbon credits and the many co-benefits provided by such projects (e.g. biodiversity, shoreline stabilization, improved water quality, etc.). For example, Maryland's Office of Sustainability has expressed interest in offsetting state travel within Maryland, which could lead to a higher cost for carbon credits within Maryland. More details on the assumptions regarding discount rate, uncertainty, leakage, and non-permanence can be found in *Error! Reference source not found.*.

TABLE 2-3
SUMMARY OF OVERALL AND CARBON REVENUE ASSUMPTIONS

	Component	Assumption
Overall	Discount rate	4%
Carbon revenue assumptions	Uncertainty	0%
	Leakage	0%
	Non-permanence	20%
	Initial carbon price	\$20/tCO_2e \$50/tCO_2e \$100/tCO_2e
	Carbon price increase	2.5% per year

2.3 Legal Considerations

2.3.1 Ambulatory Property Boundaries at the Coast

In Maryland, submerged land below mean high tide is considered public lands and is managed by MD DNR and impacts to resources are subject to regulatory review by the Maryland Department of the Environment. If private property becomes submerged, it becomes public land. Tidal wetlands below mean high water are public property while those above are often private property. The potential for blue carbon projects in Maryland to convert to public land could be both an additionality and ownership issue. If a project is claiming credit for seagrass habitat or wetland habitat that is created through habitat evolution (and not active restoration), this may not be additional, since the state protects seagrass and tidal wetland habitat already. Additionally, selling credits for submerged areas would require consideration of MD DNR's current or eventual ownership of the land. The discussion of both additionality and ownership herein suggests the need for further requirements for verification and monitoring on private property over extended time periods and possibly the need to specify ownership of carbon credits through state policy or in contracts for the sale of credits.

The Chesapeake Bay Critical Area Act (1984) and its Criteria (1986) established protection criteria for the region bordering the Chesapeake and Atlantic Coastal Bays in Maryland. The Critical Area is generally defined as all land and water areas within 1,000 feet beyond the landward boundaries of tidal wetlands, the Bay, and its tributaries. All development and land-disturbing activities within the Critical Area are guided by specific provisions found in the State-adopted Critical Area Criteria and the local Critical Area programs. Those provisions cover issues from clearing trees and removing vegetation to limiting areas of impervious surface. Migration of tidal wetlands inland due to sea level rise, or projects that increase the extent of tidal wetlands may extend the critical area boundary inland, with implications for the private property rights of affected landowners.

2.3.2 Private Property Rights

Projects impacting tidal wetlands are covered under COMAR §§ 16-101 – 16-503 Wetlands and Riparian Rights. This law requires that a person wanting to engage in the filling or dredging of tidal wetlands, must first apply to Maryland Department of the Environment for said activity, and then obtain a Tidal Wetlands License from the Maryland Board of Public Works. Any blue carbon project, on private or public land, would be subject to this requirement.

If the blue carbon project proponent is acquiring an easement rather than fee simple ownership, the easement language needs to ensure that the landowner would not have rights that conflict with the permanence of the habitat. For example, text could be included to ensure the easement will: "allow for ecosystem service credits to be generated and sold, including but not limited to carbon offsets." The State cannot prevent an easement holder from engaging in a private ecosystem service market, but the project must meet the additionality requirements of the carbon credit protocol being followed.

2.3.3 Maryland Conservation Finance Act

The Conservation Finance Act[4], passed in 2021, proposed a new program to provide traditional infrastructure financing equally available to green and blue infrastructure projects and promote private investment in such solutions. The Conservation Finance Act makes Maryland the first state to officially define blue infrastructure, making more initiatives eligible for funding. Under the bill, projects that filter air and water pollutants, sequester carbon, reduce erosion, increase community flood resilience, and other nature-based initiatives would be eligible for traditional infrastructure financing.

The Act states that state lands are eligible for participation in ecosystem service credit markets, such as a carbon offset market, and that the state cannot restrict a landowner or third party that receives state funds through grants or cost share from participating in an ecosystem service credit market. The bill allows for state agencies to serve as aggregators for ecosystem service projects, potentially improving the economy of scale and lowering transaction costs. Additionally, the bill allows Maryland to adopt a pay-for-success model with private investors, greatly reducing the state's financial risk for green and blue infrastructure projects.

The bill also creates a task force to account for natural capital, creates a policy advisory commission to simplify the permitting process, and other components that will increase the pace and scale of ecological restoration in the state. The bill charges MD DNR with developing two carbon offset projects on state lands, one upland project and one blue carbon project. This feasibility study is a key step in the development of a blue carbon project.

2.4 Social Considerations

Studies have shown that certain communities such as low-income communities, communities of color, linguistically isolated communities and immigrant communities, children, and the elderly are especially vulnerable to the impacts of climate change as well as to health impacts and economic disruptions. Certain populations such as low-income communities and communities of color have also been historically marginalized and not included in community and environmental planning. The vulnerability of communities is heightened when they experience intersecting vulnerabilities such as being both low-income, linguistically isolated and when they live in high-risk areas such as floodplains or the coastal zone.

To contextualize the communities in which these projects are taking place and to understand any potential positive or negative impact, data from the EPA EJScreen (Environmental Justice Screening and Mapping Tool), CDC PLACES (population and community level health indicators), and the Census Bureau American Community Survey was evaluated for this study.

Several social, economic, and health factors were examined for communities surrounding project sites to understand these communities' levels of vulnerability. These indicators included:

[4] SB0348. Maryland Conservation Finance Act. https://mgaleg.maryland.gov/mgawebsite/Legislation/Details/sb0348?ys=2022RS

- Social: linguistic isolation, level of education, number of children, number of seniors, broadband access, health insurance, number of people of color.
- Economic: employment, income.
- Health: prevalence of heart disease, prevalence of asthma, food desert.

Any indicator scores placing a community in the 50^{th}-100^{th} percentile were flagged for further discussion and investigation. Additionally, proximity to hazardous materials, pollution sources, and industry were considered.

On a broader scale, it is important to consider that if blue carbon credits are used to offset emissions elsewhere, the impact of these emissions may result in unequal harm to vulnerable communities. This is addressed in part through the leakage portion of the VCS methodologies, which requires a buffer of credits to account for potential leakage to other places. However, for VM0033, if the applicability conditions of the methodology are met (e.g., the project restores tidal wetlands via approved project activities), leakage is deemed not to occur (VCS 2023).

2.5 Coastal Resilience Standard and Methodology

The applicability of the Coastal Resilience Methodology from the Sustainable Development Verified Impact Standard was assessed for projects that reduce flood risk. This methodology, which is currently in validation, assesses the benefits provided by coastal ecosystems by estimating how many people or property are at reduced flood risk per unit area of the ecosystems. The potential to "stack" these benefits on top of carbon credits could further incentivize project implementation.

The core steps of the methodology (TNC 2022) are to:

1. Characterize offshore hydrodynamics.
2. Characterize nearshore hydrodynamics for the baseline scenario.
3. Characterize nearshore hydrodynamics with restored/conserved habitat project.
4. Estimate inland flooding reductions due to the project.
5. Estimate flood damage (i.e., the number of people impacted or cost of infrastructure) reductions due to the project.

At this early stage of feasibility assessment, the applicability of the methodology was evaluated for each coastal resilience project site prior to running the model itself. The main consideration for each site was whether the proposed project was likely to provide increased flood resilience to enough people or property for this financing mechanism to be feasible. **Appendix C** goes into further detail on modeling methodology used for the Baltimore Wetlands project.

SECTION 3
Blue Carbon Crediting Case Studies

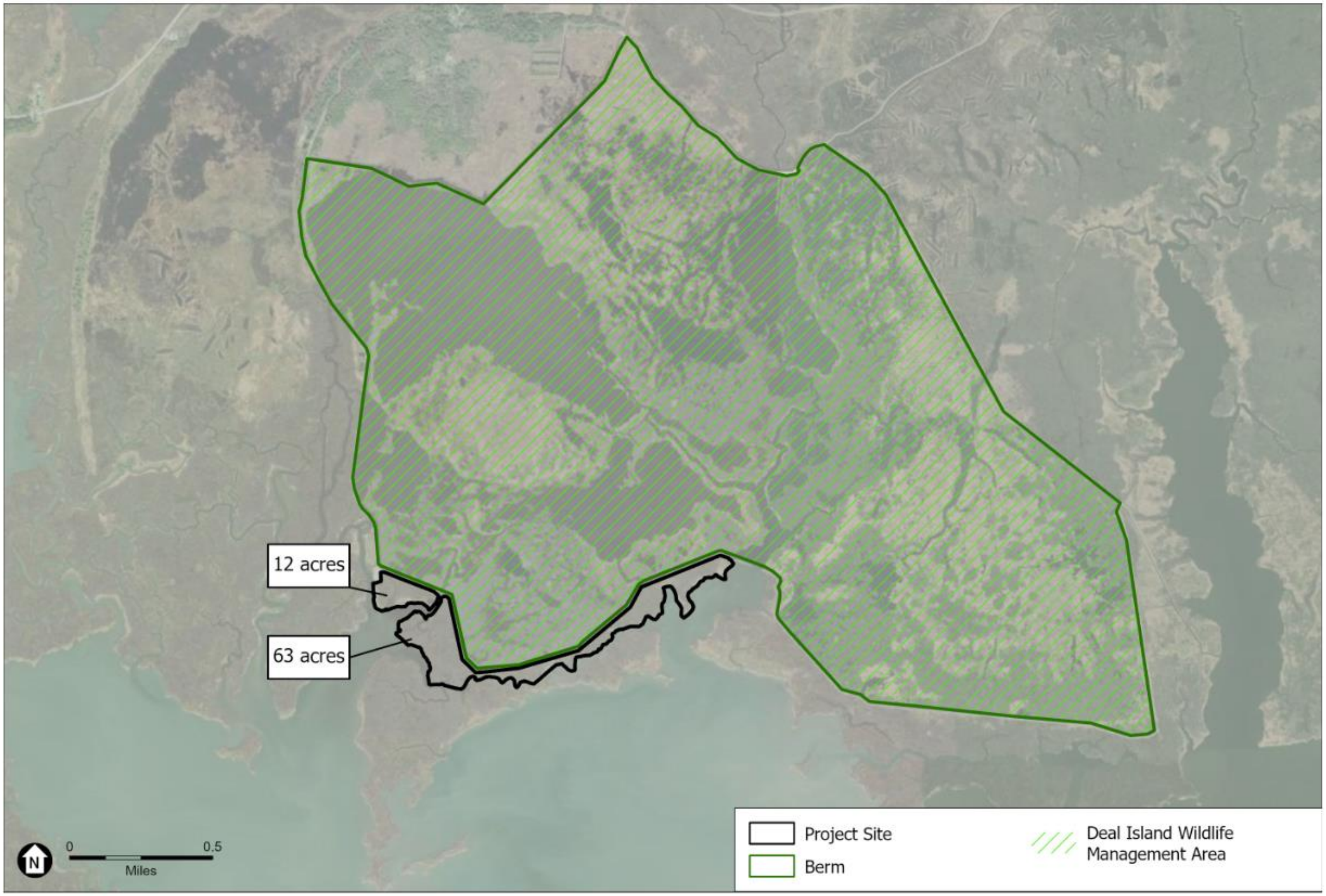
3.1 Deal Island Marsh Restoration

The U.S. Army Corps of Engineers (USACE) conducts regular dredging of Wicomico River but has limited remaining opportunities for upland dredge placement. As a result, they have partnered with MD DNR and Wicomico County to identify a marsh site in need of dredge placement to restore and prevent further loss. The Deal Island Marsh Restoration project involves the placement of an 18-inch layer of dredge material in two areas just south of the Deal Island Wildlife Management Area (WMA; managed by MD DNR) to help the marsh keep up with sea-level rise (**Figure 3-1**). The 75-acre property is divided into two sites: a 12-acre pilot project (Area #1) and the remaining 63-acre marsh (Area #2).

The WMA impoundment berm, built in the 1950s, is 6 ft tall and 100 ft wide. It creates a ponded, managed marsh area behind it which provides habitat for hunting and fishing and serves as a natural refuge for wildlife. The site, which contains estuarine and marine wetland and provides nesting habitat for birds (**Figure 3-2**), is experiencing subsidence and sea-level rise. A new channel has been developing perpendicular to the impoundment berm which is causing further marsh loss. The impoundment berm has been breached (later repaired) during past storms and is vulnerable to further impacts due to sea-level rise. The wetland outside of the berm to the south provides protection to the impoundment berm from erosion and overtopping, but also offers habitat for the saltmarsh sparrow and black rail, whose populations are in sharp decline (Roberts et al 2019). Placement of fill at Deal Island is an opportunity to maintain the marsh habitat south of the WMA, provide protection to the berm, and dispose of dredged materials.

The current project is using straw bales and tidal ditch plugs around the perimeter of the site to contain placed dredged material (**Figure 3-3**). Once the dredge material is placed across the 12-acre and 63-acre sites (expected to be completed by March 1, 2024), planting of a mix of four native species (i.e., *Spartina patens*, *Spartina alterniflora*, *Spartina cynosuroides*, *Distichlis spicata*) at low to high marsh elevations would occur to stabilize the sediments and provide habitat benefits. There are 1.5 million plants expected to be planted in the summer of 2024.

The Wicomico River is dredged approximately every 5-7 years with roughly 50,000 cy of material generated every year (i.e., 350,000 cy of material every 7 years) (correspondence with Danielle Szimanski, USACE). Additional potential placement sites are shown in **Figure 3-4** although construction for the sites in red may be unfeasible.



SOURCE: ESA 2023

Maryland Blue Carbon Resilience Credit Feasibility Study

Figure 3-1
Deal Island Site Map

SOURCE: Wetlands: NWI 2023; ESA 2023

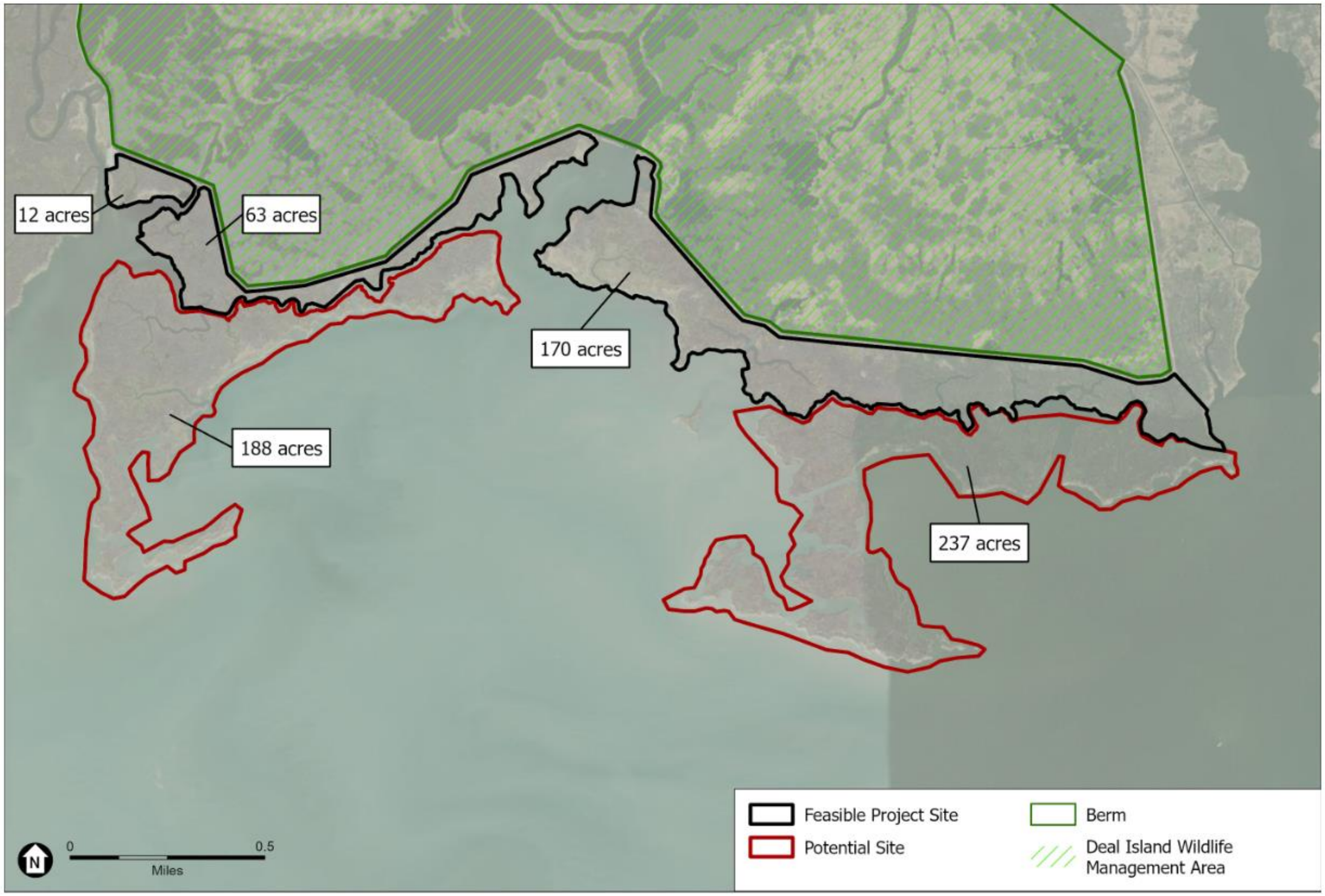
Maryland Blue Carbon Resilience Credit Feasibility Study

Figure 3-2
National Wetland Inventory and SLAMM Habitat Maps for Deal Island Project Site

SOURCE: ESA 2023

Maryland Blue Carbon Resilience Credit Feasibility Study

Figure 3-3
Deal Island 16-acre site Lined with Straw Bales and Preparing for Construction



SOURCE: ESA 2023

Maryland Blue Carbon Resilience Credit Feasibility Study

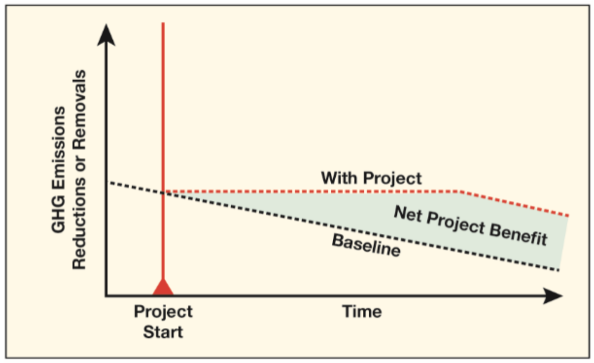
Figure 3-4
Deal Island Potential Dredge Material Placement Sites

3.1.1 Carbon Standard and Technical Feasibility Analysis

3.1.1.1 Scenarios

According to the 2023 Sea-level Rise Projections for Maryland (Boesch et. al. 2023), sea levels are predicted to rise 2.79 ft by 2100[5] (relative to a 1995-2014 average baseline). The marsh south of the Deal Island WMA is rapidly converting from marshland to open water due to rising waters and erosion. Without the marsh acting as a buffer, the WMA is increasingly at risk of flooding.

In the baseline scenario, the existing marsh to the south of the impoundment berm is predicted to be lost over time due to sea-level rise. The impoundment berm is predicted to be overtopped by approximately 2060 to 2100. If the habitat south of the berm converts from irregularly flooded marsh to regularly flooded marsh and estuarine open water, GHG removals and carbon stored in the sediments at the site would decrease over time, as shown in the simplified graphic to the right.



In the with-project scenario, it is assumed that the existing marsh south of the WMA would be filled with dredge material to help the marsh keep pace with sea-level rise. The project scenario assumes that in 2023, the project sites (the 12- and 63-acre areas) would receive 18 inches of fill, or 181,500 cy. Following this initial fill, 350,000 cy of material would be placed every 7 years at the various potential sites (**Table 3-1**). Given the varying site areas, fill depths would range from 10-18 inches.

TABLE 3-1
FILL PLACEMENT ASSUMPTIONS OVER TIME

Year	Acres	Fill (inches)	Fill (cy)
2023	75 (12 + 63)	18	181,500
2030	170	15.3	350,000
2037	188	13.9	350,000
2044	237	11.0	350,000
2051	245 (12 + 63 + 170)	10.6	350,000
2058	188	13.9	350,000
2065	237	11.0	350,000

The site topography was adjusted for these fill placements assuming the fill was placed to the same depth across the site. Under these conditions, the marsh would be maintained longer, providing sequestration for longer and slowing loss of habitat and subsequent soil carbon loss as shown in the graphic above.

5 50% Quantile for the Cambridge tide gauge under the SSP2-4.5 emissions scenario (i.e., only the present national commitments for emissions reductions are met).

3.1.1.2 Applicable Methodology and Additionality

VM0033, Methodology for Tidal Wetland and Seagrass Restoration, applies to this project, as the dredge material placement would help the marshes keep up with sea-level rise, thereby restoring and improving wetland habitat.

Under this methodology, all tidal wetland restoration in the US meets the additionality requirement if the project is in regulatory surplus (i.e., not used for mitigation). Since this is not a mitigation project, it meets the additionality requirement.

3.1.1.3 Carbon Pools and Emissions Sources

Carbon Pools

This analysis considers biomass and sediment carbon. Since most of the habitat is marsh (and not mangrove or other tree habitat), mangrove litter, dead wood, and wood products carbon pools were considered negligible.

Emissions Sources

The Deal Island wetland system is considered mesohaline because porewater salinities at similar, adjacent sites are approximately 11.4 – 15.3 ppt (Derby 2016). As a result, wetland habitats are expected to be a source of methane emissions, and so are considered in this analysis.

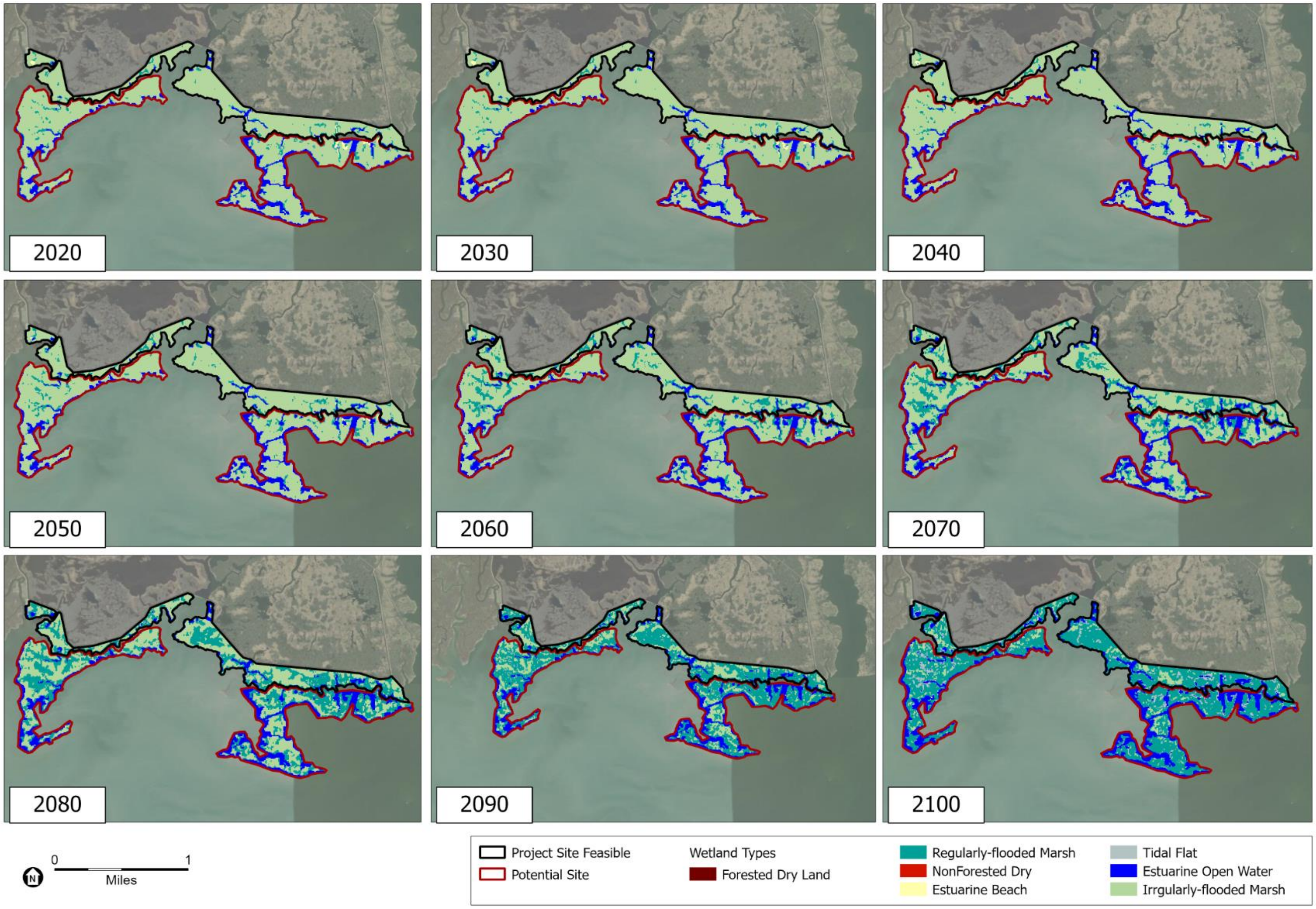
Construction emissions should be quantified in the next phase of analysis when additional data is available. For this project, the emissions associated with the pumps that move the dredged material from the river to the wetland would need to be considered since they would be specific to the restoration project. The emissions associated with the dredging itself may not need to be considered part of the project since the dredging would occur even without the wetland restoration.

3.1.1.4 Project Boundaries

The project boundaries were defined by the limits of the marsh south of the WMA (as shown in **Figure 3-3**) provided by USACE (correspondence with Danielle Szimanski, USACE). Because SLAMM can only model through 2100, this analysis's temporal range is 77 years assuming construction begins in 2023. However, discussion of the project's permeance through 2123 (100 years) is discussed in the following section.

3.1.1.5 Habitat Evolution

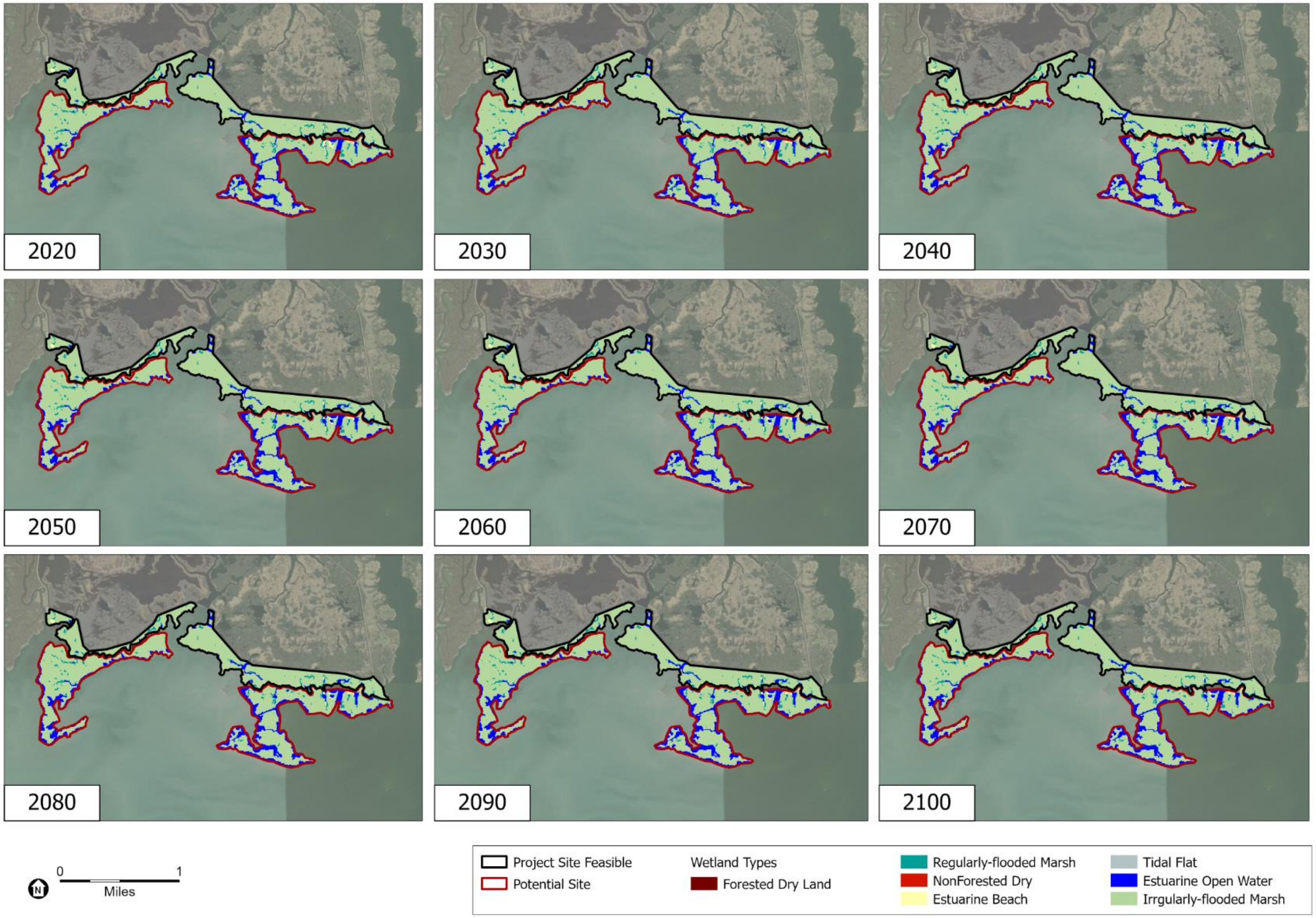
Changes in wetland habitats were modeled to look at the effects of sea-level rise with and without the project (see Section 2.2 for methodology). **Table 3-2** shows the modeled habitat areas for each scenario over time, while **Figures 3-5 and 3-6** show the habitat distribution over time. In the baseline scenario, the existing marsh slowly drowns so that by 2100, the model shows most of the irregularly flooded marsh is lost and converted to regularly flooded marsh or open water. Only 52 acres of irregularly flooded marsh habitat remains (a loss of 90 percent) without the project.



SOURCE: ESA 2023

Maryland Blue Carbon Resilience Credit Feasibility Study

Figure 3-5
Deal Island Baseline Scenario



SOURCE: ESA 2023

Maryland Blue Carbon Resilience Credit Feasibility Study

Figure 3-6
Deal Island Project Scenario

With the project, the model predicts that irregularly flooded marsh will change from 503 acres in 2023 to 488 acres in 2100 (a loss of 3 percent).

TABLE 3-2
ACREAGE OF HABITATS OVER TIME FOR DEAL ISLAND

		2050		2070		2100	
	2023	**Baseline**	**Project**	**Baseline**	**Project**	**Baseline**	**Project**
Forested dry land	0.20	0.20	0.20	0	0	0	0
Transitional salt marsh	0	0	0	0.20	0.20	0	0
Regularly flooded marsh	42	46	30	143	30	383	41
Non-forested dry land	0.40	0.40	0.40	0.17	0.25	0	0.02
Estuarine beach	5.0	2.5	3.6	0.72	3.4	0	3.4
Tidal flat	2.4	0.89	2.0	1.2	1.9	45	1.9
Estuarine open water	117	139	135	159	135	190	136
Irregularly flooded marsh	503	481	499	366	499	52	488
Total	670	670	670	670	670	670	670

3.1.1.6 Project Permanence

While SLAMM only produces results through 2100, the permanence of the irregularly flooded marsh can be roughly estimated by considering the accretion rate, the fill placement height, and the rate of sea-level rise. **Table 3-3** provides an estimate of how long the fill placement would last at the project site assuming an accretion rate of 0.13 in/yr (3.2 mm/yr, the same rate used for the SLAMM runs) and the 50% Growing sea-level rise projections[6]. Around 2110, the relative site elevations (i.e., the elevation relative to sea levels) would be comparable to the relative elevations today (i.e., sea levels would have risen enough to offset the effects of the fill). By 2122, the irregularly flooded marsh would be around 4.1 inches lower than it is today relative to the water[7]. Compared to 2100, the 2122 marsh would be 7.4 inches lower with the project.

6 The WPC (2021) study projections only go through 2100, so the 50% Increasing Emissions scenario from Boesch et al (2023) was used for 2110, 2120, and 2130.

7 In other words, although the marsh is a higher elevation in 2122 compared to 2023, sea-level rise is even higher- by 4.1 inches.

TABLE 3-3
RELATIVE ELEVATION OF IRREGULARLY FLOODED MARSH OVER TIME

Year	Accretion (in)	Change in Sea Level (in)	Fill Placement (in)	Relative Elevation (in)
2023			18	+18
2030	0.9	2.2		+16.7
2037	0.9	2.2		+15.4
2044	0.9	2.8		+13.5
2051	0.9	3.6		+10.8
2058	0.9	3.6	10.6	+18.7
2065	0.9	3.0		+16.6
2072	0.9	3.3		+14.1
2079	0.9	3.3		+11.7
2086	0.9	3.3		+9.3
2093	0.9	3.0		+7.1
2100	0.9	3.6		+3.3
2107	0.9	3.6		+1.7
2114	0.9	3.6		-1.0
2121	0.9	3.6		-3.7
2122	0.1	0.5		-4.1

Assuming no fill is placed (i.e., baseline conditions), irregularly flooded marsh is expected to drop 7.4 inches after 2050. Using the baseline 2050 scenario as a reference, this relative elevation drop corresponds to a loss of 52 acres of irregularly flooded marsh (**Table 3-2**). So by 2123, the project scenario is likely to have lost an addition 52 acres since 2100 and would have 436 acres of irregularly flooded marsh remaining (87% of the original irregularly flooded marsh).

3.1.1.7 Carbon Quantification

Table 3-4 presents the cumulative carbon sequestered over time for the baseline and project scenarios based on the habitat areas in **Table 3-2** and the carbon rates in **Appendix A**. The project would sequester 20,970 tonnes of CO_2 equivalent more than the baseline scenario by 2100. The baseline scenario shows a decrease in sequestration over time, while the project would maintain marsh, and therefore maintain sequestration capabilities longer.

TABLE 3-4
CUMULATIVE CARBON SEQUESTERED FOR DEAL ISLAND OVER TIME (TONNES CO_2 EQUIVALENT)

	Baseline				Project[1]				
	Carbon change in biomass	Carbon sequestered in soil[2]	Methane Emissions	Total[3]	Carbon change in biomass	Carbon sequestered in soil	Methane Emissions	Total[3]	Difference
2020	60	-15,000	15,040	100	60	-15,000	15,040	100	0
2030	40	-15,530	15,040	-450	11	-16,340	15,040	-1,290	-840
2040	90	-12,860	15,040	2,270	111	-12,730	15,040	2,410	140
2050	40	-14,710	15,030	370	29	-15,270	15,040	-200	-570
2060	90	-13,360	15,000	1,730	7	-16,220	15,040	-1,170	-2,900
2070	130	-12,510	14,950	2,570	23	-16,250	15,040	-1,190	-3,750
2080	90	-12,850	14,890	2,130	8	-16,250	15,050	-1,190	-3,330
2090	150	-12,850	14,800	2,100	2	-16,230	15,050	-1,170	-3,260
2100	460	-9,910	14,710	5,250	0	-16,270	15,050	-1,210	-6,460
2110	SLAMM data not available beyond 2100								
2120									
Total									**-20,970**

1. This is for the with-project scenario and includes reoccurring fill at all the potential sites.
2. This includes soil carbon sequestered and emitted through inundation/erosion.
3. Values have been rounded, so adding the first three columns may not total the fourth column.
Note: Negative numbers indicate removals while positive numbers represent emissions

3.1.1.8 Sensitivity and Additional Considerations

The values in Table 3-4 assume a methane emission rate of 0.20 Mg CH_4/ha/yr for irregularly flooded marsh (adjacent to the project area), which is based on Derby et al.'s (2022) locally collected mean emission rate for *S. alterniflora* and 0.19 Mg CH_4/ha/yr for regularly-flooded marsh (Campbell et al. 2020), and estuarine beach and tidal flat (IPCC 2014). If an average of the other reported rates (for *S. patens* and low and high *J. roemerianus*) of 0.89 Mg CH_4/ha/yr is used for the habitat categories listed above, the benefits of the project increase to 21,900 tonnes of CO_2 equivalent. The more conservative estimate (20,970 tonnes of CO_2 equivalent) was used for this feasibility study, but future work could further divide the "irregularly flooded marsh" category to capture the variation in methane emissions between species and elevations. However, it is interesting to note this only resulted in a 3% difference between estimates. Additional studies on the variation by habitat type, including open water would allow for further refinements in the future.

The analysis also assumed that shallow drowned marsh would emit a similar amount of methane as the vegetated marsh, but there may be less methane emitted, especially if there is a strong tidal flow. If the analysis assumed that no methane was emitted from estuarine open water, the project would provide a lower benefit of 17,790 tonnes of CO_2 equivalent. There is high variability in methane emission rates for marshes within the mesohaline salinity range (Poffenbarger et al.

2011), so the benefit provided by the project could range from 17,790 – 21,900 tonnes of CO_2 equivalent due to different methane rates alone.

The project benefit calculation includes benefits for maintaining soil carbon longer than the baseline condition. This assumes that once an area of marsh is inundated, all of the soil carbon is released back into the atmosphere. However, additional research is needed to estimate carbon emissions from eroded/drowned marsh sediments, and it is not clear if all of the carbon would be lost (Warnell et al. 2022, McTigue et al. 2021). If instead the analysis assumed 60% of the soil carbon is lost, the project benefit would be reduced to 4,770 tonnes of CO_2 equivalent.

The analysis assumes that the fill can be placed evenly across the site. However, the dredge material will be piped along the berm and then sprayed over the site, so the material will likely fan out, creating varying elevations across the site. Post-settlement elevation monitoring after the initial project will provide useful information on how fill placement actually impacts the topography at the site and future efforts could use this information to refine the habitat evolution analysis. The initial monitoring framework identifies surface elevation as a monitoring parameter.

This analysis does not consider the impacts of the fill placement on the existing vegetation. The amount of fill that is being considered (10-18 inches) is not considered “thin-layer placement” and would likely bury and kill most of the existing vegetation. The buried biomass could potentially provide a boost in sequestration. The current project proposes planting after the fill has settled, which would offset the impact to the existing vegetation to some extent. However, the analysis does not consider the loss of sequestration capacity that would occur before the vegetation is fully established. The analysis also does not include any changes to emissions/sequestration during the period when the fill is being placed and before revegetation while the fill is settling. Monitoring of emissions during the first fill placement effort would provide valuable information that could be used to refine this feasibility analysis. The initial monitoring framework identifies methane flux as a monitoring parameter but does not clarify the methods.

The analysis is sensitive to sea-level rise as well. If sea levels rise faster than under the 50% growing projection, the wetlands in the baseline scenario would drown out sooner and the fill would provide more of a benefit. Conversely, slower sea-level rise could mean that the baseline provides greater sequestration for a longer period of time and the fill is not as beneficial.

3.1.2 Financial Feasibility

3.1.2.1 Cost assumptions

Table 3-5 illustrates the estimated costs accrued in a 20-year timeframe related to the Deal Island project. The table also indicates whether the cost is incorporated in Scenario 1 (blue carbon market costs only) or 2 (all project costs).

The vast majority (approximately 95%) of the total costs are directly associated with the project's implementation. The implementation cost is estimated based on the project's fill assumptions, with fill placements scheduled every seven years (**Table 3-1**). The initial placement of 181,500 cubic yards (cy) is estimated to incur a cost of approximately $13.5 million (correspondence with Danielle Szimanski, USACE). Dredging of the Wicomico River and placement of the material at upland sites has historically cost between $3 - $4 million (ibid.). Since the USACE conducts dredging of the river independent of whether restoration is implemented or not, this cost has been deducted from the total implementation cost of the project. Consequently, the initial placement of 181,500 cy is estimated to cost ~$10.5 million, with subsequent efforts involving 350,000 cy estimated at approximately $23 million (calculated proportionally). Further details on the implementation cost incurred through fill placements are available in Table B-1 in **Appendix B**.

Detailed definitions and assumptions of all cost components can be found in Table B-4 in **Appendix B**.

TABLE 3-5
TOTAL PROJECT COSTS FOR DEAL ISLAND RELATED TO A 20-YEAR TIMEFRAME

Cost estimates (USD)	NPV	Scenario
Capital expenditure (CAPEX)	**$36,141,000**	
Feasibility analysis	$ 50,000	2
Conservation planning and admin	$ 311,000	2
Data collection and field costs	$ 144,000	2
Community representation / liaison	$ 173,000	2
Blue carbon project planning	$ 44,000	1 and 2
Establishing carbon rights	$ 90,000	1 and 2
Validation	$ 22,000	1 and 2
Implementation labor	$35,307,000	2
Operating expenditure (OPEX)	**$ 1,539,000**	
Maintenance	$ 604,000	2
Monitoring	$ -	2
Community benefit sharing fund	$ -	2
Carbon standard fees	$ 200	1 and 2
Baseline reassessment	$ 38,000	1 and 2
MRV[8]	$ 112,000	1 and 2
Long-term project operating	$ 785,000	2
Total cost	**$37,680,000**	
Total carbon market costs	**$ 306,000**	

Note: Scenario 1 is costs required for just the blue carbon market, while Scenario 2 includes costs for project implementation as well.

8 The costs associated with measuring, reporting, and verifying GHG emissions that occur post-implementation to enable carbon benefit sales through a third party.

3.1.2.2 Results

As discussed in Section 2.2, two scenarios were modelled: (1) incorporating only the costs related to establishing the carbon credits to evaluate if bringing the project to the market would be financially feasible, and (2) incorporating all project costs to determine how blue carbon revenues could contribute to project funding. The results are summarized in **Table 3-6** and **Table 3-7** below. The carbon offsets were calculated for the first 20 years of the project and include a 20% buffer to account for uncertainties and ensure the integrity of the carbon credits.

Looking at a 20-year timeframe and modeling three carbon prices ($20, $50 and $100/tCO2e), carbon revenues do not cover the costs for either scenario 1 or 2. This is largely due to the bulk of the carbon reduction benefits arriving later in the 21st century and the overall benefits being relatively small. The scenario with all project costs included (Scenario 2) shows a large funding gap, mainly resulting from the high implementation costs. The breakeven price for the costs associated with the carbon credits is ~$690/tCO2e, and the breakeven price for all project costs is ~$87,000/tCO2e. Therefore, Deal Island is not expected to be financially feasible during the 20-year time frame. The next section provides a discussion of how a longer timeframe affects the results of this analysis.

TABLE 3-6
SUMMARY OF FINANCIAL ANALYSIS RELATED TO DEAL ISLAND FOR SCENARIO 1 FOR A 20-YEAR TIMEFRAME

Scenario 1 – Only carbon market costs, 20-year timeframe	**Carbon price ($/tCO2e)**		
	$20	**$50**	**$100**
Carbon offsets	539	539	539
Carbon price in 2023	$20	$50	$100
Carbon price in 2043	$32	$80	$160
Carbon revenues (NPV)	$9,000	$22,000	$44,000
Costs (NPV)	$306,000	$306,000	$306,000
Net earnings (Revenue – Costs) (NPV)	**-$298,000**	**-$284,000**	**-$262,000**

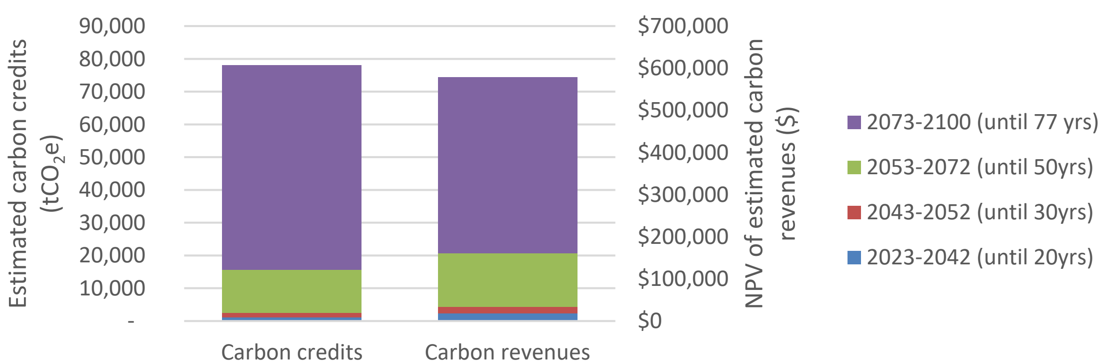
TABLE 3-7
SUMMARY OF FINANCIAL ANALYSIS RELATED TO DEAL ISLAND FOR SCENARIO 2 FOR A 20-YEAR TIMEFRAME

Scenario 2 – All project costs, 20-year timeframe	Carbon price ($/tCO2e)		
	$20	$50	$100
Carbon offsets	539	539	539
Carbon price in 2023	$20	$50	$100
Carbon price in 2043	$32	$80	$160
Carbon revenues (NPV)	$9,000	$22,000	$44,000
Costs (NPV)	$37,680,000	$37,680,000	$37,680,000
Net earnings (Revenue – Costs) (NPV)	**-$37,673,000**	**-$37,660,000**	**-$37,638,000**

3.1.2.3 Sensitivity analysis

A breakeven price analysis for the two scenarios was conducted to assess the significance of the chosen timeframe's impact on the financials for Deal Island, as outlined in **Table 3-8**In Scenario 1, when only the carbon market costs (CAPEX AND OPEX) are considered, the breakeven price is estimated to be $690/tCO2e over a 20-year period. However, the breakeven price would decrease significantly to approximately $43/tCO2e if the analysis period is extended to 2100. When only considering the OPEX carbon market costs, which include baseline reassessment, measuring, reporting, and verifying (MRV), and carbon standard fees, the breakeven price decreases from $340/tCO2e in a 20-year timeframe to $21/tCO2e in a 77-year timeframe (through 2100) (refer to **Table 3-8**).

Table . This analysis looks at both the Operating expenditure (OPEX) breakeven price and the total cost breakeven price, which encompasses both OPEX and capital expenditures (CAPEX). **Figure 3-7** shows how more carbon credits are generated towards the end of the century and the longer time frames capture more of the financial benefit.



SOURCE: TNC 2023

Maryland Blue Carbon Resilience Credit Feasibility Study

Figure 3-7
Cumulative Carbon Credits and Related Carbon Revenues by Length of Project

In Scenario 1, when only the carbon market costs (CAPEX AND OPEX) are considered, the breakeven price is estimated to be \$690/tCO_2e over a 20-year period. However, the breakeven price would decrease significantly to approximately \$43/tCO_2e if the analysis period is extended to 2100. When only considering the OPEX carbon market costs, which include baseline reassessment, measuring, reporting, and verifying (MRV), and carbon standard fees, the breakeven price decreases from \$340/tCO_2e in a 20-year timeframe to \$21/tCO_2e in a 77-year timeframe (through 2100) (refer to **Table 3-8**).

TABLE 3-8
DEAL ISLAND BREAKEVEN PRICES FOR THE TWO SCENARIOS

Deal Island		Total OPEX and CAPEX cost breakeven price (in \$/tCO2e)	OPEX breakeven price (in \$/tCO2e)
Scenario 1 Carbon market costs only	20-year timeframe	\$690	\$340
	30-year timeframe	\$327	\$160
	50-year timeframe	\$84	\$41
	77-year timeframe (until 2100)	\$43	\$21

Looking at it another way, **Table 3-9** presents the timelines at which carbon revenues exceed the considered costs for carbon prices of \$20, \$50 and \$100/tCO2e in the two scenarios for Deal Island.

TABLE 3-9
BREAKEVEN TIMELINE FOR CARBON PRICES OF \$20, \$50 AND \$100/TCO2E

Deal Island		Total OPEX and CAPEX breakeven timeline	OPEX breakeven timeframe
Scenario 1 Carbon market costs only	\$20/tCO2e	N/A	N/A
	\$50/tCO2e	71 years	45 years
	\$100/tCO2e	46 years	34 years

Note: "N/A" indicates that no breakeven timeframe was found, considering the latest projection reaching up to the year 2100.

3.1.2.4 Financial Feasibility Conclusion

Setting up a blue carbon market project for Deal Island would only be financially feasible when considering a longer timeframe and higher carbon prices. For example, a carbon price of \$50/tCO2e would take 71 years before the carbon revenues would offset the costs related to setting up a carbon market project. It is unlikely that carbon prices will reach a price that would offset the full cost of the project in this century. As a result, the Deal Island project is likely not financially feasible.

3.1.3 Organizational Feasibility

The project site is a part of MD DNR's public land system and is managed by the Wildlife and Heritage Service. Funding for the maintenance of the WMA comes from the US Fish and Wildlife Service.

The Wicomico River navigational channel is Federally maintained by USACE and Wicomico County is the local sponsor of the channel maintenance dredging.

Post-construction monitoring will be conducted by MD DNR, NOAA's National Centers for Coastal Ocean Science (NCCOS), Audubon Mid-Atlantic, and Deal Island Peninsula Partnership (DIPP), with monitoring costs split among agencies.

3.1.4 Social Considerations

The project site and wildlife management area are located within the boundaries of Dames Quarter, a census-designated place (CDP) in northern Somerset County. The nearest populated towns include Deal Island and Chance to the west, and Dames Quarter to the north. The U.S. Census Bureau's most recent estimates from 2021 show a population of 279 for Deal Island, 142 for Dames Quarter, and 244 for Chance. The towns include lower-density residential (single-family homes) with some retail and civic facilities, however, the majority of the land is natural/conservation area and designated for long-term conservation.

Within Dames Quarter and Deal Island, vulnerable populations include lower-income, seniors (age 65+), and individuals with less than a high school education. Measures for health indicators show higher levels of heart disease, cancer, and asthma compared to the state, and lower average life expectancy. Additionally, both CDPs have low rates for broadband access and health insurance, which represent service gaps. While this is more common for rural areas like Dames Quarter and Deal Island, it does increase vulnerability for individuals to access appropriate and timely care, particularly for the area's high flooding risk. There are 261 households within Deal Island and Dames Quarter, all of which are vulnerable to damage and inundation from projected sea-level rise and flooding hazards.

In regard to environmental indicators, a preliminary review showed relatively low levels of pollution (relative to the state), with the highest pollution concentrations attributed to lead, wastewater discharge, and ozone.

Deal Island serves as a significant recreation area for the communities - the state's Department of Natural Resources identifies this site as one of the best places in Maryland for wildlife watching, photography, and hunting, particularly for ducks and geese that inhabit the marsh. The Maryland Ornithological Society's local chapter, Tri-County Bird Club, regularly offers field trips and guest-speaker meetings on the WMA, which are free to the public.

North of the WMA, there are recreation areas for camping, boat launch ramps, trails for hikers and bicyclists, and water trails for paddlers (vehicles are not allowed onsite). It is open to the public year-round for recreation, with hunting restrictions in accordance with open seasons.

While the dredge fill placement would increase emissions in the area during the duration of construction, the fill of the marsh habitat would provide benefits for longer. The long-term maintenance and upkeep of the marsh for wildlife habitat, carbon sequestration, and recreation (hunting and fishing) provide long-term benefits to the nearby communities of Dames Quarter and Deal Island, notably for benefits to pollution for water quality. Without the project, the site would lose carbon sequestration potential and become unstable or unusable for recreation activities as it would be regularly flooded marsh or open water.

3.2 Maryland Coastal Bays Marsh Restoration

The Maryland Coastal Bays Marsh Restoration project, a partnership among Maryland Coastal Bays Program, U.S. Fish and Wildlife Service, and Audubon, aims to restore and protect marshland habitat to both create and stabilize saltmarsh sparrow habitat. The marshes in this area were historically grid ditched to reduce mosquito populations, with the excavated material sidecast along the ditches. Then when the tides came in, the ditches would overflow and sediment would drop out on top of the sidecast material, building up berms along the ditches (similar to the processes that build natural berms along rivers). As a result, the network of ditches and berms formed rectangular areas of bermed-off marsh. While high tides still overtop into these areas, the water can no longer drain out at low tide, so the water ponds and eventually evaporates, drowning out the marsh vegetation and/or creating salt pan conditions that kill most of the vegetation.

There are currently 8 project sites on privately-owned properties and 1 owned by Worcester County (**Figure 3-8** and **Table 3-10**). The projects are in various stages, with some currently funded with conceptual designs and others at the beginning of the design process. There is a total of 1,314 acres: 174 acres in the implementation phase and 1,140 acres awaiting funding for design and implementation. The sites mostly contain regularly flooded marsh and irregularly flooded marsh (**Figure 3-9**).

TABLE 3-10
PROJECT SITE ACREAGES

Site	Project Activities	Area (ac)	Status
Stark-Bliss Happens Ln.	Runneling, some nourishment	25	Survey and design completed
Croppers Island	Nourishment, creation of freshwater marsh	114	Survey and design completed
Stark-Langmaid Rd.	Nourishment, runneling, planting	35	Survey and design completed
Marsh Harbor	Nourishment, runneling, planting, installation of berm	20	Not yet funded
Bay Creek LLC	Nourishment, runneling, planting	473	Not yet funded
Horner	Nourishment, runneling, planting	225	Not yet funded
Worcester County	Nourishment, runneling, planting	187	Not yet funded
Smithson	Nourishment, runneling, planting, living shoreline	84	Not yet funded
Tizzard Island	Nourishment, runneling, planting, living shoreline	151	Not yet funded

Anticipated project activities include cutting runnels (mini-ditches) through the berms to allow for drainage at low tide, filling the subsided interiors of the bermed-off marsh areas, and in a few cases, construction of erosion control features such as a berm or living shoreline. This study focuses on the fill used for these projects although runneling is considered a cost-effective method for improving these systems (but is challenging to model with SLAMM due to the fine scale of the excavation work).

SOURCE: ESA 2023

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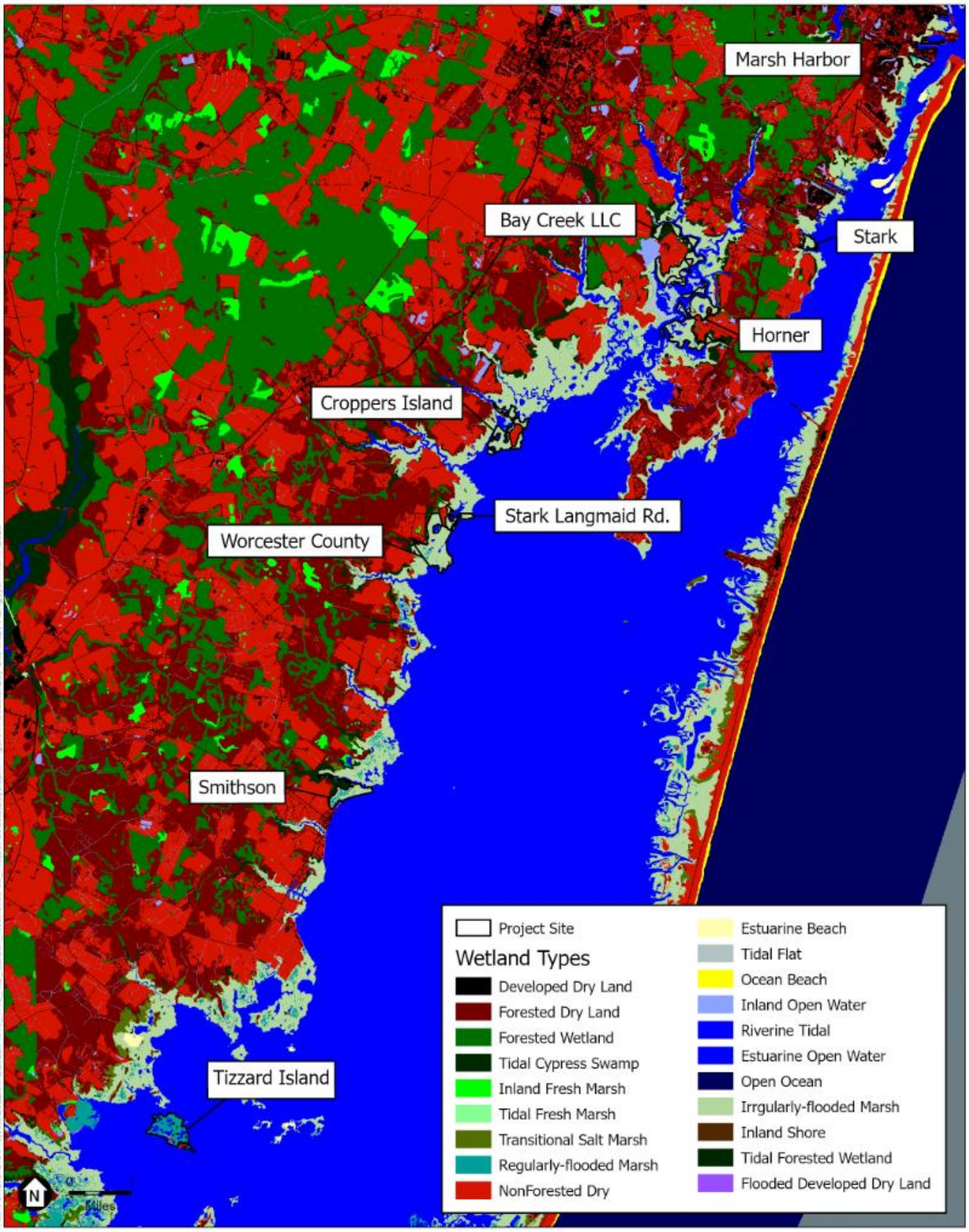
Figure 3-8
Coastal Bays Site Map



SOURCE: ESA 2023

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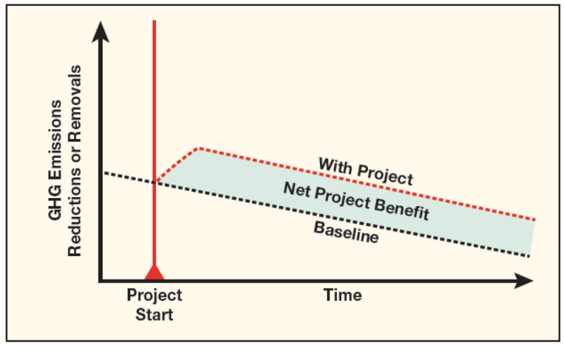
Figure 3-9
Coastal Bays SLAMM Habitat Map

3.2.1 Carbon Standard and Technical Feasibility Analysis

3.2.1.1 Scenarios

In the baseline scenario, the existing marsh would continue to convert to salt pan or open water and would eventually drown over time with sea-level rise. As the habitat converts from irregularly flooded marsh to regularly flooded marsh and estuarine open water, GHG removals at the site would decrease over time and there would be a loss of stored carbon, as shown in the simplified graphic to the right.



In the with-project scenario, it is assumed that the ponded areas would be filled with dredge material to help the marsh keep pace with sea-level rise and reduce the drainage issue. The project scenario assumes that around 2020, the project sites would receive fill as shown in **Table 3-10**. Section 3.1.1.8 provides more details on how this fill was estimated and the differences between these estimates and those made by the Coastal Bays Program.

The site topography was adjusted for these fill placements assuming the fill was placed at the same elevation across the site (i.e., so any area below a certain elevation received fill). The elevations for each site (**Table 3-11**) were chosen based on the surrounding topography. Under the fill conditions, the marsh would be maintained longer, providing sequestration for longer and slowing loss of habitat and subsequent soil carbon loss as shown in the graphic above.

TABLE 3-11
FILL PLACEMENT ASSUMPTIONS

Site	Fill elevation (ft NAVD88)	Fill used in modeling (cy)	Fill estimated by Coastal Bays Program (cy)
Stark-Bliss Happens Ln.	0.34	28,837	700
Tizzard Island	0.66	2,575	54,000 – 84,000
Smithson	0.10	1,339	30,000 – 45,000
Marsh Harbor	0.36	17,941	37,000
Bay Creek LLC	0.82		168,000 – 218,000
Horner		338,204	80,000 – 105,000
Worcester County	2.30		66,000 – 86,000
Stark Langmaid Rd.	0.66		8,500
Croppers Island	0.59	435,142	35,000

3.2.1.2 Applicable Methodology and Additionality

VM0033, Methodology for Tidal Wetland and Seagrass Restoration, applies to this project, as the dredge material placement would help the marshes keep up with sea-level rise and reduce drainage problems, thereby restoring and improving wetland habitat.

Under this methodology, all tidal wetland restoration in the US meets the additionality requirement if the project is in regulatory surplus (i.e., not used for mitigation). Since this is not a mitigation project, it meets the additionality requirement.

3.2.1.3 Carbon Pools and Emissions Sources

Carbon Pools

This analysis considers biomass and soil carbon. Since most of the habitat is marsh (and not mangrove or other tree habitat), mangrove litter, dead wood, and wood products carbon pools were considered negligible.

Emissions Sources

The Coastal Bays wetland system is considered polyhaline because salinities are greater than 18 ppt. As a result, the wetland habitats are expected to emit little to no methane.

Construction emissions should be quantified in the next phase of analysis when additional data is available. For this project, the emissions associated with the equipment that moves the fill material from surrounding areas to the wetland would need to be considered. However, most sites have identified fill material supplies from adjacent properties which is expected to keep construction emissions fairly minimal when compared to larger projects such as Deal Island (Section 3.1).

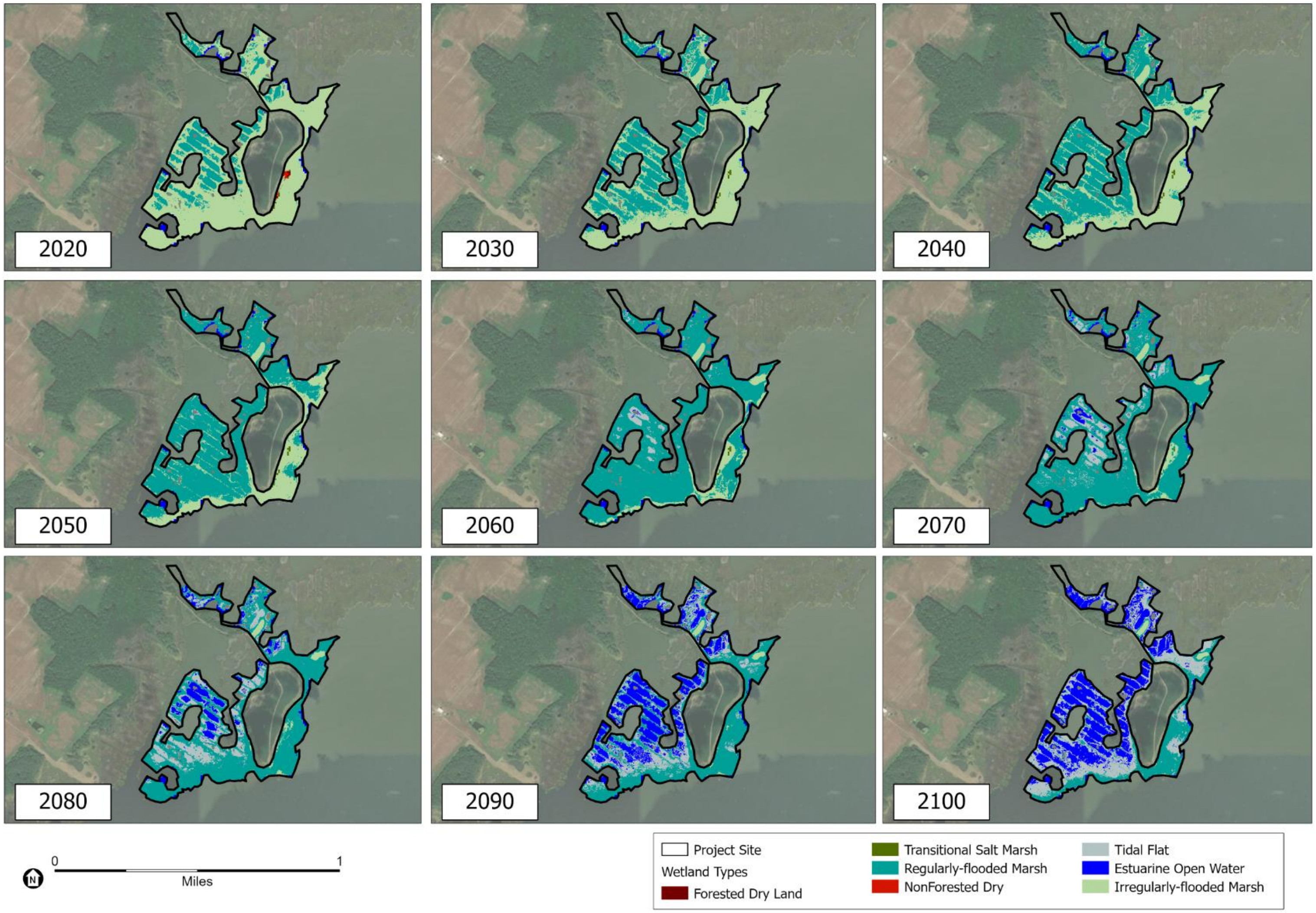
3.2.1.4 Project Boundaries

The project boundaries were defined by shapefiles provided by the Maryland Coastal Bays Program (correspondence with Rich Mason). Because SLAMM output ends at 2100, this analysis’s temporal range is 77 years assuming construction begins in 2023. However, discussion of the project’s permeance through 2123 (100 years) is included in the following section.

3.2.1.5 Habitat Evolution

Changes in wetland habitats were modeled to look at the effects of sea-level rise with and without the project (see Section 2.2 for methodology). **Table 3-12** shows the modeled habitat areas for each scenario over time, while **Figures 3-10 and 3-11** show the habitat distribution over time for Croppers Island. Figures for the rest of the sites are included in Appendix D.

Considering all of the sites together under the baseline scenario, the existing marsh slowly drowns so that by 2100, the model shows most of the irregularly flooded marsh is lost (98 percent) and converted to regularly flooded marsh or open water and only 134 acres of regularly flooded marsh remain (a loss of 45 percent). With the project, the model predicts that irregularly flooded marsh will also be lost (98 percent) but that project will help maintain 201 acres of regularly flooded marsh (a loss of only 17 percent).



SOURCE: ESA 2023

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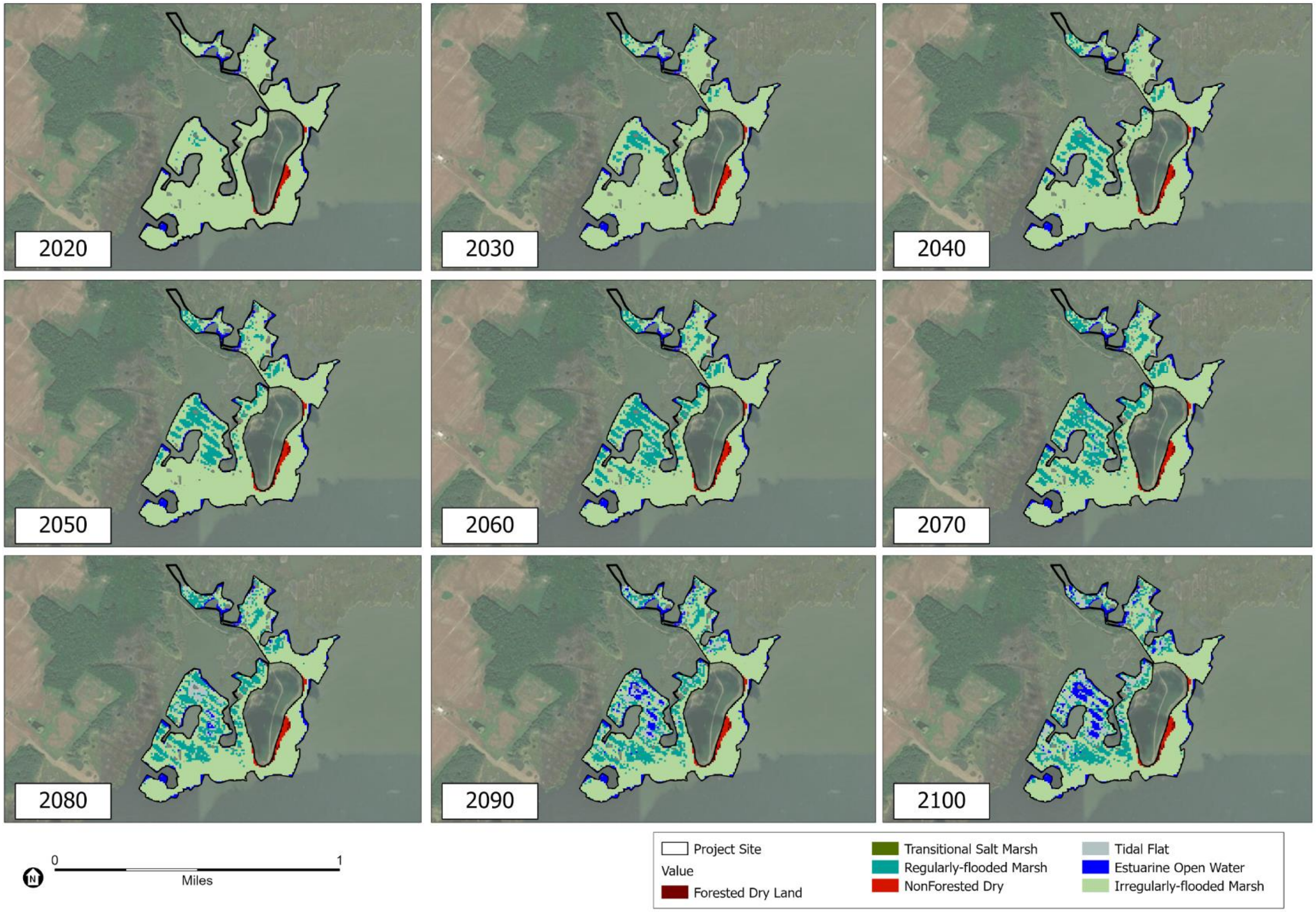
Figure 3-10
Croppers Island Baseline Scenario



SOURCE: ESA 2023

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Figure 3-11
Croppers Island Project Scenario

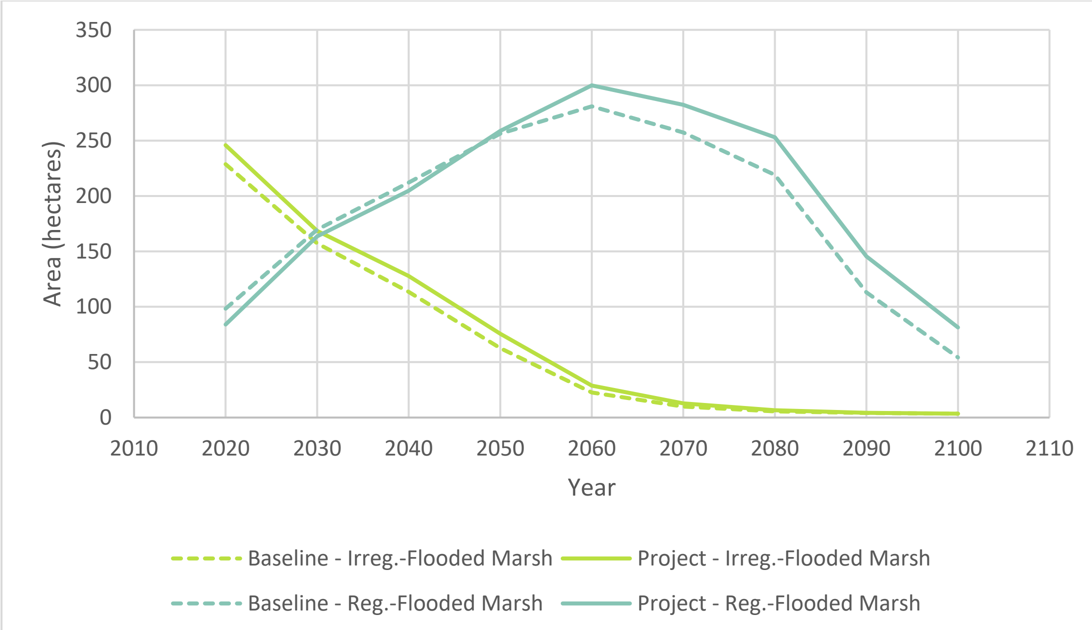
TABLE 3-12
ACREAGE OF HABITATS OVER TIME FOR ALL COASTAL BAYS SITES

		2050		2070		2100	
	2023	**Baseline**	**Project**	**Baseline**	**Project**	**Baseline**	**Project**
Developed dry land	0.26	0.26	0.26	0.26	0.26	0.24	0.24
Forested dry land	5.3	2.8	2.8	2.1	2.1	1.1	1.1
Transitional salt marsh	3.2	2.7	2.8	1.2	1.2	0.7	0.7
Regularly flooded marsh	243	633	639	636	698	134	201
Non-forested dry land	3.9	1.7	1.7	1.1	1.1	0.74	0.74
Estuarine beach	0.07	0.05	0.07	0.04	0.07	0	0.07
Tidal flat	13	30	5.1	109	96	230	203
Inland open water	0.02	0	0	0	0	0	0
Estuarine open water	63	81	66	144	89	546	506
Irregularly flooded marsh	565	155	187	24	32	8.6	8.7
Tidal forested wetland	27	16	18	4.5	4.8	1.6	1.6
Flooded developed dry land	0	0	0	0	0	0.02	0
Total	923	923	923	923	923	923	923

3.2.1.6 Project Permanence

While SLAMM only produces results through 2100, the permanence of the irregularly flooded marsh can be roughly estimated using **Figure 3-12**. By 2100, irregularly flooded marsh is below 9 acres for both the baseline and project conditions as this higher marsh converts to regularly flooded marsh (**Table 3-12**). Due to the fill, the project conditions maintain 67 acres more regularly flooded marsh than the baseline conditions (**Table 3-12**).

Using the rate of change of regularly flooded marsh between 2090 and 2100, the marsh is expected to drown out before 2110 for the baseline conditions and around 2115 for project conditions. As a result, the project permanence requirement (i.e., maintenance for 100 years) is not likely to be met without additional fill placements after the initial project. The analysis in this study only includes the initial fill placement but future studies could evaluate when and how much additional fill may be needed to achieve project permanence.



SOURCE: ESA 2023

Maryland Blue Carbon Resilience Credit Feasibility Study

Figure 3-12
Marsh Over Time at Coastal Bays

3.2.1.7 Carbon Quantification

Table 3-13 presents the cumulative carbon sequestered over time for the baseline and project scenarios based on the habitat areas in **Table 3-12** and the carbon rates in **Appendix A**. The project would sequester 25,000 tonnes of CO_2 equivalent more than the baseline scenario by 2100. The baseline scenario shows a decrease in sequestration over time, while the project would maintain marsh, and therefore maintain sequestration capabilities, longer. However, the results also show that credits are lost towards the end of the century. While 34,000 tonnes of CO_2 equivalent are created by 2090, some of these credits are not permanent and are lost in 2100 and expected to be lost into the future.

TABLE 3-13
CUMULATIVE CARBON SEQUESTERED FOR COASTAL BAYS OVER TIME (TONNES CO_2 EQUIVALENT)

	Baseline				Project				
	Carbon change in biomass	Carbon sequestered in soil[1]	Methane Emissions	Total[2]	Carbon change in biomass	Carbon sequestered in soil[2]	Methane Emissions	Total[2]	Difference
2020	0	0	0	0	-150	0	0	-150	-150
2030	1,470	-22,460	880	-20,110	1,370	-25,610	880	-23,340	-3,230
2040	1,330	-24,740	880	-22,540	1,030	-25,510	880	-23,600	-1,060
2050	2,900	-22,900	880	-19,120	2,040	-24,970	880	-22,060	-2,940
2060	4,110	-16,620	880	-11,620	2,860	-24,770	880	-21,030	-9,410
2070	2,390	-10,470	890	-7,190	4,290	-18,010	890	-12,840	-5,660
2080	1,770	6,070	890	8,730	1,670	2,220	890	4,780	-3,960
2090	2,980	20,350	890	24,220	3,040	12,700	890	16,630	-7,600
2100	1,660	54,860	890	57,400	1,810	63,670	890	66,370	8,960
2110	SLAMM data not available beyond 2100								
2120									
Total									25,030

1. This includes soil carbon sequestered and emitted through inundation/erosion.
2. Values have been rounded, so adding the first three columns may not total the fourth column.
Note: Negative numbers indicated removals while positive numbers represent emissions.

3.2.1.8 Sensitivity and Additional Considerations

The analysis assumes that the fill would be placed in deeper areas across each site. To simplify the data processing across the 9 sites, one elevation was chosen for each site and any areas below that elevation were filled up to that elevation. However, the fill material will likely be placed using a more targeted method. As a result, carbon estimates may be under or overestimated depending on the final design. Future work could replicate this analysis using surfaces developed as part of the project design once the projects are further developed.

The analysis is sensitive to sea-level rise as well. If sea levels rise faster than under the 50% Growing projection, the wetlands in the baseline scenario would drown out sooner and the fill would provide more of a benefit. Conversely, slower sea-level rise could mean that the baseline provides greater sequestration for a longer period of time and the fill is not as beneficial.

3.2.2 Financial Feasibility

3.2.2.1 Cost assumptions

Table 3-14 illustrates the estimated costs accrued in a 20-year timeframe related to the Coastal Bays project. The table also indicates whether the cost is incorporated in Scenario 1 (blue carbon market costs only) or 2 (all project costs).

The vast majority (approximately 92%) of the total costs are directly associated with the project's implementation. The **implementation cost** was estimated through a two-step process. The first step calculated the unit costs for fill (cost / cy) and planting (cost / acre) based on the three sites with complete design plans and costs (Stark-Bliss Happens Ln., Croppers Island, Stark-Langmaid Rd) as shown in Table B-2 in **Appendix B**. Based on these projects and ESA's engineering judgement, fill placement costs were estimated at $18/ cy, and planting costs were estimated at ~$14,064 / acre. Additionally, a 10% mobilization cost to get contractors to the site and wrapped up was assumed. These costs were then used to estimate the total implementation cost for all sites (see Table B-3 in **Appendix B**). The implementation costs for the original three sites, Stark, Croppers Island and Stark Langmaid Rd., were re-estimated based on the assumptions used in **Table 3-11** and the estimated unit costs.

Detailed definitions and assumptions of all cost components can be found in Table B-4 *Error! Reference source not found.*in **Appendix B**).

TABLE 3-14
TOTAL PROJECT COSTS FOR COASTAL BAYS RELATED TO A 20-YEAR TIMEFRAME

Cost estimates (USD)	NPV	Scenario
Capital expenditure (CAPEX)	**$33,737,000**	
Feasibility analysis	$ 50,000	2
Conservation planning and admin	$ 311,000	2
Data collection and field costs	$ 144,000	2
Community representation / liaison	$ 173,000	2
Blue carbon project planning	$ 44,000	1 and 2
Establishing carbon rights	$ 90,000	1 and 2
Validation	$ 22,000	1 and 2
Implementation labor	$32,903,000	2
Operating expenditure (OPEX)	**$ 2,140,000**	
Maintenance	$ 604,000	2
Monitoring	$ 600,000	2
Community benefit sharing fund	$ -	2
Carbon standard fees	$ 1,000	1 and 2
Baseline reassessment	$ 38,000	1 and 2
MRV[9]	$ 112,000	1 and 2
Long-term project operating	$ 785,000	2
Total cost	**$35,877,000**	
Total carbon market costs	**$ 307,000**	

Note: Scenario 1 is costs required for just the blue carbon market, while Scenario 2 includes costs for project implementation as well.

9 The costs associated with measuring, reporting, and verifying GHG emissions that occur post-implementation to enable carbon benefit sales through a third party.

3.2.2.2 Results

As discussed in Section 2.2, two scenarios were modeled and are presented in **Table 3-15** and **Table 3-16** below. The carbon offsets were calculated for the first 20 years of the project and include a 20% buffer to account for uncertainties and ensure the integrity of the carbon credits.

Similar to Deal Island, the majority of carbon reduction benefits are expected to be generated in the later part of the 21st century. However, when considering the 20-year timeframe, Coastal Bays generates ~7 times the total carbon credit benefits (tonnes CO_2 equivalent) or almost ~3.5 times the carbon credit benefits per hectare when compared to Deal Island.

For a 20-year timeframe and three different carbon prices: \$20, \$50, and \$100 per tCO_2e, the analysis indicates that the costs associated with the carbon markets cannot be covered with up to a \$100/tCO_2e carbon price. The breakeven price required to offset the costs to develop the carbon credits is approximately \$107/tCO_2e.

In Scenario 2, where all project costs are considered, a substantial funding gap remains for all carbon prices. This can primarily be attributed to the high implementation costs. To cover all project expenses in Scenario 2, the breakeven price for carbon would need to be approximately \$12,400/tCO_2e.

TABLE 3-15
SUMMARY OF FINANCIAL ANALYSIS RELATED TO COASTAL BAYS FOR SCENARIO 1 FOR A 20-YEAR TIMEFRAME

Only carbon costs (scenario 1) 20-year timeframe	**Carbon price (\$/tCO2e)**		
	\$20	**\$50**	**\$100**
Carbon offsets	~3,600	~3,600	~3,600
Carbon price in 2023	\$20	\$50	\$100
Carbon price in 2043	\$32	\$80	\$160
Carbon revenues (NPV)	\$58,000	\$144,000	\$288,000
Costs (NPV)	\$307,000	\$307,000	\$307,000
Net earnings (Revenue – Costs) (NPV)	-\$249,000	-\$163,000	-\$19,000

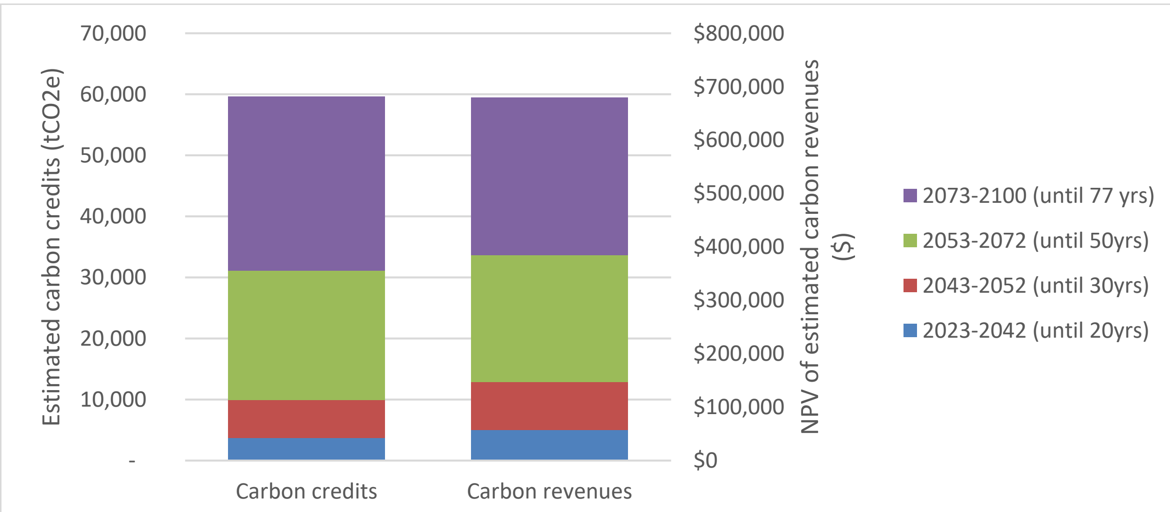
TABLE 3-16
SUMMARY OF FINANCIAL ANALYSIS RELATED TO COASTAL BAYS FOR SCENARIO 2 FOR A 20-YEAR TIMEFRAME

All project costs (scenario 2) 20-year timeframe	**Carbon price (\$/tCO2e)**		
	\$20	**\$50**	**\$100**
Carbon offsets	~3,600	~3,600	~3,600
Carbon price in 2023	\$20	\$50	\$100
Carbon price in 2043	\$32	\$80	\$160
Carbon revenues (NPV)	\$58,000	\$144,000	\$288,000
Costs (NPV)	\$35,877,000	\$35,877,000	\$35,877,000
Net earnings (Revenue – Costs) (NPV)	**-\$35,819,000**	**-\$35, 733,000**	**-\$35,589,000**

3.2.2.3 Sensitivity analysis

A breakeven price analysis for the two scenarios was conducted to assess the significance of the chosen timeframe's impact on the financials for Coastal Bays, as outlined in **Table 3-17**. **Figure 3-13** shows how more carbon credits are generated towards the end of the century and the longer time frames capture more of the financial benefit.

In Scenario 1, when only carbon market costs (CAPEX AND OPEX) are considered, the breakeven price is \$107/tCO_2e over a 20-year period and \$21/tCO_2e over a 77-year period (through 2100). When only considering the OPEX carbon market costs, which include baseline reassessment, MRV, and carbon standard fees, the breakeven price decreases from \$53/ tCO_2e in a 20-year timeframe to \$10/tCO_2e in a 77-year timeframe (**Table 3-17**).



SOURCE: ESA 2023

Maryland Blue Carbon Resilience Credit Feasibility Study

Figure 3-13
Cumulative Carbon Credits and Carbon Revenues Over Time

TABLE 3-17
COASTAL BAYS BREAKEVEN PRICES FOR DIFFERENT TIMEFRAMES

Coastal Bays		OPEX and CAPEX breakeven price (in \$/tCO2e)	OPEX Only breakeven price (in \$/tCO2e)
Scenario 1 Carbon market costs only	20-year timeframe	\$107	\$53
	30-year timeframe	\$69	\$34
	50-year timeframe	\$26	\$13
	77-year timeframe (until 2100)	\$21	\$10

Looking at it another way, **Table 3-18** provides a detailed overview of the timelines when carbon revenues surpass the associated costs in Coastal Bays, under varying carbon prices (\$20, \$50, and \$100/tCO2e) for each scenario.

TABLE 3-18

BREAKEVEN TIMELINE FOR CARBON PRICES OF $20, $50 AND $100/TCO2E

Coastal Bays		OPEX and CAPEX breakeven price	OPEX Only breakeven price
Scenario 1 Carbon market costs only	$20/tCO2e	N/A	37 years
	$50/tCO2e	34 years	21 years
	$100/tCO2e	22 years	8 years

Note: "N/A" indicates that no breakeven timeframe was found, considering the latest projection reaching up to the year 2100.

3.2.2.4 Financial Feasibility Conclusion

Setting up a blue carbon market project for Coastal Bays would only be financially feasible when considering a longer timeframe and higher carbon prices. For example, a carbon price of $50/tCO2e would take 34 years before the carbon revenues would offset the costs related to setting up a carbon market project.

As a result, the Coastal Bays project is less financially feasible. However, the project could be implemented as an important proof-of-concept for the state of Maryland given the right price and timeline. Additionally, the carbon revenues could be used as a financial incentive for land owners to agree to restoration.

3.2.3 Organizational Feasibility

In January 2021, a group of government agencies and non-government organizations met and formed a team to focus on a critical need to protect and restore salt marshes in the Maryland Coastal Bays. The group, Salt Marsh Assessment and Restoration Team (SMART), includes representatives from the Maryland Coastal Bays Program, U.S. Fish and Wildlife Service, and Audubon. In the spring of 2022, the team completed outreach to mostly private landowners inquiring about their interest in marsh restoration and received positive feedback as the landowners had observed significant marsh degradation over the last few decades. Most of the properties are already under easements.

The U.S. Fish and Wildlife Service funded designs for Stark-Blass Happens Lane, Croppers Island, and Stark-Langmaid Road which were completed in November 2022. The SMART team is currently seeking construction funding for those sites. For the remaining sites, the team is looking for funds for survey and design and, ultimately, implementation. (correspondence with Rich Mason, February 1, 2022).

3.2.4 Social Considerations

The project sites are spread along the eastern edge of Worcester County, within mostly rural unincorporated land or census designated places (CDP). The northernmost site is Horner (#5), located within West Ocean City CDP, and the southernmost is Tizzard Island, located east of Girdletree CDP and Stockton CDP. The majority of the sites are within Worcester County's

District 2 - Central, with the exception of Horner and Stark, which fall within District 3 - Sinepuxent.

Land uses here are primarily state- and locally designated for green infrastructure, with few residential uses (single-family homes) adjacent to Smithson, Worcester County, and Marsh Harbor sites. Green infrastructure areas are designated for their significance to maintaining environmental functions for water quality and flood control, and preserving the existing natural landscape that is unique to Worcester County's character (Worcester County Comprehensive Development Plan, 2006).

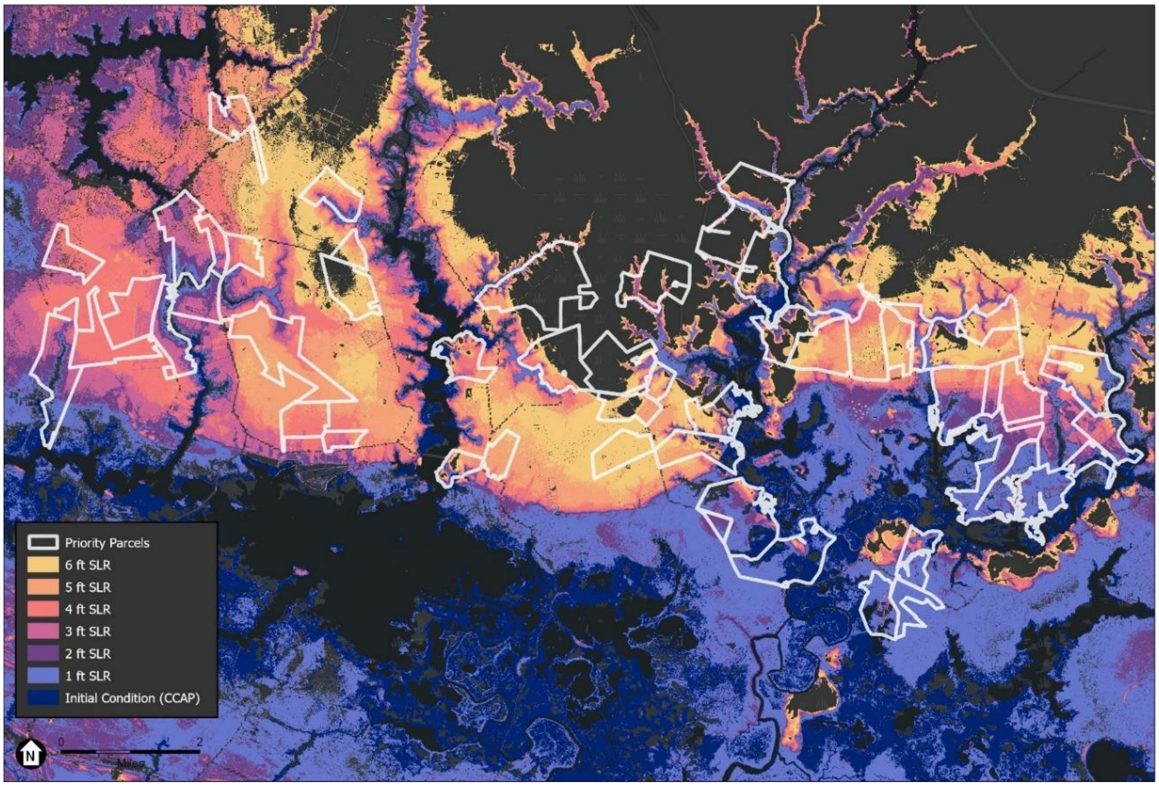
The recent census provides population estimates for Worcester County of 52,607. This is expected to grow to almost 62,000 by 2045, with most increases expected in individuals over age 50 (Worcester County, 2022). The U.S. EPA's Environmental Justice Screening and Mapping tool provides census population estimates and socioeconomic data at a block group level [10]. In the combined block group, the population is 3,836, with vulnerable groups including lower income (22% of the population), seniors over age 65 (27%), and people of color (18%). For health disparities, cancer (except skin cancer) rates are particularly high (87th percentile) compared to state and national rates. Cardiovascular disease is also a concern (74th percentile). A preliminary review of environmental hazards shows relatively low levels of environmental pollution from common criteria pollutants, water and waste pollutants. There is also low traffic proximity, which provides for healthier environmental conditions for air quality.

The project supports the local and regional preservation goals for natural lands and their ecosystem benefits, as well as preservation of the County's coastal character. As the sites are not publicly accessible and there are few residents in the vicinity, the project is not expected to have significant socioeconomic impacts. Qualitatively, preserving and improving the existing land use for flood control and increased carbon capture potential can promote public health, an important consideration for the region's larger percentage of seniors and of individuals with existing health conditions (e.g., cancers). Since fill would be coming from adjacent properties and in relatively small volumes, the emissions caused by the project are not expected to have significant impacts on the surrounding community.

3.3 Blackwater Marsh Migration Space

The Blackwater Marsh Migration Space project involves conserving various upland properties along the Blackwater National Wildlife Refuge for future marsh migration. TNC identified the priority parcels based on areas that would be inundated with 4-6 ft of sea-level rise (**Figure 3-14**). Properties in the 1-4 ft of sea-level rise range are already experiencing regular flooding and are expected to transition to wetland marshes regardless of conservation. TNC’s intent is to protect higher elevation lands in order to prevent further development and allow for wetland migration in the long-term. TNC is in the process of working with various private landowners to develop conservation easements with funding from a Readiness and Environmental Protection Integration (REPI) grant.

[10] Sites are spread across 5 block groups: Tizzard and Smithson (9512003), Marsh Harbor (9517004), Bay Creek LLC and Horner #3 (9509001), Stark and Horner #1, #2, #4, #5 (9517003), and Worcester County, Stark Langmaid Rd and Croppers Island (9512001).



SOURCE: TNC; NOAA 2022; ESA 2023

Maryland Blue Carbon Resilience Credit Feasibility Study

Figure 3-14
Blackwater Priority Parcels SLR

3.3.1 Feasibility Evaluation

Since the Blackwater Marsh Migration Space project would preserve land for future wetland creation with sea-level rise, the VM0033 Methodology can be applied. However, the project areas would not convert to marsh until 4-6 feet of sea-level rise, which is expected to occur just before 2100 even considering the 95 percentile projections. Assuming the easements are put in place in the next 10 years, the return on investment (i.e., the generation of the carbon credits) would not occur for 70 years or more. This makes carbon finance infeasible for this project.

Also, to prove additionality, the area under threat must be substantiated by a history of planned land use change. This area is not at threat of rapid development, so this would be hard to show, making the project technically infeasible as well.

3.3.2 Recommendations

For conservation projects more generally, it is worth reviewing the language in the easement to ensure it allows for credit sales. It is important to avoid exclusions for business sales. For example, the following text can be added to the easement to allow for blue carbon credit development: “The easement shall allow for ecosystem service credits to be generated and sold, including but not limited to carbon offsets.”

SECTION 4

Resilience Crediting Study: Baltimore Wetland Restorations

The Baltimore Wetland Restoration project involves the construction of a berm and beneficial use of dredge material to create a coastal wetland at Soller's Point just north of the Interstate 695 bridge. The wetland would be designed to create habitat and to reduce wave energy to the shoreline during storm events. The project would provide protection for the Baltimore Gas and Electric (BGE) property which includes two substations and the Exelon-operated power plant (Riverside Generating Station), which is a 261 MW electric generating station (Maryland Department of the Environment 2018).

TNC developed four alternatives and has moved three options forward for consideration: Option A: Dike, Option B: Diving Dike, and Option C: Debris Dike (**Figure 4-1**).

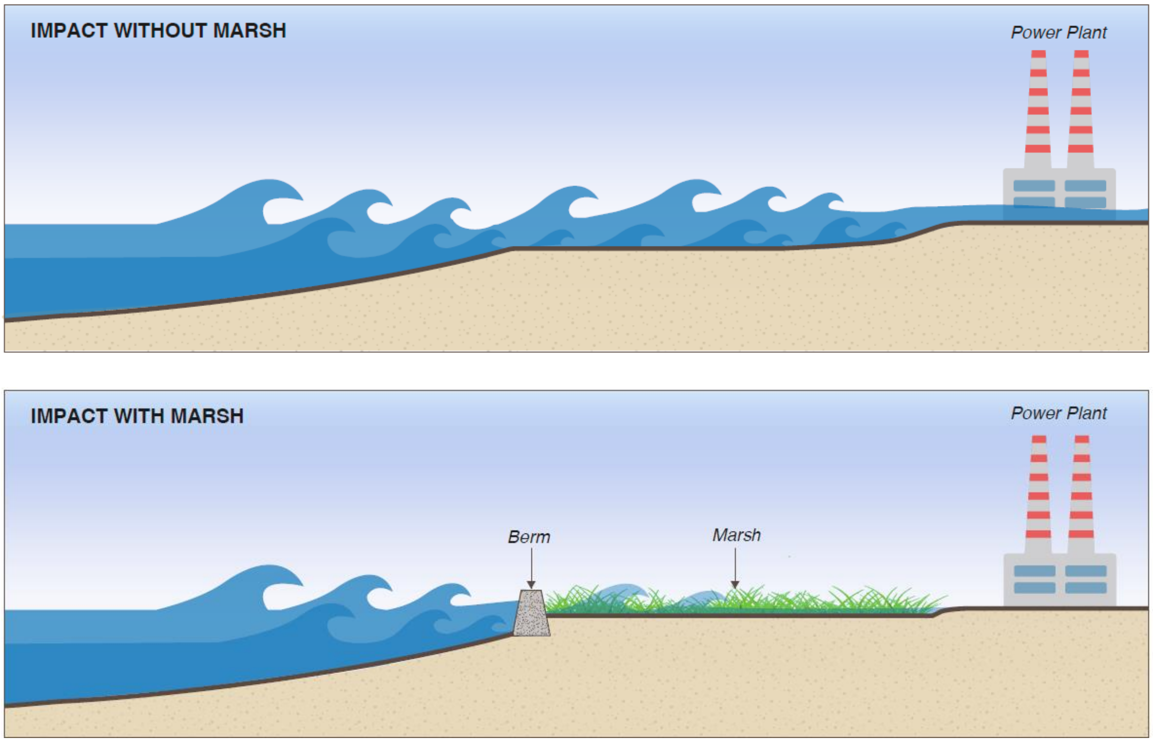
SOURCE: ESA 2023

Maryland Blue Carbon Resilience Credit Feasibility Study

Figure 4-1
Baltimore Wetlands Design Alternatives

4.1 Scenarios

Conceptually, the project would reduce wave energy and provide a resilience benefit to the BGE property. In the baseline scenario, the property would flood during storm events, and the project scenario would reduce wave energy reaching the shoreline and therefore reduce flooding.



SOURCE: ESA 2023

Maryland Blue Carbon Resilience Credit Feasibility Study

Figure 4-2
Conceptual Scenarios for Baltimore Wetland Restoration Project

4.2 Applicable Methodology and Additionality

The Sustainable Development Verified Impact Standard, Methodology for Coastal Resilience Benefits from Restoration and Protection of Mangroves and Tidal Marshes, applies to this project, because the project would create a wetland that would (theoretically) reduce flooding at the BGE property, which would be a benefit to the communities that rely on the power provided by the substations and generating station.

4.3 Project Boundaries

The project area was defined by surfaces provided by TNC (correspondence with Austin Bamford). The project impact area was defined by all areas where the project flooding changed due to the project.

4.4 Quantification of Sustainable Development Impacts

4.4.1 Terms

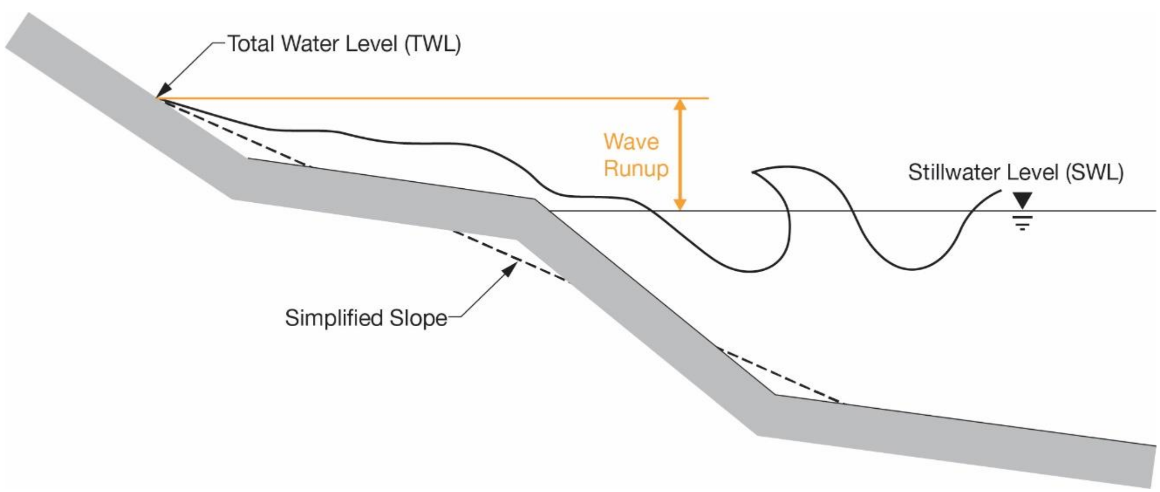
The following terms are used in the discussion of the modeling analysis (**Figure 4-3**):

Wave runup – the inland vertical extent of waves as they break and run up the shore.

Still water level (SWL) – the elevation of the water when there are no waves affecting it.

Total water level (TWL) – the elevation of the water with waves; TWL = SWL + wave runup.

Return period – the average amount of time between events, or the frequency at which a given event may occur (also known as a recurrence interval). For example, the 100-year event refers to a storm with a 1 in 100 (or 1%) chance of occurring annually, and a ~ 67% chance of being exceeded once in 100 years.



SOURCE: ESA 2023

Maryland Blue Carbon Resilience Credit Feasibility Study

Figure 4-3
Coastal Modeling Terms

4.4.2 Modeling Methodology

Modeling was conducted to evaluate the relative benefits between the three alternatives. ESA used the 2D version of the XBeach model. XBeach uses wave and water level inputs to propagate offshore waves inland and to estimate the landward extend of coastal flooding. To compare the alternatives, ESA selected one scenario to model for all three options. The model was run for a 10-year still water level combined with a 50-year wave event, which is an event similar to Hurricane Sandy. It should be noted that this event is more extreme than a 50-year storm event (Garrity et al. 2007) but likely not as extreme as a 100-year event.

4.4.3 Alternative Analysis Results

Figure 4-4 shows the coastal flood depth (> 0.5 ft) for each alternative. The model results show no significant difference when compared with existing conditions or between alternatives.

SOURCE: ESA 2023

Maryland Blue Carbon Resilience Credit Feasibility Study

Figure 4-4
Coastal Modeling Terms

Figure 4-5 shows the maximum velocities at the site during the storm event. In general, wave velocities higher than 3 ft/s tend to cause erosion. The model results show that all three alternatives reduce wave velocities to close to zero behind the berms. Alternative A provides the most protection, but the model shows a small area of high erosion where the berm meets the shoreline due to a small gap in the surface which was likely not intended to be part of the design.

SOURCE: ESA 2023

Maryland Blue Carbon Resilience Credit Feasibility Study

Figure 4-5
Coastal Modeling Terms

4.4.4 Sustainable Development Impacts Results

To develop credits, project proponents must quantify the flood impacts (and project benefits) to people or property for the 10-, 25-, 50-, and 100-year storm events. The model results show that for existing conditions and all three alternatives, none of the shoreline behind the project floods except for an area of marsh. This is due to relatively high elevations along the shoreline that are not overtopped during the event. Since this event is expected to be larger than the 50-year storm, that means that the 10-, 25-, and 50-year events are not expected to flood development with or without the project.

The Federal Emergency Management Agency (FEMA) produces Flood Insurance Rate Maps (FIRMs) which show the 100- and 500-year flood zones. In the area of the project, the FIRM shows that the 100- and 500-year events are not expected to flood any property (**Figure 4-6**).

SOURCE: FEMA NFHL 2023

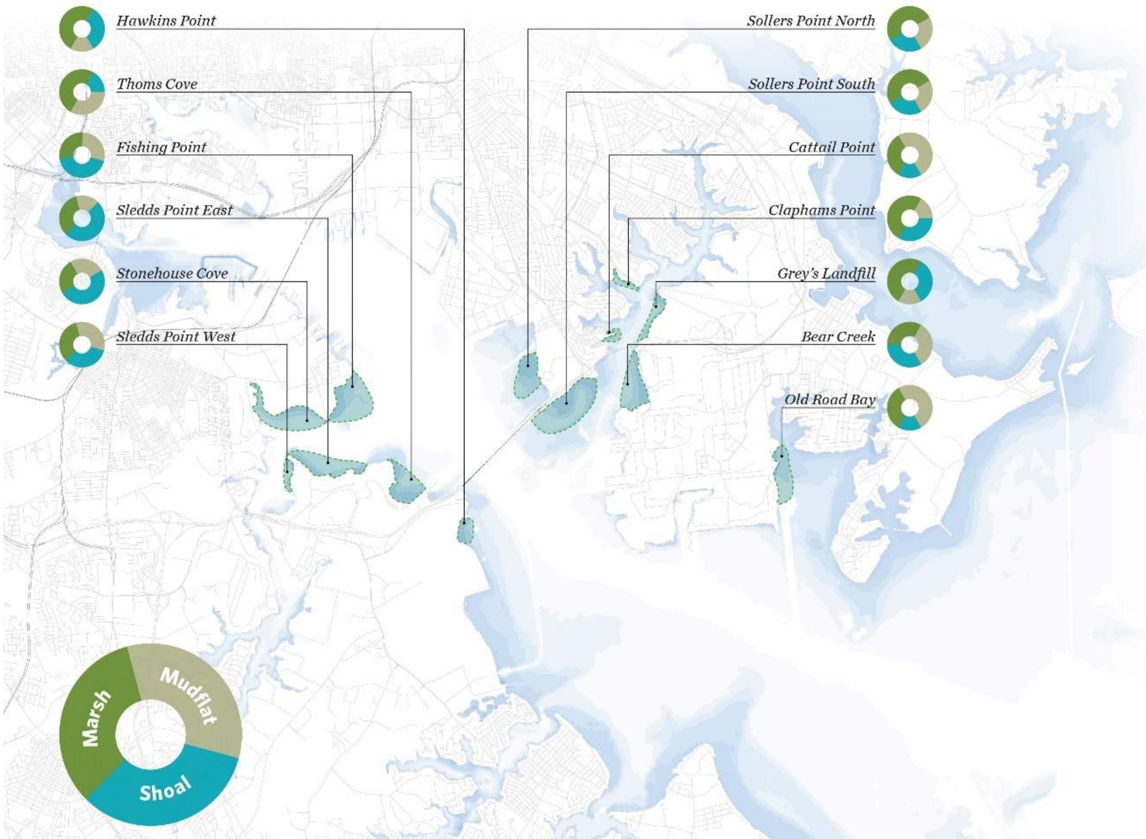
Maryland Blue Carbon Resilience Credit Feasibility Study

Figure 4-6
Coastal Modeling Terms

Since no properties or people are at risk of flooding during all four storm events (i.e., 10-, 25-, 50-, and 100-year events) under the baseline conditions, the project would not provide any additional benefits as defined by the methodology.

4.5 Project Recommendations

TNC is considering other sites for restoration as well (**Figure 4-7**). To feasibly develop resilience credits, project impact areas need to already be experiencing flooding or at risk of flooding of people or property under the baseline condition. FEMA's National Flood Hazard Layer (NFHL) viewer provides FIRM data and is a helpful tool for identifying locations already at risk of flooding. For example, the neighborhoods east and northeast of the BGE property show extensive flooding during the 100-year event, so the Cattail Point project may provide some benefit. Additionally, the Stonehouse Cove project and the Fishing Point project could provide resilience benefits to the USALCO chemical plant and the Kinder Morgan Baltimore Transload Terminal.



SOURCE: TNC 2023

Maryland Blue Carbon Resilience Credit Feasibility Study

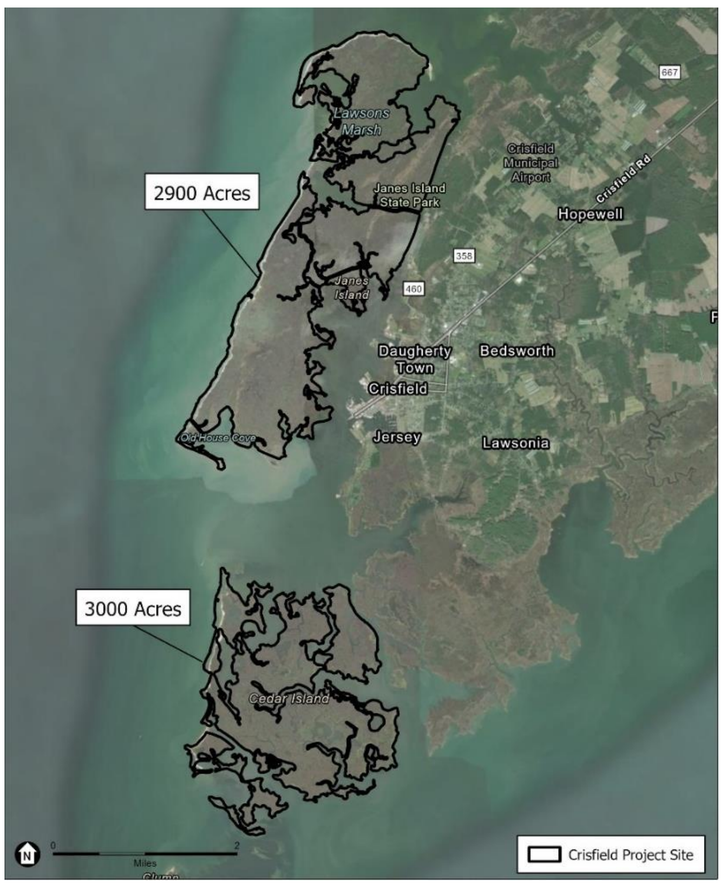
Figure 4-7
Potential Opportunity Sites

Beyond Baltimore, the NFHL viewer is a good way to filter for sites that would have flooding impacts under the baseline condition. Since the modeling required for the coastal resilience methodology is intensive and expensive, it is recommended that the NFHL be used as a first review for projects in the U.S.

SECTION 5

Combined Blue Carbon and Resilience Crediting: Crisfield Barrier Island

The City of Crisfield is at the frontline of climate impacts, experiencing regular disruptions from nuisance flooding and storms. TNC has been collaborating with the MD DNR and George Mason University to assess the wave attenuation benefits of coastal habitats across Maryland, including those of Janes Island and Cedar Island, which surround Crisfield. The George Mason team modeled the wave reduction benefits that would be provided by restoring the marshes of these barrier islands, making this an opportunity to assess the potential for both blue carbon and resilience credits.



SOURCE: ESA 2023

Maryland Blue Carbon Resilience Credit Feasibility Study

Figure 5-1
Crisfield Barrier Island Site Map

5.1 Coastal Resilience Feasibility Evaluation

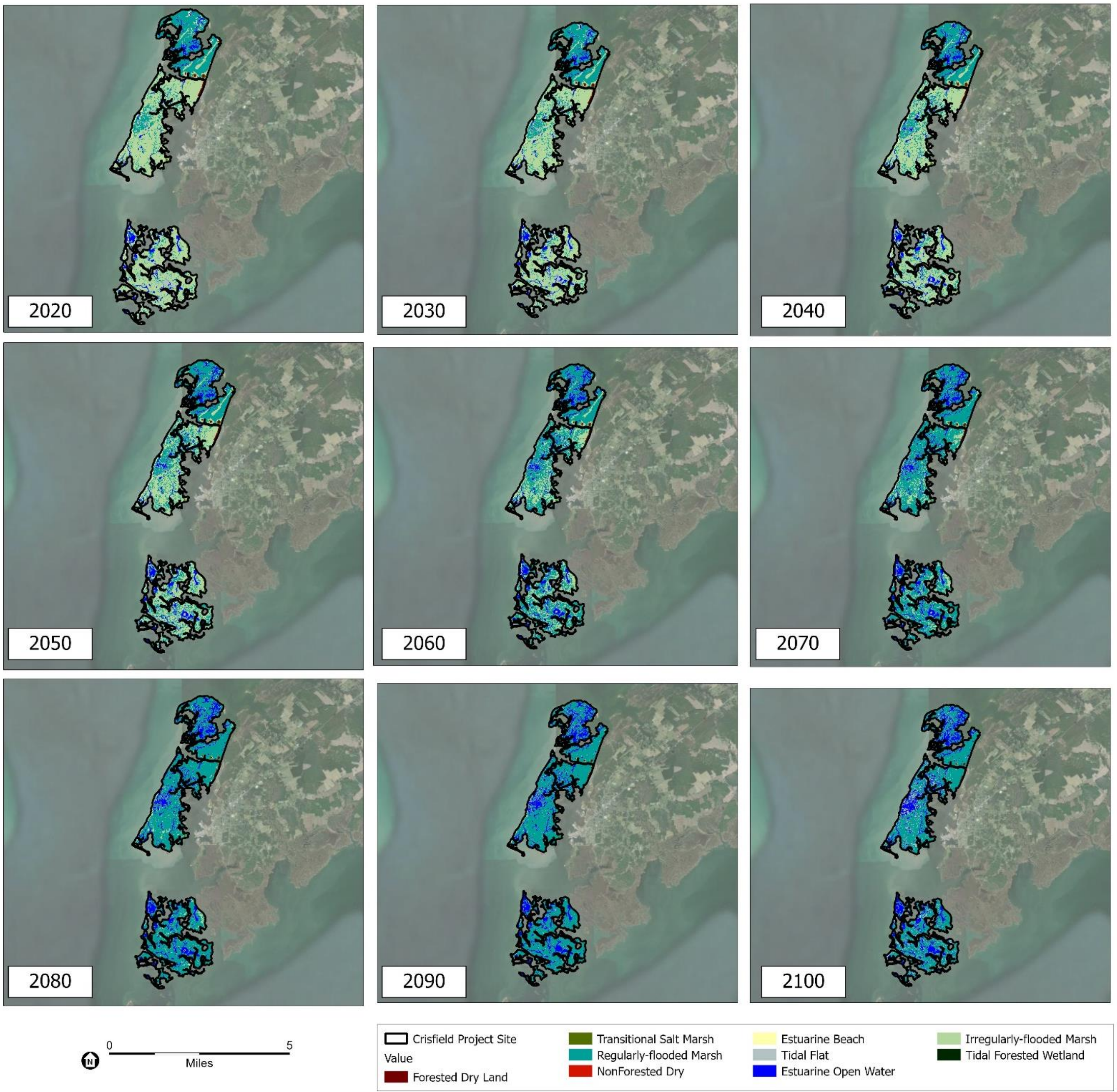
The George Mason team modeled wave attenuation under current conditions, for 2050, and for 2080 using the WPC SLAMM results to define habitats. They also modeled a scenario where the existing marsh is maintained (e.g., through thin layer placement) for the same time steps. Their model results showed that the maintained marsh did not provide any additional flood reduction to Crisfield since the islands are separated from each other by a channel through which water still reaches Crisfield and causes flooding. Additionally, the WPC SLAMM results do not show either island breaching by 2100. Therefore, a thin layer placement project would not provide any resilience credits.

5.2 Blue Carbon Feasibility Evaluation

Changes in wetland habitats were modeled to look at the effects of sea-level rise on the baseline condition (see Section 2.2 for methodology). **Table 5-1** shows the modeled habitat areas for each scenario over time, while **Figure 5-2** shows the habitat distribution over time. The existing marsh slowly drowns so that by 2100, the model shows most of the irregularly flooded marsh is lost (99.8 percent) and converted to regularly flooded marsh or open water. While there is still substantial regularly flooded marsh in 2100 (3,222 acres), the total marsh has decreased by 1,056 acres.

TABLE 5-1
ACREAGE OF HABITATS OVER TIME FOR CRISFIELD BARRIER ISLANDS (BASELINE ONLY)

	2023	2050	2070	2100
Forested dry land	30	23	17	7.5
Transitional salt marsh	21	28	22	13
Regularly flooded marsh	1,428	2,012	3,339	3,222
Non-forested dry land	2.6	0.7	0.2	0.1
Estuarine beach	86	69	47	24
Tidal flat	129	98	105	464
Estuarine open water	537	785	1,111	1,357
Irregularly flooded marsh	2,857	2,076	550	6.9
Tidal forested wetland	3.2	3.2	2.6	0.2
Total	5,094	5,094	5,094	5,094



SOURCE: ESA 2023

Maryland Blue Carbon Resilience Credit Feasibility Study

Figure 5-2
Crisfield Barrier Island Baseline Scenario

5.3 Recommendations

To maximize blue carbon credits, a restoration project in the Crisfield Barrier Islands should focus on areas that are regularly flooded marsh today and expected to convert to open water in the near term, such as the north end of Janes Island. Reducing conversion from irregularly flooded marsh to regularly flooded marsh does not provide as much carbon benefit, although this type of restoration is still valuable as habitat. For example, if the 1,056 acres of marsh that is lost to open water was maintained for 20 years, that project would avoid losing 10,030 tonnes CO_2 equivalent in biomass and sequester 32,550 tonnes of CO_2 equivalent for a total blue carbon benefit of 42,550 tonnes of CO_2 equivalent, which would be more than both the Deal Island and Coastal Bays projects.

SECTION 6
Landscape Feasibility

Broadening the lessons learned from the case studies, this section examines feasibility for carbon credit and resilience credit projects along the entire Maryland shoreline. This is a high-level analysis meant to identify parcels and areas that *may* be candidates of interest for credit projects. Further analysis will be needed to determine site feasibility.

To assess potential blue carbon projects, the projected inundation extents for 1 and 2 feet of sea-level rise were overlaid on parcel data from the State of Maryland Department of Planning. Only parcels larger than 25 acres—roughly the scale of the smallest projects considered in this study—and within a mile of the current shoreline were considered. The dominant land use type within each parcel was extracted from the National Land Cover Database.

Brackish marshes may emit sufficient methane to significantly discount their carbon sequestration benefits, but methane emissions can be fairly variable for given salinity values. As a result, this landscape-level assessment included only those parcels near water with a surface salinity greater than 8 ppt.

The following two types of blue carbon credit projects were considered and are discussed in further detail in Section 6.1 and 6.2:

- Conservation of marsh migration space through land or easement acquisition for areas that are uplands today but are expected to convert to wetlands in the near- to mid-term with 2 feet of sea-level rise.
- Conservation of present-day wetlands that may be at risk of conversion or drowning with 1 foot of sea-level rise.

Section 6.3 qualitatively discusses the potential for using runneling as a restoration strategy on a broader scale.

To assess potential resilience credit projects, FEMA flood hazards were intersected with development to find areas that may benefit from the storm attenuation effects of marsh creation or restoration projects. The FEMA 100-year floodplain was overlaid on areas mapped as medium- or high-intensity development in the National Land Cover Database. Unlike the carbon credit analysis which depends on conservation or restoration of specific parcel(s), the resilience analysis looks at people and property affected by flooding, the extents of which are not governed by parcel boundaries. There is no salinity restriction placed on this analysis. Results are discussed in Section 6.4.

6.1 Potential Conservation Areas for Marsh Migration

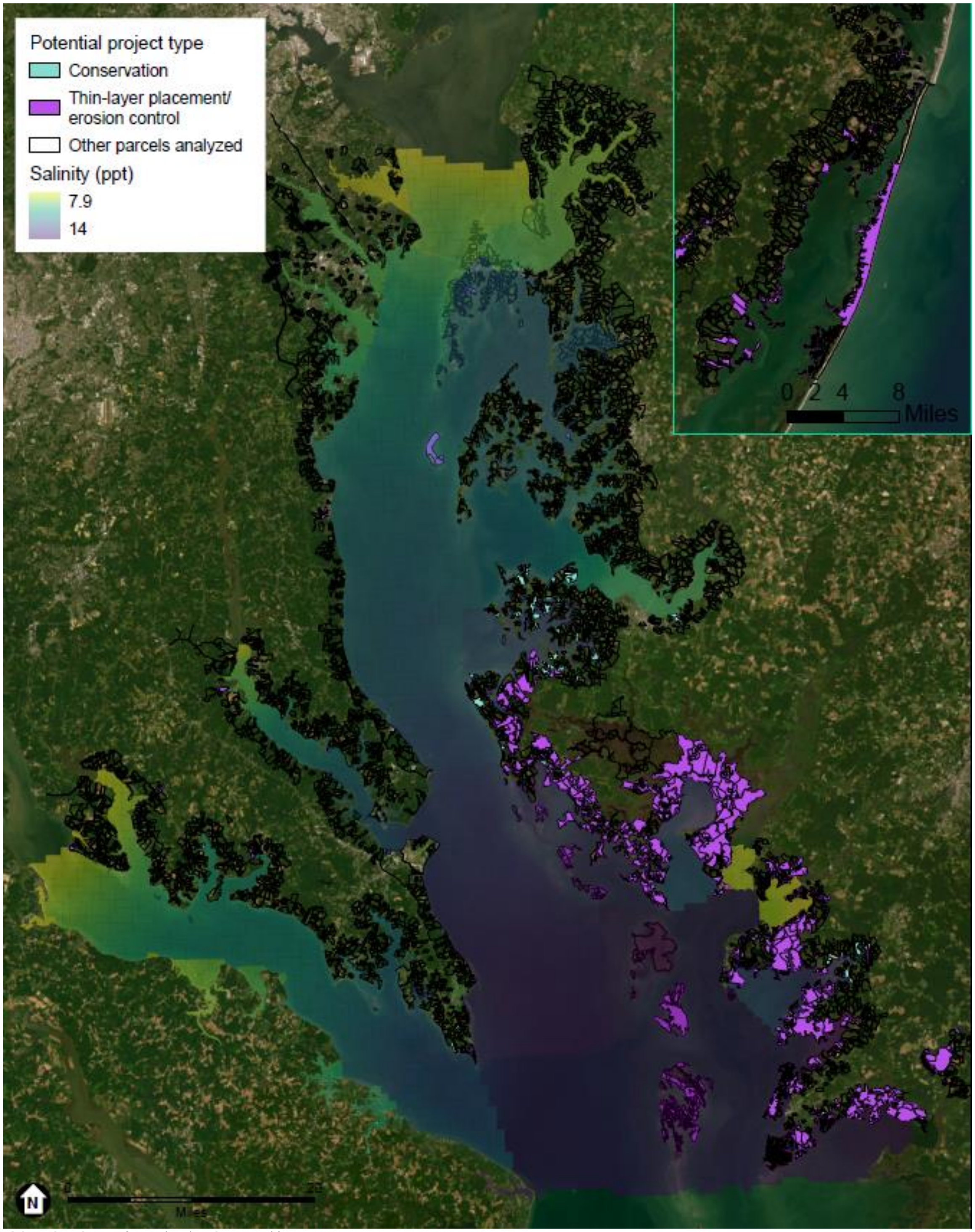
Parcels mapped as grassland, pasture/hay, cultivated crops, developed open space, or shrub/scrub within a mile of the current-day shoreline and that are vulnerable to up to 2 feet of sea-level rise were identified as potential marsh migration sites. These sites would be analogous to the Blackwater Marsh Migration Space project—that is, by conserving property now, land would be preserved for wetlands migration space as sea-level rise progresses. As discussed in Section 3.2, that Blackwater Marsh parcels are not expected to flood (and therefore generate blue carbon credits) until 4-6 feet of sea-level rise or the end of the century, so this analysis focuses on sites that will be impacted by sea-level rise sooner.

The results are shown in **Figure 6-1** as the teal parcels. Of the 4,508 parcels analyzed, just 68 were mapped into this category. The largest concentrations of these parcels are in Dorchester and Somerset Counties. These counties are shown in more detail in **Figure 6-2**. There are 68 parcels identified as land or easement acquisition sites and over 6,130 acres.

TABLE 6-1
SUMMARY OF LAND OR EASEMENT ACQUISITION OPPORTUNITIES

County	Number of parcels	Average parcel size (ac)
Calvert	1	49
Dorchester	46	101
Somerset	12	80
St Mary's	3	70
Talbot	2	28
Worcester	4	45
Total	**68**	**6,130**

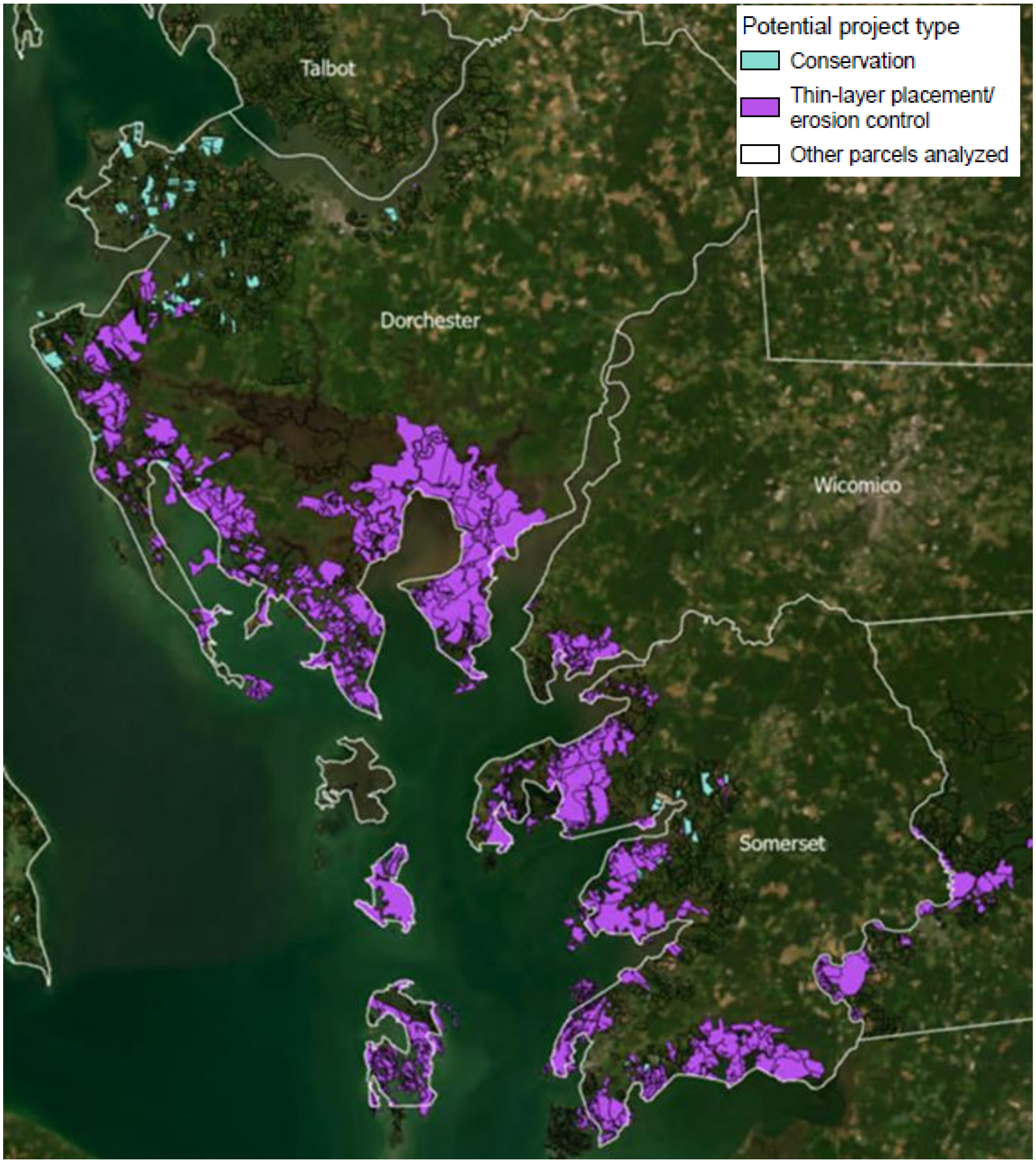
More site-specific data is needed to accurately evaluate the potential blue carbon credits for these sites. However, a very rough estimate of the potential amount of blue carbon can be approximated by assuming that the sites fully convert to salt and brackish tidal marsh by 2075, by which time 2 ft of sea-level rise is projected to have occurred. Approximately 70% of the land area identified in **Table 6-1** is mapped within the 1-ft sea-level rise inundation band, which is projected to occur by 2050 (**Table 2-1**).



SOURCE: State of Maryland, NOAA, Multi-Resolution Land Characteristics Consortium

Maryland Blue Carbon Resilience Credit Feasibility Study

Figure 6-1
Potential Blue Carbon Project Sites



SOURCE: State of Maryland, NOAA, Multi-Resolution Land Characteristics Consortium

Maryland Blue Carbon Resilience Credit Feasibility Study

Figure 6-2
Parcels of Interest in Dorchester, Wicomico, Somerset, and Worcester County

Assuming these properties (6,130 acres) are at risk of development, acquisition or easements that would allow the lands to convert to wetland instead could result in sequestration of 1,295,000 tonnes of CO_2 equivalent over 100 years. It is important to note that this assumes all properties would be converted to development by 2050. It is likely that many of these properties, like at Blackwater Marsh, are not at risk of development, so may not qualify as providing additionality.

6.2 Potential Thin-Layer Placement Sites

As shown by the Deal Island and Coastal Bays projects, beneficial reuse of sediment may be a promising way to conserve or maintain wetlands and prolong longevity, an important consideration for carbon credit projects. This analysis identified sites mapped as woody wetlands or as emergent herbaceous wetlands that are within areas expected to flood with 1 foot of sea-level rise. This additional foot of water depth may convert, erode, or drown out existing wetlands without proactive measures.

Much more land area was mapped in this category than for marsh migration space, with more than 10% of the parcels analyzed (490 of 4,508) meeting the criteria. This totals 109,922 acres across the Maryland shoreline.

Most of the parcels and land area were again in Dorchester (222 parcels, 48,960 acres) and Somerset (145 acres, 38,725 acres) Counties. **Table 6-2** presents this information by county and parcel characteristics.

TABLE 6-2
SUMMARY OF THIN-LAYER PLACEMENT OPPORTUNITIES

County	Number of parcels	Average parcel size (ac)
Anne Arundel	3	31
Calvert	4	60
Charles	3	50
Dorchester	222	221
Queen Anne's	7	52
Somerset	145	267
St Mary's	5	89
Talbot	3	362
Wicomico	9	279
Worcester	89	195
Total	**490**	**109,922**

More site-specific data is needed to accurately evaluate the potential blue carbon credits for these sites. However, the potential amount of blue carbon can be very roughly estimated by assuming that these sites (44,485 acres) would be maintained as wetland for 30 years longer than under baseline conditions. This would result in 7.8 million tonnes of CO_2 equivalent (1 million tonnes avoided biomass loss and 6.8 million tonnes sequestered), which indicates that thin-layer placement has significant potential for blue carbon projects.

6.3 Potential for Use of Runneling

The Coastal Bays case study suggests that runneling is a promising and cost-effective method of marsh restoration for carbon credit projects. By cutting small channels through locally high areas or berm-like features in marsh topography, this technique can improve drainage at low tide and overall marsh function. However, its fine scale makes it difficult to distinguish in topography datasets and to analyze in detail at this scale of analysis.

By visual inspection, Worcester County, which contains all of the Coastal Bays sites, has many areas that could be candidates for runneling based on evidence of grid ditching. Figure 6-3 shows an example.

SOURCE: State of Maryland, NOAA, Multi-Resolution Land Characteristics Consortium

NOTE: Purple outlines denote parcels designated as candidates for thin-layer placement per analysis in Section 6.2

Maryland Blue Carbon Resilience Credit Feasibility Study

Figure 6-3
Example Area with Grid Ditching in Worcester County

6.4 Potential Resilience Credit Sites

The current version of the SD VISta coastal resilience benefits methodology defines and measures resilience by quantifying the reduction in 1) number of people and 2) property values at risk of coastal flooding. Accordingly, areas of medium- and high-intensity development were mapped with the current FEMA 100-year floodplain. **Figure 6-4** shows these areas as well as nearby wetlands whose conservation or restoration may be an avenue to increasing resilience of coastal populations and properties. **Figure 6-5** presents a zoomed-in view of a few regions with larger at-risk areas.

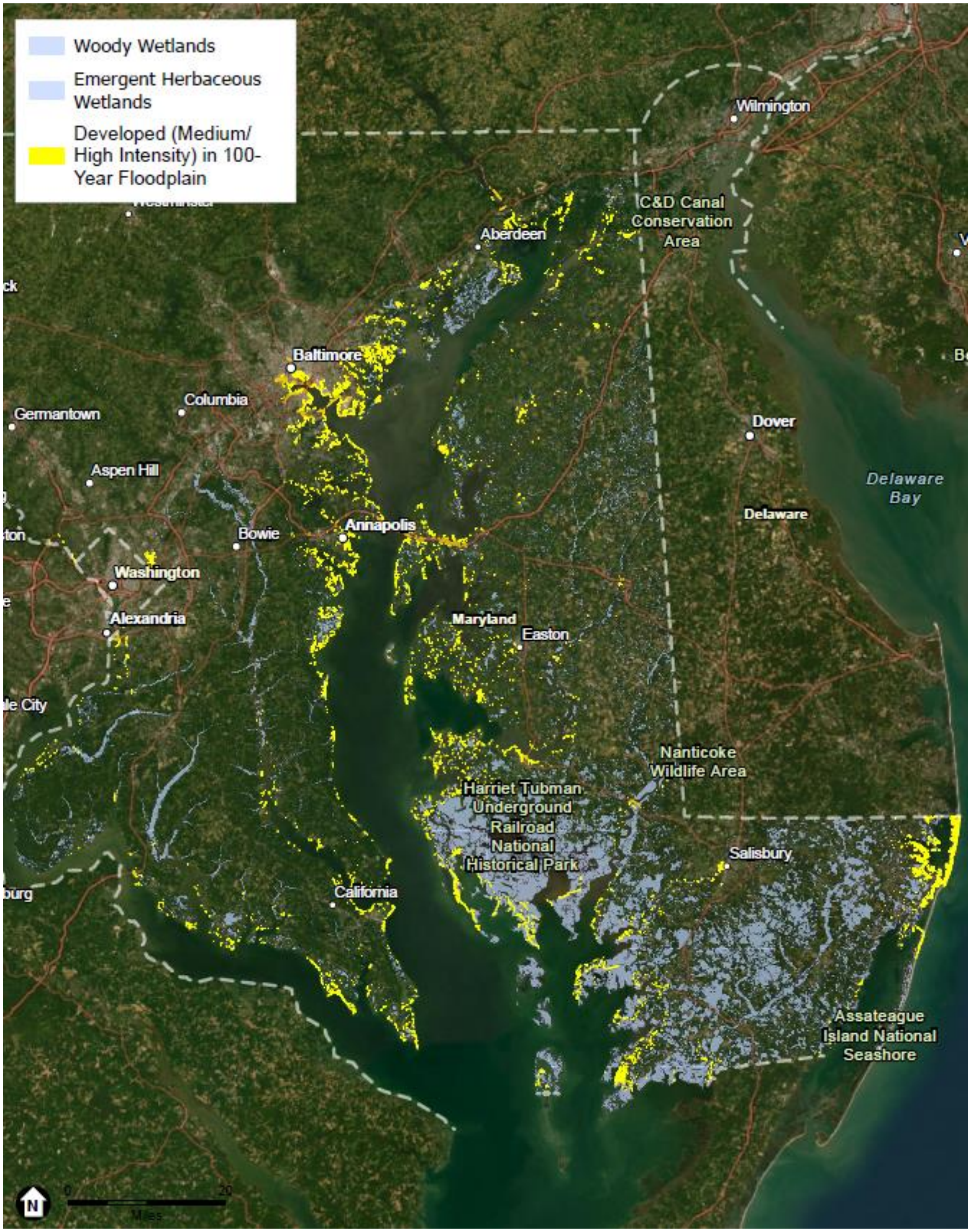
Finding the intersection of these two data sources (developed land use and FEMA floodplain) resulted in many small areas dotting the entire Maryland shoreline. The particularly small and scattered polygons may be due in part to differing levels of accuracy and cell sizes at the shoreline between the two data sources.

These areas and a description of nearby marshes are listed in approximate north-to-south order below in **Table 6-3**.

TABLE 6-3
SUMMARY OF RESILIENCE CREDIT OPPORTUNITIES

Area	County	Nearby Marsh
Charlestown	Cecil	Minimal
Havre de Grace at mouth of Susquehanna River	Harford	Minimal
Hawthorne and Martin State Airport	Baltimore	Some, but minimal outboard of areas at risk
Baltimore – Inner Harbor to Beltway Outer Loop	Baltimore City/Baltimore	Some at Sparrows Point and North Point
Annapolis	Anne Arundel	Some north and south of areas at risk, but none directly outboard
Bay Bridge Airport	Queen Anne's	Some north and south of areas at risk, but none directly outboard
Kent Narrows	Queen Anne's	Extensive south of area at risk
North Beach and Chesapeake Beach	Calvert	Some north and south of areas at risk, but none directly outboard
Cambridge	Dorchester	Some bayward of the city
Crisfield	Somerset	Extensive and outboard in north and south directions
Worcester City and Ocean City	Worcester	Located on a barrier island but marshes are all on inboard side
Ocean Pines	Worcester	Extensive to north of areas at risk

The table above underscores a lesson from the Crisfield and Baltimore wetland restoration projects, which is that feasibility of resilience credit projects is complex and dependent on several factors. For instance, Crisfield has some of the most extensive marshes surrounding it compared to the other sites listed in **Table 6-3**, but modeling showed that restoration of Janes and Cedar Island would not be sufficient to protect the City due to fetch direction, interaction of storm conditions with local topography, and existing low City topography, among other reasons. Thorough site characterization and modeling will be needed to advance any of the sites listed above.



SOURCE: State of Maryland, Multi-Resolution Land Characteristics Consortium

Maryland Blue Carbon Resilience Credit Feasibility Study

Figure 6-4
Potential Resilience Credit Opportunities

SOURCE: State of Maryland, Multi-Resolution Land Characteristics Consortium

Maryland Blue Carbon Resilience Credit Feasibility Study

Figure 6-5
Potential Resilience Credit Opportunities – Zoomed In

SECTION 7
Conclusions and Next Steps

This study has examined the potential for three different methods – land or easement acquisition, beneficial use of dredged material, and flood reduction – to produce viable and financially-sound credit projects for the voluntary carbon market.

Beneficial reuse of dredged material at Deal Island and Coastal Bays provides an opportunity to examine how these types of projects may be applied for restoration and carbon crediting efforts. Both projects have a relatively high price tag for the amount of carbon they sequester. Deal Island would break even on the blue carbon costs within a 20-year timeframe at a carbon price point of $690/tonne, while Coastal Bays would break even at a price of $107/tonne. The Coastal Bays project could cover its blue carbon operating expenses over 21 years at a cost of $50/tonne.

Deal Island was assumed to receive regular fill placement through 2065, which is expected to maintain the marsh for 100 years after initial construction. Coastal Bays was assumed to receive a one-time fill placement, and as a result, the marshes drown out much faster. The increased fill at Deal Island outweighs the benefit of lower salinity (and therefore less methane) at Coastal Bays. The results indicate that recurring fill placement will be necessary to maintain project permanence.

As shown in the landscape feasibility analysis (Section 6.2), 110,000 acres of existing marsh are vulnerable to 2 feet of sea-level rise, so there is a great need for beneficial reuse projects. Finding cost effective ways to implement these projects will be key to maintaining habitat in the future and blue carbon financing may play a role in these efforts if credit prices or the scale of projects increase.

Conservation easements may be feasible, but only in areas that are both at risk of development, and likely to convert to wetland in the near-term. Considering a 20-year timeframe for financial returns, any site converting to marsh is unlikely to be at risk of development due to flood risk, but potential opportunities may exist. The landscape feasibility analysis showed the number of sites that are not currently marsh but likely to be marsh soon are minimal.

The results of the analysis of Crisfield and the Baltimore wetland restoration projects showed that feasible resilience credit projects need to be located in communities where the flood risk is already evident. The landscape feasibility showed that these locations do exist, but are not necessarily adjacent to existing marsh or are constrained by other community needs (such as the navigation channels adjacent to Crisfield). Further analysis of these sites is needed to understand the potential opportunities for these types of projects.

It is important to remember that the case studies analyzed for this project have widely varied and unique combinations of habitats, environmental challenges, ownership situations, and restoration opportunities, making the results difficult to generalize.

It is also important to note that all of the projects analyzed in this study provide benefits beyond blue carbon, including providing habitat for threatened species, protecting against storm surges, and providing livelihoods for local communities. The carbon benefit provided by these projects is still important, even if carbon credits are not going to pay for the projects. Quantifying carbon benefits can be used to help project proponents win grant funding and used towards state emissions reductions goals, which often require less rigorous assessment than crediting. So, while the sites analyzed in this study may not be feasible on the blue carbon market, they still provide numerous ecosystem, climate, and resilience benefits.

To further analyze developing feasible credit projects in Maryland, next steps could include:

- Analyzing how carbon credits can be considered permanent when habitats are faced with sea-level rise. This could include studying what happens to soil carbon when habitats become submerged or eroded and studying how seagrasses may be able to migrate into submerged habitats and maintain soil carbon.
- Working with USACE and others to identify ways to make beneficial reuse projects more cost effective.
- Monitoring Deal Island post-construction to understand where the standing biomass carbon goes and any changes in emissions between dredge material placement and settlement of the material. Documentation of any monitoring efforts is recommended so that Deal Island can be used as a blue carbon pilot project.
- Developing a finer scale habitat evolution model to be able to analyze changes in habitat types due to runneling. Continued monitoring of existing projects to determine how long it takes vegetation to reestablish and how elevations change post-runneling is recommended to inform any habitat evolution modeling.
- Analyzing construction emissions for proposed projects and/or developing innovative methods to reduce construction emissions for restoration.
- Identifying a feasible pilot project for developing resilience credits. TNC’s Cattail Point, Stonehouse Cove, or Fishing Point projects in Baltimore should be considered.

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Appendix A
Sequestration and Emission Rates

Habitat	Aboveground Carbon Stock (MgC/ha)	References/ Assumptions	C Removal Rate (g C/m^2/yr)	References/ Assumptions	Soil Carbon (Mg C/ha)	Reference/ Assumptions	CH4 Emission Rate (g CH4/m^2/yr) – Coastal Bays	References/ Assumptions	CH4 Emission Rate (g CH4/m^2/yr) – Deal Island	References/ Assumptions
Forested Dry Land	90.0	Calculation from USFS average biomass on eastern shore forests	0	Assumed	77.5	Mulkey et al. 2008 - Table 12	0	Assumed because dry habitat	0	Assumed because dry habitat
Non-Tidal Forested Wetland	90.0	Calculation from USFS average biomass on eastern shore forests	106.15	Campbell et al. 2020 - Table 1, Palustrine Forested	N/A	Not used in calculations	82.03	Assumed same as tidal fresh marsh	N/A	Not present at Deal Island
Inland Fresh Marsh	6.4	Assumed the same as regularly flooded marsh	333.41	Campbell et al. 2020 - Table 1, Palustrine Emergent	N/A	Not used in calculations	82.03	Assumed same as tidal fresh marsh	N/A	Not present at Deal Island
Tidal Fresh Marsh	6.4	Assumed the same as regularly flooded marsh	391.72	Campbell et al. 2020 - Table 1, Estuarine Fresh	N/A	Not used in calculations	82.03	Campbell et al. 2020 - Table 2, Tidal Freshwater	N/A	Not present at Deal Island
Transitional Salt Marsh (MHHW to Salt Boundary)	6.4	Assumed the same as regularly flooded marsh	207.6	Assumed the same as regularly-flooded marsh	201.1	Warnell et al. 2022	0.85	Campbell et al. 2020 - Table 2, Polyhaline	9.3	Assumed the same as patens marsh (Derby et al. 2022 - Table 3)
Regularly-flooded Marsh (MTL to 120% of MHHW)	6.4	Flemer et al 1978	207.6	MDOE 2023 - Table 5 (0.84 MgC/ac/yr)	201.1	Warnell et al. 2022	0.85	Campbell et al. 2020 - Table 2, Polyhaline	19.2	Campbell et al. 2020 - Table 2, Mesohaline
Non-Forested Dry (Agricultural lands)	26.1	IPCC 2019 - Table 5.1 (temperate hedgerow)	23	IPCC 2019 Table 5.1 (temperate hedgerow)	77.5	Mulkey et al. 2008 - Table 12	0	Assumed because dry habitat	0	Assumed because dry habitat
Estuarine Beach	0	Assumed no vegetation	0	Assumed	0	Assumed	0	IPCC 2014 Table 4.14 (salinity > 18ppt)	19.37	IPCC 2014 - Table 4.14 (salinity < 18ppt)
Tidal Flat	0	Assumed no vegetation	0	Assumed	0	Assumed	0	IPCC 2014 Table 4.14 (salinity > 18ppt)	19.37	IPCC 2014 - Table 4.14 (salinity < 18ppt)
Inland Open Water	0	Assumed no vegetation	0	Assumed	0	Assumed	8.03	EPA US GHG Emissions and Sinks 2023; pg 6-125- assume same as flooded lands remaining flooded lands, warm temperate moist	N/A	Not present at Deal Island
Estuarine Open Water	0	Assumed no vegetation	0	Assumed	0	Assumed	19.37	IPCC 2014 Table 4.14 (salinity < 18ppt)	19.37	IPCC 2014 - Table 4.14 (salinity < 18ppt)
Irregularly-flooded Marsh (Avg MHHW, MTL to Salt Boundary)	6.4	Assumed the same as regularly flooded marsh	207.6	Assumed the same as regularly-flooded marsh	201.1	Warnell et al. 2022	Depends on salinity	Assumed the same as regularly flooded marsh	20.0	Assumed comparable to Tidal Forested Wetland
Tidal Forested Wetland	310.2	Calculated from IPCC 2006 Table 4.7 (temperate oceanic forest) and Table 4.3	106.15	Campbell et al. 2020 - Table 1, Palustrine Forested	106.15	Campbell et al. 2020 - Table 1, Palustrine Forested	82.03	Assumed same as tidal fresh marsh	N/A	Not present at Deal Island
Developed Dry Land (Flooded and not flooded)	0	Assumed	0	Assumed	0	Assumed	0	Assumed flooded >18ppt	N/A	Not present at Deal Island
Brackish (High elevation)	6.4	Assumed the same as regularly flooded marsh	293.0	Campbell et al. 2020 - Table 1, Estuarine Oligohaline	N/A	Not used in calculations	N/A	Not present at Coastal Bays	20.0	Derby et al. 2022 - Table 3 (avg of 0.07, 0.16, 0.22 Mg C/ha/yr)
Brackish (Low elevation)	6.4	Assumed the same as regularly flooded marsh	206.7	Campbell et al. 2020 - Table 1, Estuarine Mesohaline	N/A	Not used in calculations	N/A	Not present at Coastal Bays	89.3	Derby et al. 2022 - Table 3 (0.67 Mg C/ha/yr)

Appendix B

Financial Analysis Assumptions

Overall assumptions

The discount rate for calculating the NPV of cash flows was assumed to be 4% reflecting the non-profit status and high tolerance for uncertainty of TNC.

Carbon revenues assumptions

Emission reductions are the difference between with-project and baseline carbon sequestered (in tCO2e).

Uncertainty refers to the degree of doubt or lack of precision in estimating the amount of carbon dioxide equivalent emissions reduced or removed by a particular project, and it can lead to deductions from the credits issued to account for this variability. Deductions are made for uncertainty when uncertainty exceeds 25% or 30% of the mean value at a 90% confidence level. However, for either Deal Island or Coastal Bays, we will assume no uncertainty deduction should be made, assuming that the precision is achievable with reasonable effort.

Leakage refers to the reduction in carbon credits due to offsite emissions resulting from activities displaced by the project. For Deal Island and Coastal Bays, leakage is assumed to be zero as no productive activities are being displaced, and ecological leakage is prevented in accordance with the methodology applicability conditions.

The **Non-permanence buffer** represents the project's obligation to contribute to the VCS Non-Permanence Risk Pool to guard against potential future reversals. These reversals might occur if the project activity fails and the previously credited carbon is released back into the atmosphere. This buffer is expressed as a percentage of the gross emission reductions, which is calculated as the difference between with-project stock changes, minus the impacts of uncertainty, baseline stock changes, and leakage. The buffer is established during the project's initial registration and must be updated during each verification event. We have assumed a 20% non-permanence buffer for both sites, as 20% is considered typical for many land-use carbon offset projects.

Verified Carbon Units (VCUs) are computed as the GHG difference between the project and the baseline, and then accounting for any deductions made for uncertainty, leakage, or non-permanence. VCUs represent the quantity of carbon offset credits available for sale.

Cost assumptions

The detailed implementation cost assumptions for Deal Island can be found in ***Table B- 1***.

Table B- 1 | Estimated implementation cost associated with fill placement for Deal Island

Year	Acres	Hectares	Fill (inches)	Fill (cy)	Cost with dredging	Cost without dredging
2023	75 (12 + 63)	30	18	181,500	$13,500,000	$10,500,000
2030	170	69	15.3	350,000	$26,033,058	$23,033,058

2037	188	76	13.9	350,000	$26,033,058	$23,033,058
2044	237	96	11	350,000	$26,033,058	$23,033,058
2051	245 (12 + 63 + 170)	99	10.6	350,000	$26,033,058	$23,033,058
2058	188	76	13.9	350,000	$26,033,058	$23,033,058
2065	237	96	11	350,000	$26,033,058	$23,033,058
TOTAL	1,340	542		2,281,500	$169,698,347	$148,698,347

To estimate the implementation costs for Coastal Bays, two steps were taken. In the first step, we estimated the per unit costs for fill (cost per cubic yard) and planting (cost per acre) by referencing the available implementation costs for sites Stark, Croppers Island, and Stark Langmaid Rd, as detailed in ***Table B-2*** (unit costs highlighted in red).

Table B- 2 | Estimating per unit costs for fill and planting for Coastal Bay site based on design plans (implementation cost)

		Acreage	Planting cost/ acre	Fill volume (CY)	Fill cost/cy	10% mobilization	Total cost *(based on design plans)*
Stark	Runnels and some nourishment	25	$14,256	700	$18	$41,000	$410,000
Croppers Island	Nourishment, creation of freshwater marsh	114	$16,769	35,000	$18	$282,410	$2,824,100
Stark Langmaid Rd.	Nourishment, runnelling, planting	35	$11,168	8,500	$18	$60,430	$604,300
AVERAGE unit cost			$14,064		$18		

Next, these estimated unit costs were used to estimate the implementation cost for all sites (see ***Table B-3***). The implementation cost for the original three sites, Stark, Croppers Island and Stark Langmaid Rd., has again been estimated based on the new fills that the model has assumed, which differs compared to the original fill assumption from the design plans.

Table B- 3 | Estimated implementation cost associated with Coastal Bays

		Fill Volume (cy)	Fill cost/cy	Acreage	Planting cost/acre	10% Mobilization	Total Cost
Stark	Runnels and some nourishment	28,800	$18	25	$14,064	$96,668	$966,675
Croppers Island	Nourishment, creation of freshwater marsh	15,539	$18	114	$14,064	$241,168	$2,411,678

Stark Langmaid Rd.	Nourishment, runnelling, planting	37,738	$18	35	$14,064	$133,867	$1,338,669
Worcester County	Nourishment, runnelling, planting	381,822	$18	187	$14,064	$67,054	$670,540
Marsh Harbor	Nourishment, runnelling, planting, installation of berm	17,900	$18	20	$14,064	$1,195,675	$11,956,752
Bay Creek LLC	Nourishment, runnelling, planting	228,259	$18	473	$14,064	$571,490	$5,714,901
Horner	Nourishment, runnelling, planting	109,941	$18	225	$14,064	$1,055,870	$10,558,700
Smithson	Nourishment, runnelling, planting, living shoreline	1,300	$18	84	$14,064	$130,171	$1,301,711
Tizzard Island	Nourishment, runnelling, planting, living shoreline	2,600	$18	151	$14,064	$209,226	$2,092,265
TOTAL		**1,314**		**823,900**		**$3,701,189**	**$37,011,890**

Table B-4 provides a comprehensive breakdown of all cost components and the underlying assumptions associated with them, after which we will dive a bit deeper into the assumptions regarding the implementation labor cost. The table also indicates whether a cost is shared between the Deal Island and Coastal Bay sites and whether the cost is incorporated in Scenario 1 (blue carbon market costs only) or 2 (all project costs).

Table B- 4 | Cost assumptions for Maryland projects

Cost component	**Cost assumption**	**Scenario?**	**Cost component**
CAPEX	Feasibility analysis	The production of a feasibility assessment, evaluating GHG mitigation potential and financial and non-financial considerations (e.g., legal, social)	
		$100,000 one off cost **across both sites**	2
	Conservation planning & admin	Activities involved in the project start-up phase, such as project management, vendor coordination, fundraising, research, and travel.	
		$165,000/year during startup period (4 years) **across both sites**	2
	Data collection and field costs	The expenses associated with onsite and field sampling to gather necessary data for conservation plan, blue carbon plan, and credit creation (e.g., carbon stock).	
		$100,000/year during 3 years **across both sites**	2
	Community representation / liaison	Efforts aimed at developing a community-led project design, including assessing community needs and priorities, obtaining free, prior, and informed consent, conducting stakeholder surveys, and building capacity for long term management.	
		$125,000 /year during startup period (4 years) **across both sites**	2

	Blue carbon project planning	The preparation of the project design document (PD), which may include potential sea level rise, hydrological or other modelling.	
		$100,000 one off cost **across both sites**	1 and 2
	Establishing carbon rights	Legal expenses related to clarifying carbon rights, establishing conservation and community agreements, and packaging carbon benefits for legally valid sales.	
		$65,000/year during 3 years **across both sites**	1 and 2
	Validation	The fee or price associated with the validation of the PD by Verra.	
		$50,000 one of cost **across both sites**	1 and 28
	Implementation labor	The costs associated with labor and materials required for rehabilitating the degraded area	
		<u>Deal Island:</u> See **Table B- 1** **<u>Coastal Bays:</u>** See **Next, these** estimated unit costs were used to estimate the implementation cost for all sites (see *Error! Not a valid bookmark self-reference.*). The implementation cost for the original three sites, Stark, Croppers Island and Stark Langmaid Rd., has again been estimated based on the new fills that the model has assumed, which differs compared to the original fill assumption from the design plans. Table B- 3	2
OPEX	Maintenance	The costs associated with the physical upkeep of the original implementation, such as pest control, removing blockages, and rebuilding small portions.	
		$1M assumed split over the timeline **per site**	2
	Monitoring	The expenses related to individuals moving throughout the project site to prevent degradation and report necessary actions/changes (e.g., locally employed guards).	
		<u>Deal Island:</u> $0, assumed part of responsibilities of wildlife management area. **<u>Coastal Bays:</u>** $49,700/yr.	2
	Community benefit sharing fund	A fund to compensate for alternative livelihoods, and opportunity cost. The objective of the fund is to meet the community's socioeconomic and financial priorities, which can be realized through goods, services, infra, and/or cash	
		0%, assumed no need for compensation for alternative livelihoods and opportunity cost **(for each site)**	2
	Carbon standard fees	Administrative fees charged by the carbon standard (e.g., Verra).	
		$0.2/credit	1 and 2
	Baseline reassessment	The costs associated with a third-party assessment to ensure the initial GHG emission/reduction estimates are accurate and remain so over time.	
		$40,000, every 10 years **across both sites**	1 and 2
	MRV	The costs associated with measuring, reporting, and verifying GHG emissions that occur post-implementation to enable carbon benefit sales through a third party.	
		$100,000, every 5 years **across both sites**	1 and 2
	Long-term project operating	The expenses related to project oversight, stakeholder management, community engagement, vendor coordination, etc., during the operating years of the project.	
		$130,000/year during project **across both sites**	2

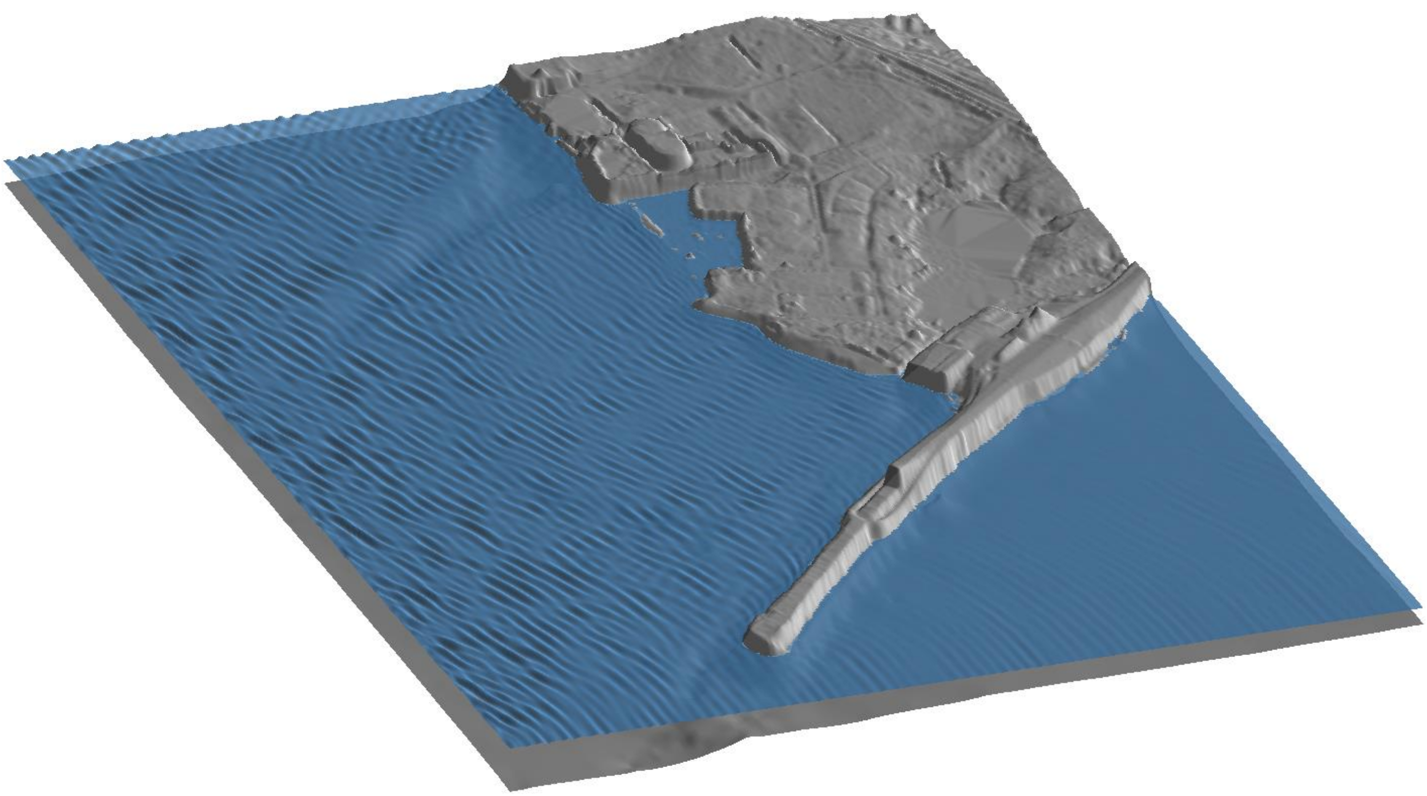
Appendix C
Wave Modeling Analysis

TNC MARYLAND BLUE CARBON RESILIENCE CREDIT FEASIBILITY STUDY

Coastal Flood Analysis

Prepared for
The Nature Conservancy

December 2023



TNC MARYLAND BLUE CARBON RESILIENCE CREDIT FEASIBILITY STUDY

Coastal Flood Analysis

Prepared for
The Nature Conservancy

December 2023

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5309 Shilshole Avenue NW
Suite 200
Seattle, WA 98107
206.789.9658
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1. INTRODUCTION

The Environmental Science Associates (ESA) is conducting a Maryland Blue Carbon Resilience Credit Feasibility Study for the Nature Conservancy (TNC) and the Maryland Department of Natural Resources (MD DNR), aiming not only to contribute to the existing knowledge about blue carbon but also to advance the emerging market of carbon and resilience credits by identifying feasible project types and addressing the key considerations in developing such projects.

As part of this study, ESA conducted a coastal flood analysis for the Baltimore Wetlands Restoration project. The Baltimore Wetland Restoration project seeks to create a coastal wetland at Soller's Point north of the Interstate 695 bridge near Baltimore (**Figure 1-1**) in order to create habitat and reduce coastal erosion and flooding during storm events. The alternatives under consideration consist of three different berm alignments that will contain new restored marsh and offer flood protection to the energy infrastructure for Baltimore Gas & Electric (BGE) and Exelon. Alternative A uses a closed dike, alternative B a diving dike, and alternative C a debris dike.

This report summarizes the coastal flood analysis and wave modeling conducted to evaluate the potential resilience credit benefits provided by the three alternatives when compared with present conditions. ESA conducted a comprehensive analysis of existing publicly available topographic, wind, and water level data (Section 2), established storm frequencies for extreme events using historical records for the region (Section 3), analyzed water levels and sea-level rise trends (Section 4), assessed the wave conditions (Section 5) and modeled coastal flooding due to a combination of waves and tides along the marsh and the surrounding areas for existing conditions and the three conceptual designs (Section 6).

Path: U:\GIS\GIS\Projects\2022xxx\D202201018_TNC_MD_Carbon_Resilience\03_Project\MD_SiteVisitMaps.aprx Figure 1-1 Baltimore Location Map, ALNguyen 11/20/2023

SOURCE: ESA, 2023

TNC Maryland Blue Carbon Resilience Credit Analysis

Figure 1-1
Project Location

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2. SITE CONDITIONS

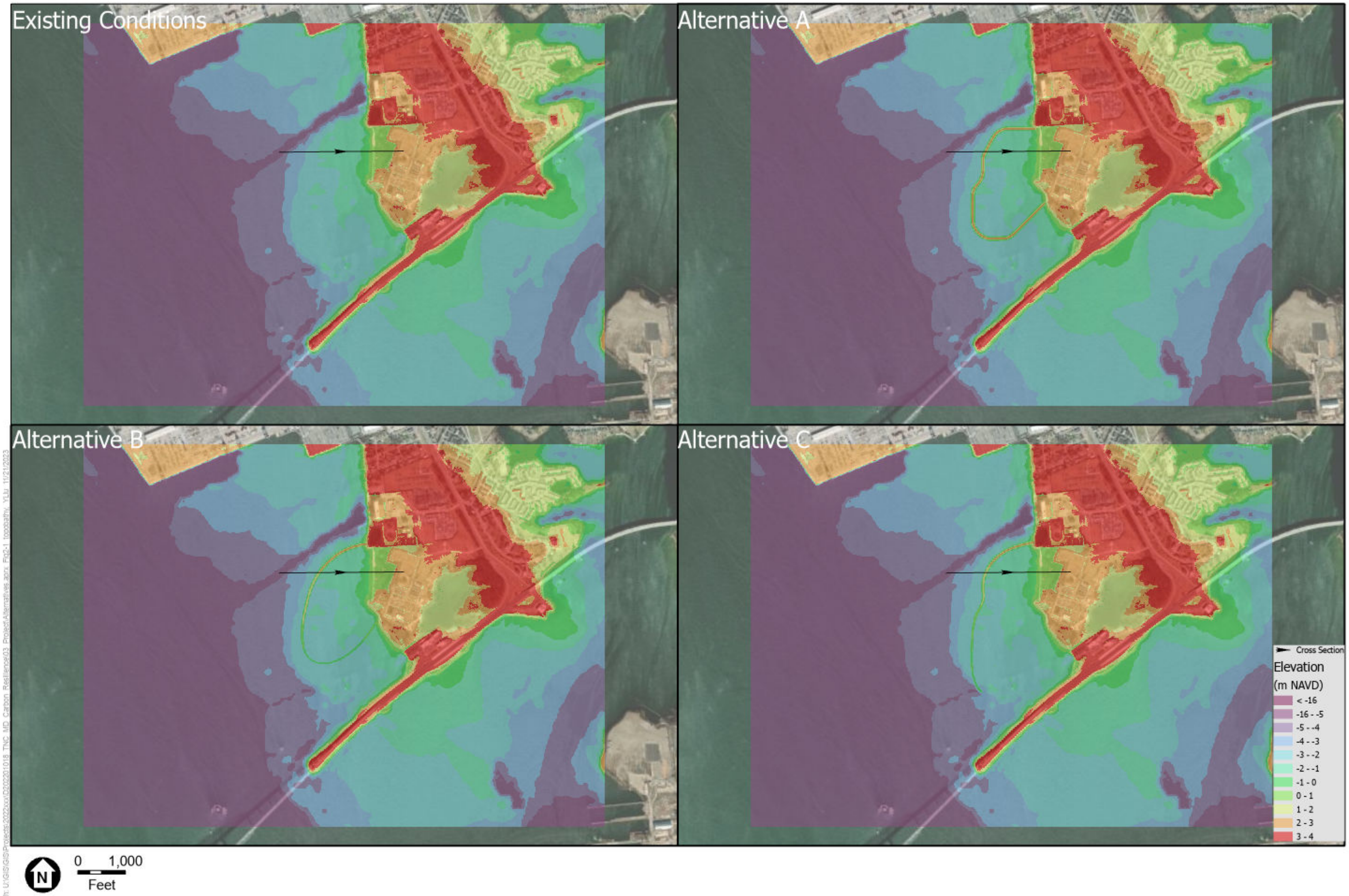
Comprehensive datasets of topographic, wind, and water level information were gathered and used to estimate wind waves and coastal flooding at the project site. This section provides a detailed description and analysis of the datasets utilized. Where available, long-term data sets were used to allow for a more accurate statistical representation of extreme events.

2.1 Topography and Bathymetry

For this study, the existing condition topographic and bathymetric data were obtained from the Coastal National Elevation Database (CoNED) by the US Geological Survey (USGS). Compiled in 2016 (OCM Partners, 2023), CONED integrates LiDAR and bathymetric data from various sources into a unified 3D database aligned both vertically and horizontally to a common reference system. For the three design alternatives, additional topographic and bathymetric data were obtained from The Nature Conservancy. All data adheres to meter NAVD and UTM Zone 18N with a 1-m horizontal resolution (**Figure 2-1**).

2.2 Water Elevations

The Baltimore tide gauge (NOAA Station 8574680) located in the Patapsco River near Baltimore Inner Harbor provided representative tide elevation data for this study (**Figure 2-2**). This tide gauge is tied into the NAVD88 datum and has established tidal datum relationships provided in **Table 2-1**. The greater diurnal tide range (MLLW to MHHW) at this location is 1.66 feet, with the highest observed tide surpassing MHHW by approximately 6.49 feet. This shows that although the tide range is small in this area, storm surge plays a major role in water level increases.

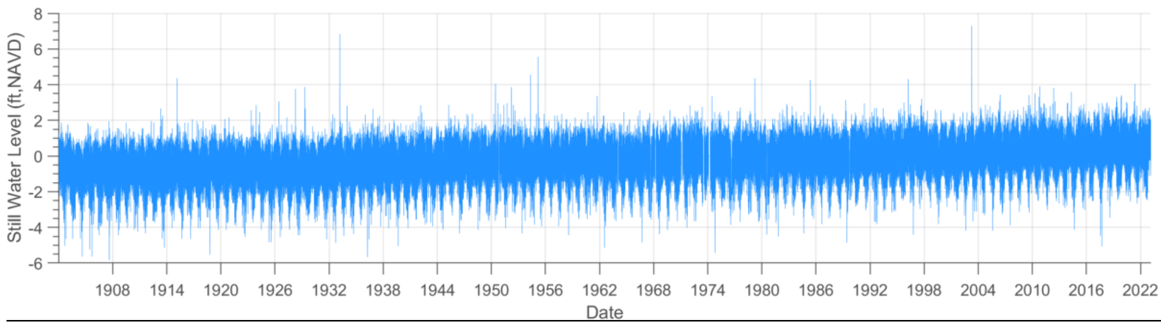


SOURCE: USGS (2016), TNC (2023)

TNC Maryland Blue Carbon Resilience Credit Analysis

Figure 2-1
Topography and Bathymetry at the Project Site
Existing Condition and Alternative Designs

ESA



SOURCE: NOAA (2023)

TNC Maryland Blue Carbon Resilience Credit Analysis

Figure 2-2
Still Water Level Time Series at Baltimore, MD

TABLE 2-1
TIDAL DATUMS IN BALTIMORE, MD (STA. 8574680, EPOCH 1983-2001)

Tidal Datum		Elevation, feet NAVD88
Highest Observed (9/19/2003)	HOT	7.31 (12:06 PM)
Highest Astronomical Tide (7/2/2004)	HAT	1.38 (11:06 AM)
Mean Higher High Water	MHHW	0.82
Mean High Water	MHW	0.53
Mean Tide Level	MTL	-0.05
Mean Sea Level	MSL	-0.03
Diurnal Tide Level	DTL	-0.01
Mean Low Water	MLW	-0.62
North American Vertical Datum	NAVD	0.00
Mean Lower Low Water	MLLW	-0.84
Lowest Astronomical Tide (1/22/2023)	LAT	-1.49 (5:42 PM)
Lowest Observed (1/24/1908)	LOT	-5.94 (9:00 PM)

NOTES: Abbrev. = abbreviation for tidal datum; NAVD88 = North American Vertical Datum of 1988
SOURCE: NOAA 2023

2.3 Wind Data

Wind data were collected from nearby meteorological stations, listed on Table 2-2 with the wind directional distribution and station locations visually depicted in Figure 2-3. The wind data were evaluated and adjusted to a standardized duration of two minutes, at a height of 10 meters, and corrected from wind over land to wind over water according to Resio and Vincent (1977) and the Coastal Engineering Manual (CEM) (USACE 2006).

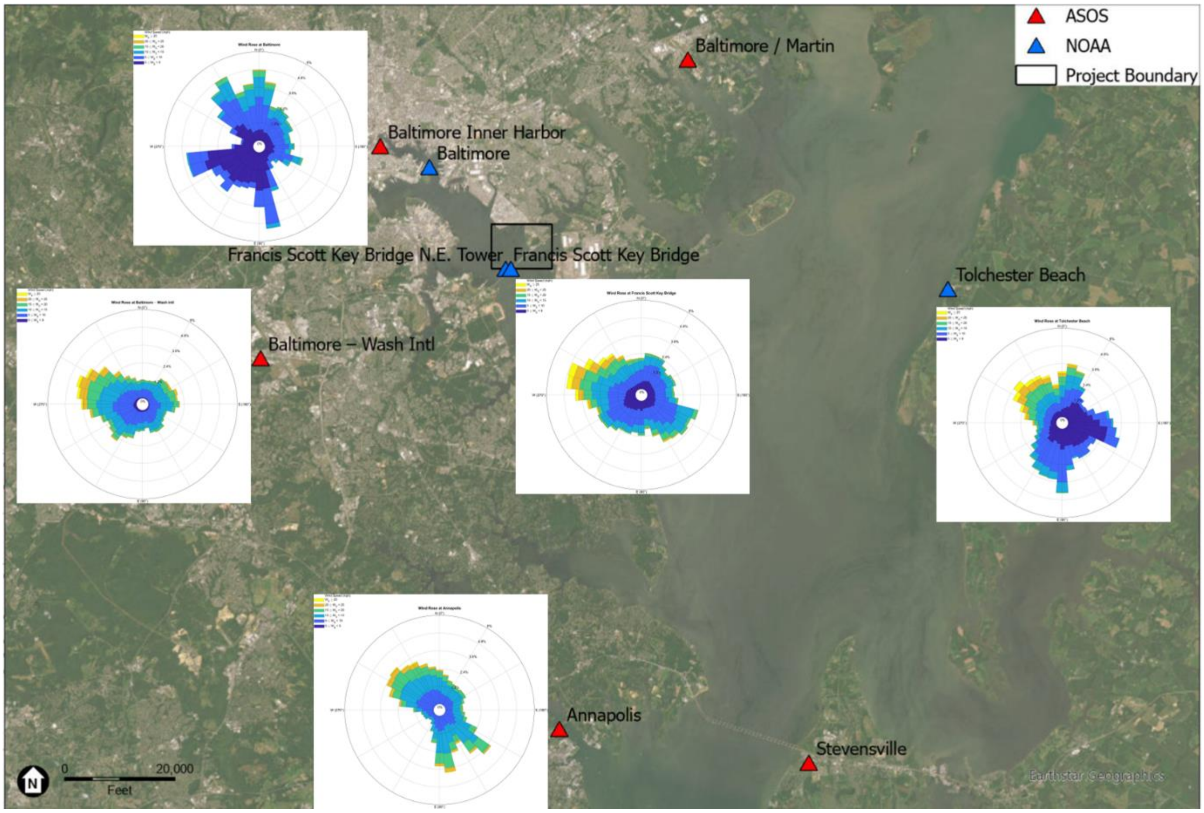
Based on the examination of the data length and data quality of all the stations, the following were selected to further investigate their wind speed and direction distributions: Francis Scott Key Bridge, Tolchester Beach, Baltimore, Baltimore – Wash Intl, and Annapolis. **Figure 2-3** shows the wind roses of the selected stations. The wind direction is reported following the meteorological convention, i.e., as the direction from which the wind is blowing. Due to its vicinity, wind rose at the Francis Scott Key Bridge is believed to represent the wind conditions at the project site the best. The figure illustrates that the prevailing wind directions are from the northwest. Winds from the northwest exhibit the highest wind speeds, with maximums speeds exceeding 25 mph. Baltimore – Wash Intl also shows the same wind conditions with a much longer data record compared to Francis Scott Key Bridge

TABLE 2-2
WIND OBSERVATIONS NEAR THE PROJECT SITE

Station Name	Station ID	Data Record	Notes
NOAA Stations			
Francis Scott Key Bridge	8574728	19 years (04/15/2004 – present)	Data gaps • 04/01/2019 – 12/31/2019
Francis Scott Key Bridge N.E. Tower	8574729	16 years (10/01/2007 - present)	Data gaps • 02/01/2008 – 21/29/2008 • 07/18/2017 – 11/29/2017
Tolchester Beach	8573364	29 years (09/12/1994 – present)	
Baltimore	8574680	15 years (06/01/2008 – present)	Data gaps • 07/01/2019 – 08/31/2019
ASOS Stations[1]			
Baltimore Inner Harbor	DMH	25 years (1998 – present)	Most wind speed is NaN.
Baltimore / Martin	MTN	53 years (1970 – present)	Contains unrealistically large wind speed
Baltimore – Wash Intl	BWI	78 years (1945 – present)	Data gaps • 2021
Annapolis	NAK	76 years (1948 – present)	Data gaps • 1963 – 2000
Stevensville	W29	17 years (2006 - present)	Data gaps • 2021 Contains unrealistically large wind speed

[1] Airport stations

Wind measurements obtained from ASOS's Baltimore – Wash Intl (BWI) were selected to represent the wind conditions at the project site due to the length, completeness, and representativeness of their wind directional distribution on the project site.



SOURCE: NOAA (2023), ASOS (2023), ESA (2023)

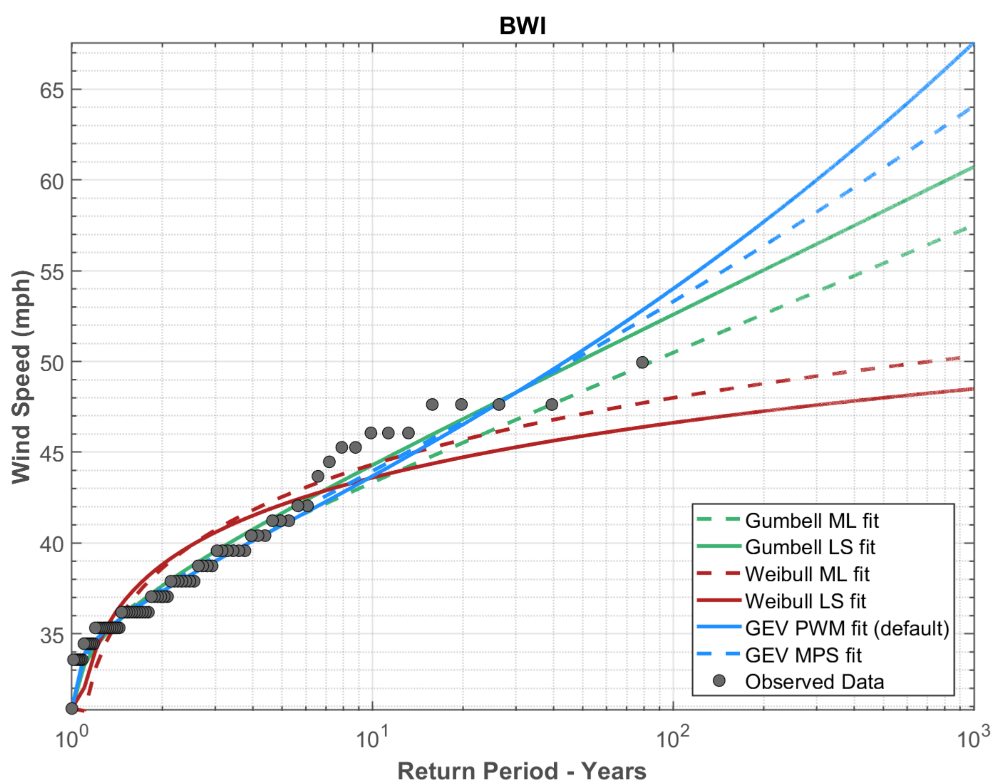
TNC Maryland Blue Carbon Resilience Credit Analysis

Figure 2-3
Wind roses at selected NOAA and ASOS Wind Stations

3. STORM FREQUENCY ANALYSIS

3.1 Extreme Wind Speed Analysis

The adjusted BWI wind data were used for an extreme-value analysis of the annual maximum wind speed (**Figure 3-1**). For each of the 78 years in the wind record, the annual maximum wind speed from any direction was identified, and these annual maximums were fit to a Generalized Extreme Value (GEV) function. The Gumbel and Weibull extreme-value functions were also tested on the annual maximums, but these functions did not provide as good a fit of the data as the GEV distribution. Results show that at BWI, 1-year events are about 30.9 mph, and a 10-year event will reach wind speeds up to 43.7 mph, while the more extreme 100-year event can reach wind speeds as high as 54 mph. These findings are summarized in **Table 3-1**.



SOURCE: NOAA (2023), ASOS (2023)

TNC Maryland Blue Carbon Resilience Credit Analysis

Figure 3-1
Extreme Value Plots at ASOS BWI station

TABLE 3-1
EXTREME WIND SPEED VALUES

Return Period (years)	Wind Speed (mph) at BWI
1	30.9
2	37.3
5	41.0
10	43.7
20	46.5
50	50.6
100	54.0

3.2 Historical Storms

ESA conducted a record search of major historical storms that made landfall or passed by the project site and documented the wind speed and water level anomaly at the closest NOAA stations. Results are summarized in **Table 3-2**. Due to the relative orientation of the project site and storm tracks, some major hurricanes (Floyd and Irene) caused lower water levels (set-downs) instead of higher water levels (set-ups) as recorded by the Baltimore water level station (ID 8574680).

TABLE 3-2
HISTORICAL HURRICANES NEAR THE PROJECT SITE

Hurricane Name	Start	End	Wind Speed[1] (mph)	Water Level Anomaly[2] (ft)
Ginger	9/6/1971	10/5/1971	n/a (no data)	1.4
David	8/25/1979	9/8/1979	n/a (no data)	3.1
Frederic	8/29/1979	9/15/1979	n/a (no data)	1.8
Bertha	7/5/1996	7/17/1996	28.4	1.4
Fran	8/23/1996	9/10/1996	16.3	4.4
Dennis	8/24/1999	9/8/1999	15.7	2.0
Floyd	9/7/1999	9/19/1999	42.5	set-down
Isabel	9/6/2003	9/20/2003	20.1	6.9
Ivan	9/2/2004	9/24/2004	33.6	2.3
Ernesto	8/24/2006	9/4/2006	n/a (gauge fail)	2.3
Hannah	8/28/2008	9/8/2008	35.8	1.6
Irene	8/20/2011	8/28/2011	44.7	set-down
Sandy	10/22/2012	11/2/2012	40.3	3.3
Isaias	7/28/2020	8/5/2020	44.7	1.6
Ida	8/26/2021	9/4/2021	31.3	2.3

NOTES:
[1] measured at NOAA Tolchester Beach Meteorological Station.
[2] measured at NOAA Baltimore Water Level Station.
SOURCE: NOAA (2023)

For the other major hurricanes, the water level anomaly shows an increase of water levels typically from 1.5 to 3.5 ft, while Hurricane Isabel caused an exceptionally high surge of 6.9 ft, likely due to the strong northwest onshore winds at the Baltimore Inner Harbor as a result of the relative location and orientation of Isabel's track near landfall Hurricane Fran with a similar track caused the second highest surge of 4.4 ft.

This shows that while the tide range (MHHW-MLLW) in the project area is about 1.3 ft, the storm surges caused by hurricanes have a major impact with a range of 1.5 to 3.5 ft. Hurricanes also bring high winds with wind events with return periods from 1-year to 20-year to the region (Table 3-1).

4. WATER LEVEL ANALYSIS

4.1 Sea Level Rise Projections

The Sea-level rise projections for Maryland 2023 guidance document (Boesch et al. 2023) incorporates the most recent scientific findings in the Sixth Assessment Report (AR6) by the Intergovernmental Panel on Climate Change (IPCC) and beyond. Boesch et al. presents the following recommendations relevant to our project:

- "The *Current commitments* sea-level rise projections, based on the intermediate (SSP2-4.5) emissions scenario of the IPCC AR6, represent the most plausible basis for anticipating the relative sea-level rise Maryland will experience over the next century."
- "*Best estimates* (median, 50th percentile) are recommended as the sea-level rise estimates for managing or restoring natural infrastructures unless the project scoping determines otherwise."

Following these recommendations, the median sea-level rise projections assuming current commitments (SSP2-4.5) for Baltimore (the gauge closest to our project site) listed in Boesch et al. 2023's Appendix 1 (**Figure 4-1**) was used in this analysis and summarized along with extreme water levels. Note that the projected changes are relative to a baseline of the 1995-2014 average (circa 2005), so an adjustment of the sea-level change from 2005 to present (2023) is needed.

4.2 Sea Level Trends

Linear, mean sea level trends at the Baltimore tide gage have been calculated by NOAA between 1902 and 2022. The trend shows an increase in sea level of approximately 0.01 ft/year (3.24 mm/year). The available tidal data was used to develop a tide time series that was corrected (normalized) for historic sea-level rise. To normalize for present day flood risk, the trend in historic water level data was removed according to this absolute sea-level rise rate (**Figure 4-2**).

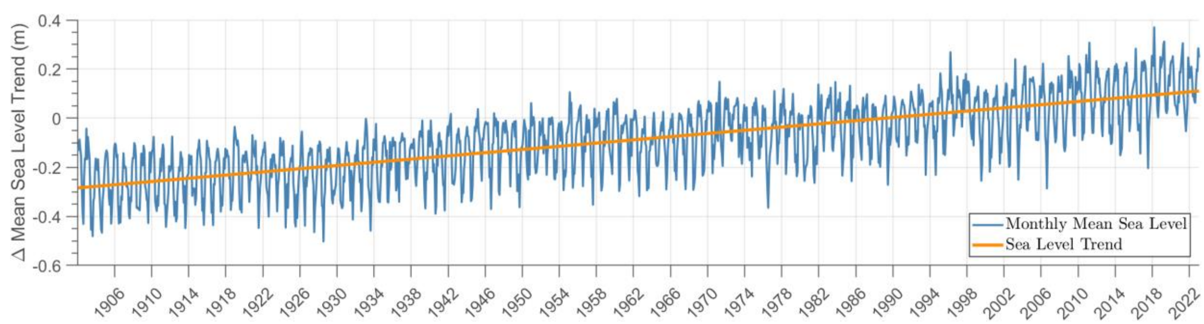
Appendix 1. Sea-level rise projections with quantile probabilities for Baltimore under the three most plausible emissions scenarios.

	Scenario		Quantile	2020	2030	2040	2050	2060	2070	2080	2090	2100	2110	2120	2130	2140	2150
METERS	Paris Agreement	SSP1-2.6	5	0.04	0.09	0.14	0.20	0.25	0.31	0.35	0.39	0.43	0.44	0.47	0.49	0.52	0.54
			17	0.07	0.13	0.19	0.26	0.32	0.38	0.43	0.47	0.52	0.54	0.58	0.61	0.65	0.68
			50	0.10	0.19	0.27	0.35	0.42	0.50	0.56	0.62	0.68	0.74	0.80	0.86	0.91	0.97
			83	0.14	0.25	0.36	0.46	0.55	0.64	0.73	0.81	0.90	1.00	1.09	1.18	1.27	1.36
			95	0.17	0.30	0.42	0.54	0.65	0.76	0.87	0.98	1.08	1.21	1.32	1.44	1.55	1.66
	Current commitments	SSP2-4.5	5	0.04	0.08	0.14	0.22	0.30	0.37	0.43	0.49	0.51	0.52	0.58	0.63	0.68	0.73
			17	0.07	0.13	0.19	0.27	0.35	0.43	0.51	0.57	0.62	0.65	0.72	0.79	0.85	0.92
			50	0.10	0.19	0.27	0.36	0.45	0.55	0.64	0.72	0.82	0.90	1.00	1.10	1.19	1.29
			83	0.14	0.25	0.36	0.46	0.57	0.69	0.81	0.93	1.08	1.23	1.37	1.50	1.64	1.78
			95	0.18	0.30	0.42	0.54	0.67	0.81	0.96	1.11	1.30	1.48	1.65	1.82	1.99	2.16
	Increasing emissions	SSP3-7.0	5	0.04	0.07	0.14	0.22	0.31	0.40	0.48	0.56	0.65	0.66	0.73	0.81	0.89	0.96
			17	0.06	0.12	0.19	0.28	0.36	0.46	0.56	0.65	0.75	0.78	0.87	0.97	1.06	1.14
			50	0.10	0.18	0.27	0.36	0.46	0.57	0.68	0.81	0.94	1.03	1.16	1.29	1.41	1.54
			83	0.15	0.25	0.35	0.47	0.58	0.71	0.86	1.03	1.21	1.36	1.54	1.72	1.89	2.07
			95	0.18	0.30	0.42	0.55	0.67	0.84	1.02	1.23	1.44	1.64	1.86	2.07	2.29	2.51
FEET	Paris Agreement	SSP1-2.6	5	0.13	0.30	0.46	0.65	0.83	1.02	1.15	1.27	1.41	1.43	1.53	1.61	1.70	1.78
			17	0.22	0.42	0.63	0.85	1.04	1.25	1.40	1.54	1.70	1.77	1.89	2.00	2.12	2.22
			50	0.34	0.61	0.88	1.15	1.38	1.63	1.83	2.03	2.23	2.42	2.62	2.81	3.00	3.18
			83	0.47	0.82	1.16	1.51	1.79	2.11	2.40	2.67	2.95	3.29	3.59	3.88	4.18	4.47
			95	0.57	0.97	1.38	1.78	2.12	2.50	2.86	3.20	3.55	3.95	4.33	4.71	5.08	5.45
	Current commitments	SSP2-4.5	5	0.13	0.27	0.46	0.72	0.97	1.20	1.42	1.60	1.68	1.72	1.90	2.07	2.24	2.40
			17	0.22	0.41	0.63	0.90	1.16	1.42	1.66	1.88	2.04	2.15	2.37	2.59	2.80	3.01
			50	0.34	0.61	0.89	1.18	1.47	1.79	2.09	2.37	2.69	2.97	3.29	3.60	3.91	4.22
			83	0.47	0.82	1.16	1.52	1.86	2.27	2.65	3.06	3.54	4.02	4.48	4.93	5.39	5.84
			95	0.57	0.98	1.37	1.78	2.18	2.66	3.15	3.63	4.25	4.84	5.41	5.97	6.52	7.08
	Increasing emissions	SSP3-7.0	5	0.11	0.24	0.44	0.71	1.01	1.30	1.57	1.83	2.13	2.15	2.41	2.66	2.91	3.15
			17	0.21	0.39	0.62	0.90	1.19	1.51	1.82	2.13	2.47	2.56	2.86	3.17	3.46	3.75
			50	0.34	0.60	0.88	1.19	1.50	1.86	2.24	2.65	3.08	3.39	3.81	4.23	4.64	5.04
			83	0.48	0.82	1.16	1.53	1.89	2.33	2.83	3.39	3.96	4.48	5.06	5.64	6.21	6.78
			95	0.58	0.98	1.38	1.80	2.21	2.74	3.34	4.04	4.74	5.38	6.09	6.80	7.51	8.23

SOURCE: Boesch et al. (2023)

TNC Maryland Blue Carbon Resilience Credit Analysis

Figure 4-1
Sea-level rise projections for Baltimore



SOURCE: NOAA (2023), ESA (2023)

TNC Maryland Blue Carbon Resilience Credit Analysis

Figure 4-2
Monthly Mean Sea Level (Tidal Datum) Trend from 1906 to 2014 at Baltimore Tide Station

Water levels in the past were increased by the historic sea-level rise rate multiplied by the number of years before the present. By raising the historic elevations, de-trending accounts for the consequence of historic conditions occurring at present day mean sea level conditions. Therefore, the historical sea-level rise rate of 0.01 ft/year is used to adjust the sea-level projections relative to 2005 to sea-level projections relative to present. The values before and after adjustments are presented in **Table 4-1**.

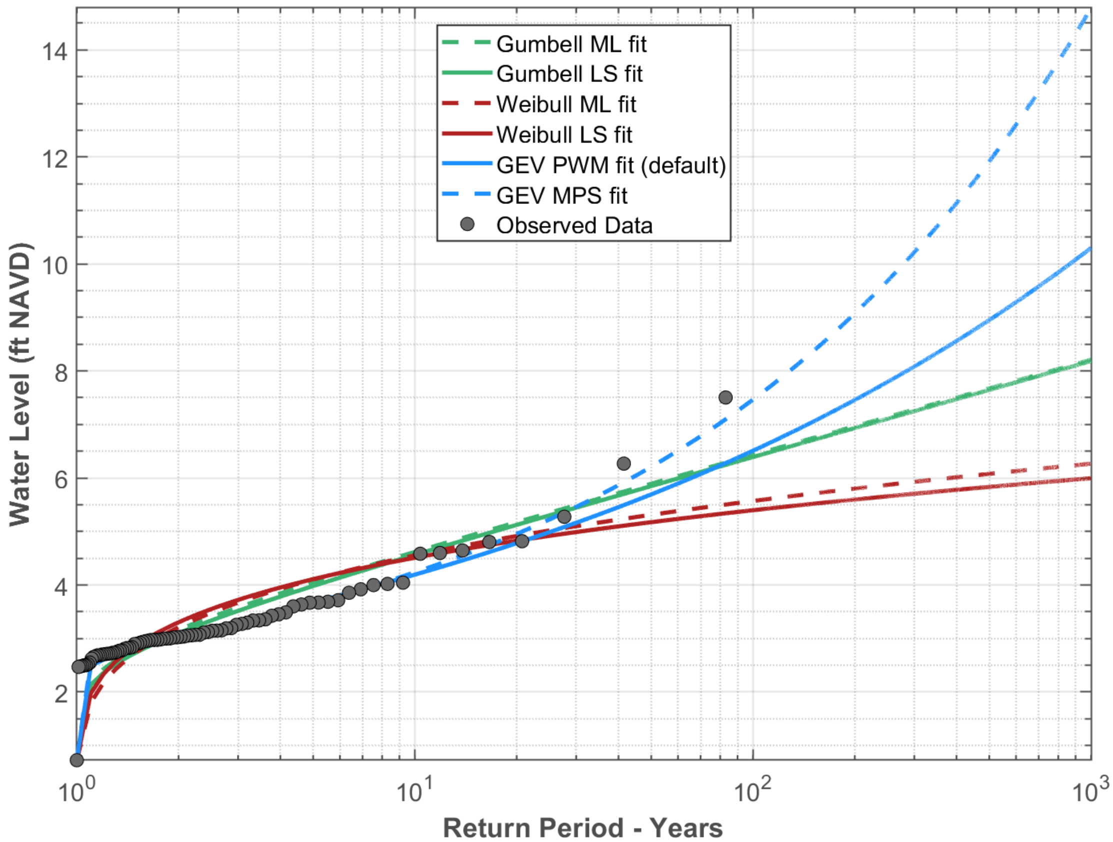
TABLE 4-1
SEA-LEVEL RISE PROJECTIONS IN BALTIMORE

Year	SLR (ft, relative to 2005)	SLR (ft, relative to present)
2030	0.61	0.43
2050	1.18	1
2100	2.69	2.51

4.3 Extreme Water Level Analysis

The water level record from the NOAA Baltimore tide gage described in Section 2 was analyzed using a time series approach and an extreme value approach to determine future typical and extreme water levels. The methods and results of this analysis are described below.

An extreme-value analysis of the recent 62 years of recorded full-year hourly water levels from 1940 to 2022 was conducted based on the de-trended tide data at the Baltimore tide station. From the de-trended time series, the maximum water level from each year was obtained and fit to a Gumbel, Weibull, and the General Extreme Value Distribution (GEV) as shown graphically in **Figure 4-3**. Several distributions were examined to find the best distribution for the data set. In this case, the GEVMPS distribution provided the best fit to the majority of the extreme data. **Table 4-2** summarizes the extreme water levels obtained from the GEVMPS distribution and shows the projected extreme water levels with the different sea-level rise scenarios described in Section 4.1 and 4.2



SOURCE: NOAA (2023), ESA (2023)

TNC Maryland Blue Carbon Resilience Credit Analysis

Figure 4-3
Water Level Extreme Value Analysis

TABLE 4-2
EXTREME WATER LEVELS IN FEET NAVD

Return Period (years)	Present	2030 (0.43 ft SLR)	2050 (1.00 ft SLR)	2100 (2.51 ft SLR)
1	0.7	1.2	1.7	3.2
2	3.0	3.5	4.0	5.6
5	3.7	4.1	4.7	6.2
10	4.2	4.7	5.2	6.7
20	5.0	5.4	6.0	7.5
50	6.2	6.6	7.2	8.7
100	7.5	7.9	8.5	10.0

5. WAVE ANALYSIS

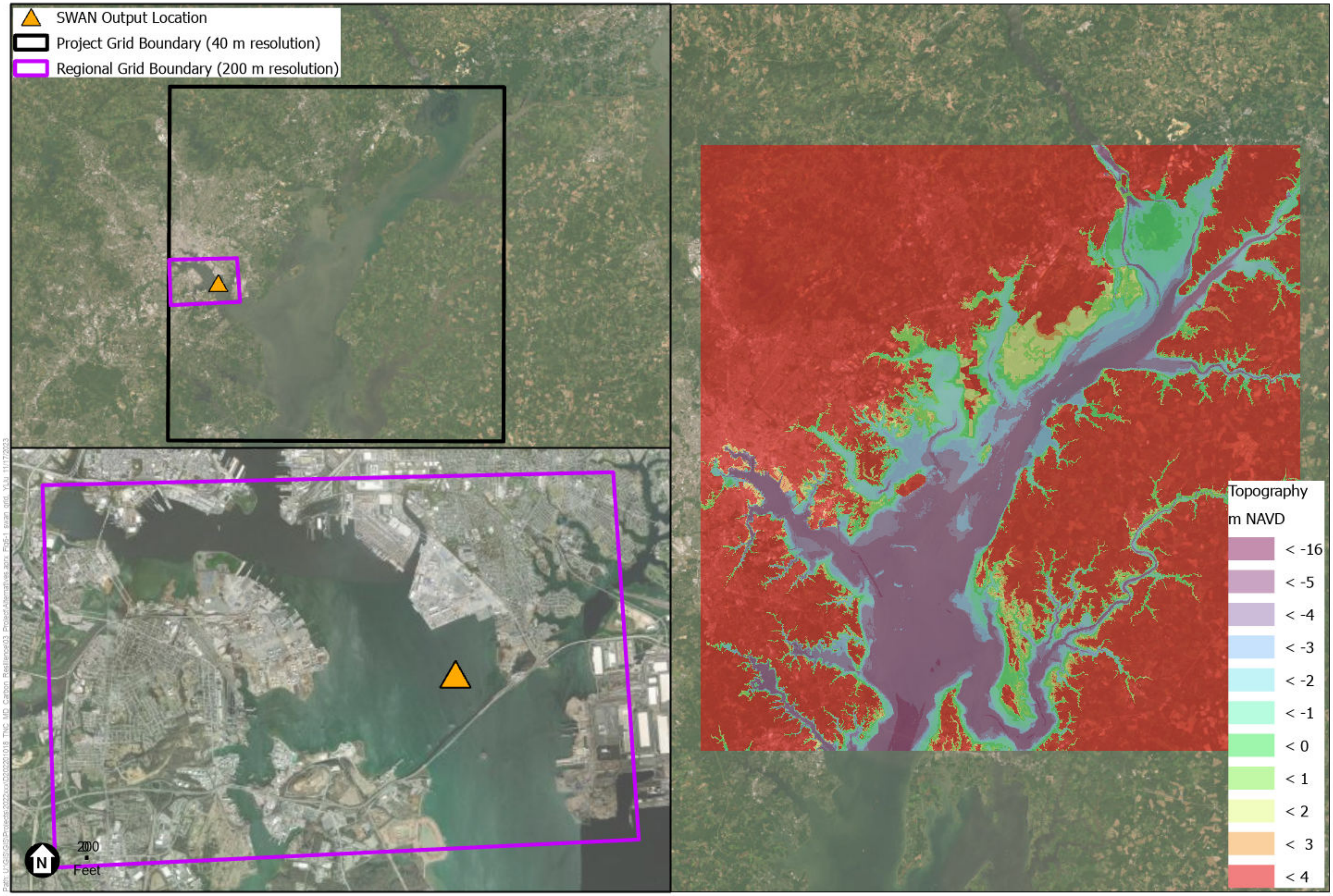
Wind waves are a function of wind speed, wind direction, water levels, and the site's geometry and bathymetry. Due to limited direct measurements of waves in the Chesapeake Bay, a numerical model was implemented to estimate wind wave conditions near the project site. This process, known as wind-wave hindcasting, involves calculating wave conditions using measured winds and other relevant data associated with the water body's geometry. Wind wave hindcasting is conducted when direct wave measurements are unavailable. The wind speed and direction, duration of the wind, fetch (length across which the wind is blowing), and water depth across that fetch are the parameters that determine the wave height, wave period, and direction of the locally generated wind waves at the site.

5.1 Regional Wave Model

This section describes the model configuration used in this study, including model grid development and scenario selection. ESA modeled the wave conditions using the industry-standard Simulating Waves Nearshore (SWAN) model. This two-dimensional model predicts waves likely to occur in response to wind speed, wind direction, water level, shoreline geometry, and bathymetry. The relevant wave processes included in the SWAN model include wave generation, refraction, shoaling, and breaking. The SWAN model was implemented using the Delft3D modeling suite (Deltares, 2014).

5.1.1 Model Configuration

The SWAN model was implemented using nested, rectilinear grids with varying levels of spatial resolution across northern Chesapeake Bay region (**Figure 5-1**). The regional SWAN grid employed in the model, with a cell size of 200 m by 200 m, was used to simulate wave growth and propagation through northern Chesapeake Bay. The project grid, which has a cell size of 40 m by 40 m, was utilized to evaluate the localized effects of bathymetric variation and wave sheltering as pertinent to this study.



SOURCE: ESA (2023), USGS (2016)

TNC Maryland Blue Carbon Resilience Credit Analysis

Figure 6-1
SWAN Wave Model Grids Coverage (left) and Bathymetry (right)

ESA

5.1.2 Scenarios

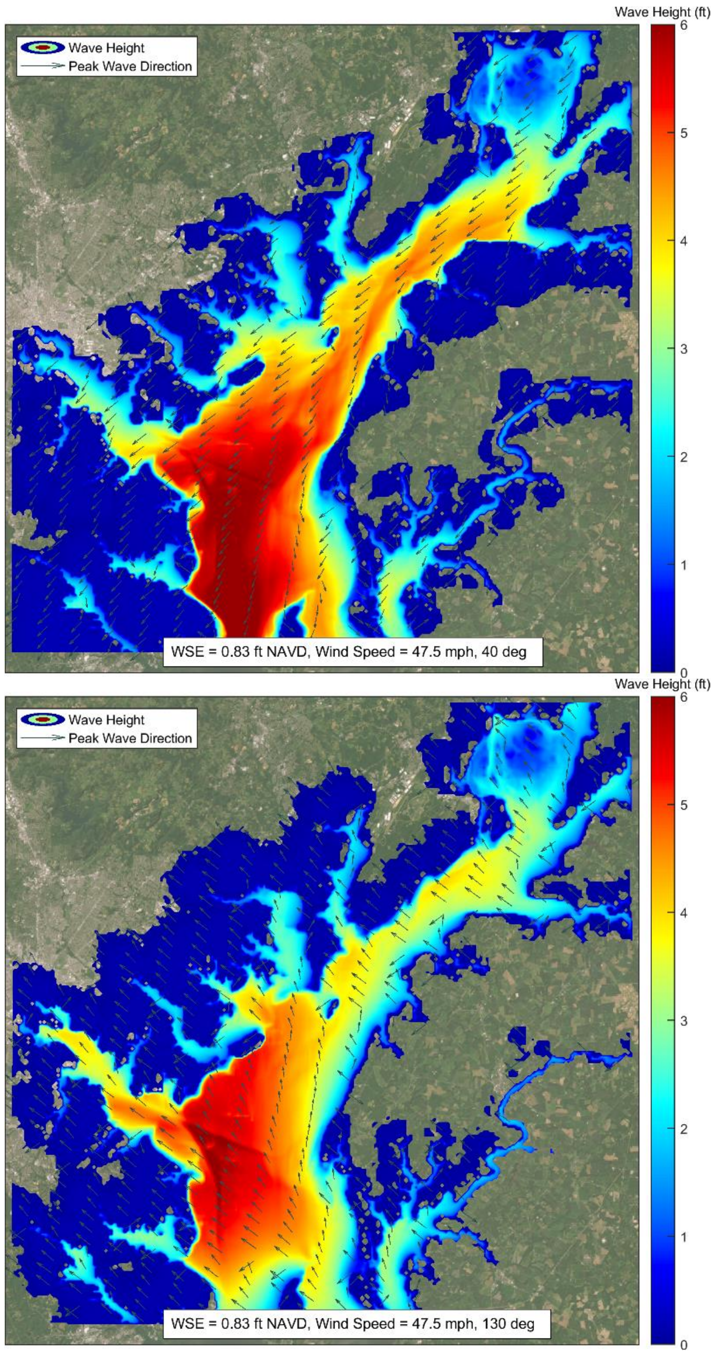
The SWAN model was implemented to investigate the full range of combinations of wind speed and wind direction that are likely to occur in northern Chesapeake Bay near the project site. The wind speed was systematically varied in 5-mph increments ranging from 2.5 mph to 47.5 mph. Wind directions varied from 10 degrees to 360 degrees with 10-degree increments to account for all the possible fetch directions.

In total, the SWAN model simulated 360 unique input combinations to provide a high-resolution wind-wave hindcasting record at the site (Figure 5-1, bottom left). The combination of different wind speeds and wind directions allowed the model to generate wave fields that represent typical wave conditions within northern Chesapeake Bay near the project site.

5.1.3 Model Output

The SWAN model outputs simulated wave information at each model grid cell, providing information for a subsequent comprehensive assessment of wave characteristics and their temporal evolution at locations of interest, which is important for understanding wave-induced hazards that can occur at the site.

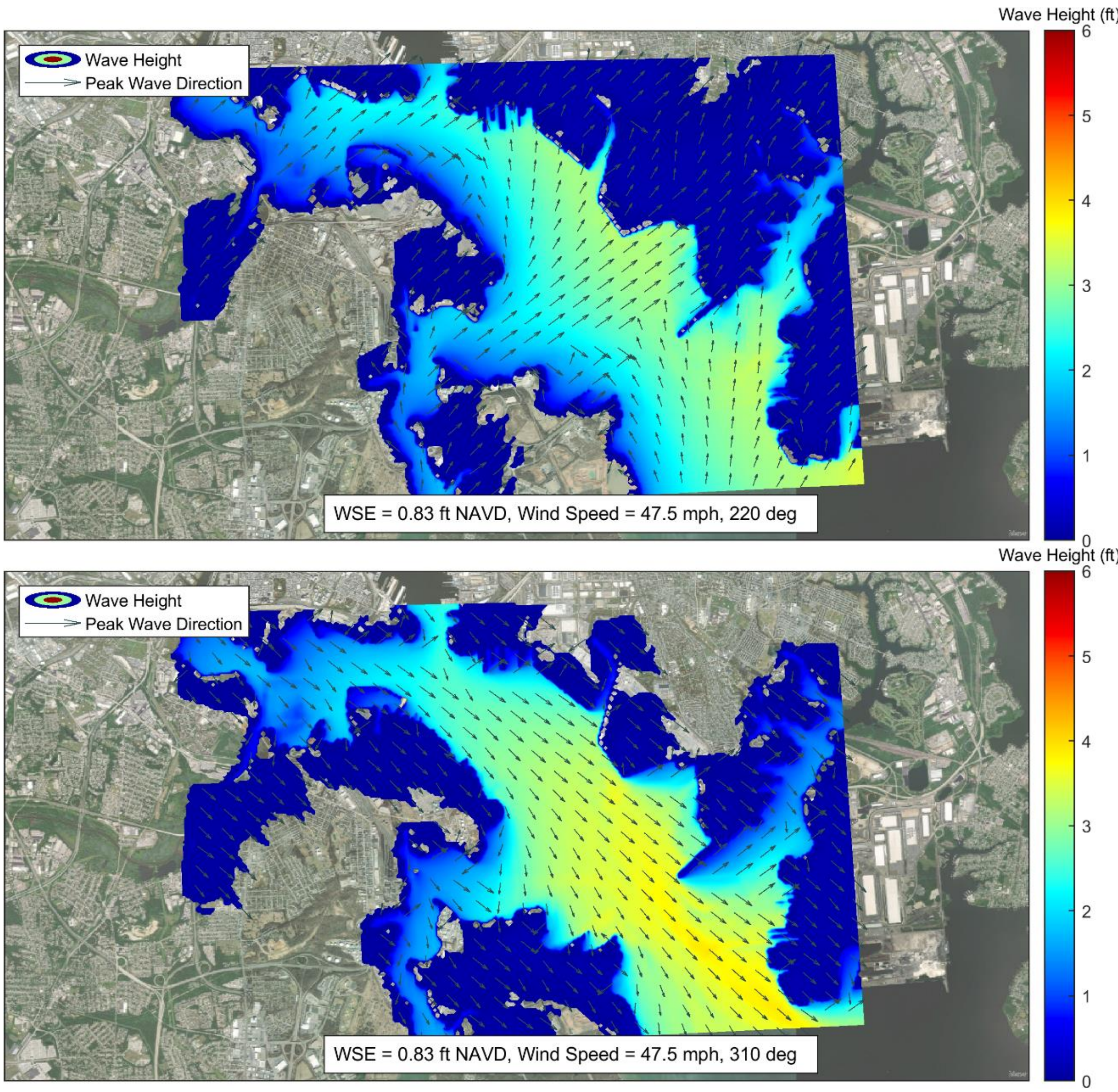
Figure 5-2 shows the regional SWAN model results with wave height as surface and peak wave direction as vectors for two extreme wind events (~ 20-year event based on Table 4-1) with winds from the northeast and southeast, the longer fetches for the region. The project SWAN model results (nested grid) with the same wind speed but from the northwest and southwest (the longer fetches for the project area) are shown in **Figure 5-3**.



SOURCE: ESA (2023)

TNC Maryland Blue Carbon Resilience Credit Analysis

Figure 5-2
Regional SWAN Model Results for an approximately 20-year Wind Event



SOURCE: ESA (2023)

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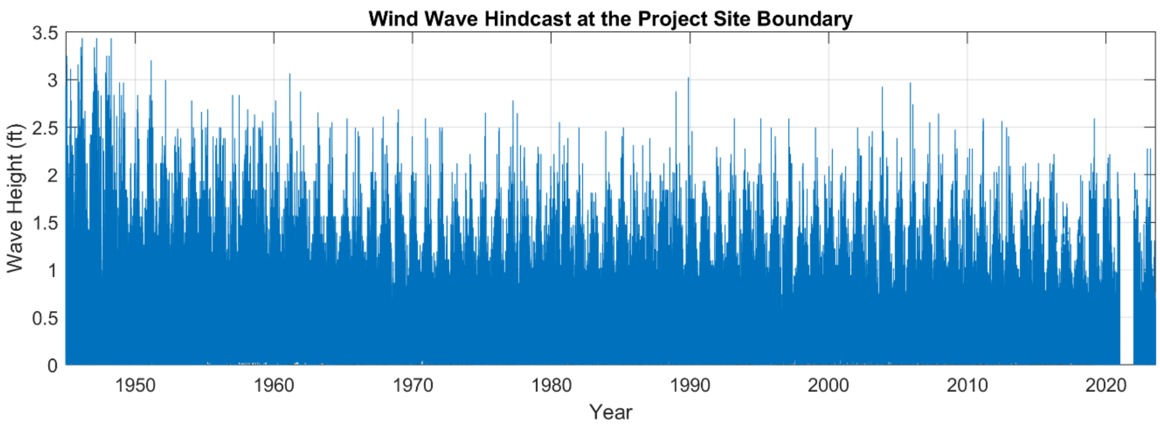
Figure 5-3
Project SWAN Model Results for an approximately 20-year Wind Event

Wave height, period, and direction resulting from the wind-wave interactions were extracted from the SWAN model at a location along the -5 m topography contour, as shown in **Figure 5-1** (bottom left)**.** The extracted data were then tabulated in a look-up table that associated wind velocity and direction with the corresponding wave parameters (wave height, period, and direction) at the output location.

5.2 Wind Wave Hindcast

The look-up table generated from the previous section was utilized to create a time series of nearshore wave parameters, by employing a hindcasting method. This method involved using observed hourly measurements of wind speed and direction. Wind data measured at Baltimore – Wash Intl (ASOS, Station ID BWI) from 1945 to 2023 was analyzed and applied as input to model the full range of wind speeds and fetch directions that generate waves near the project site. Consequently, a comprehensive hindcast dataset of wind waves of approximately 77-year period was generated. The resulting time series of wave heights is shown in **Figure 5-4**.



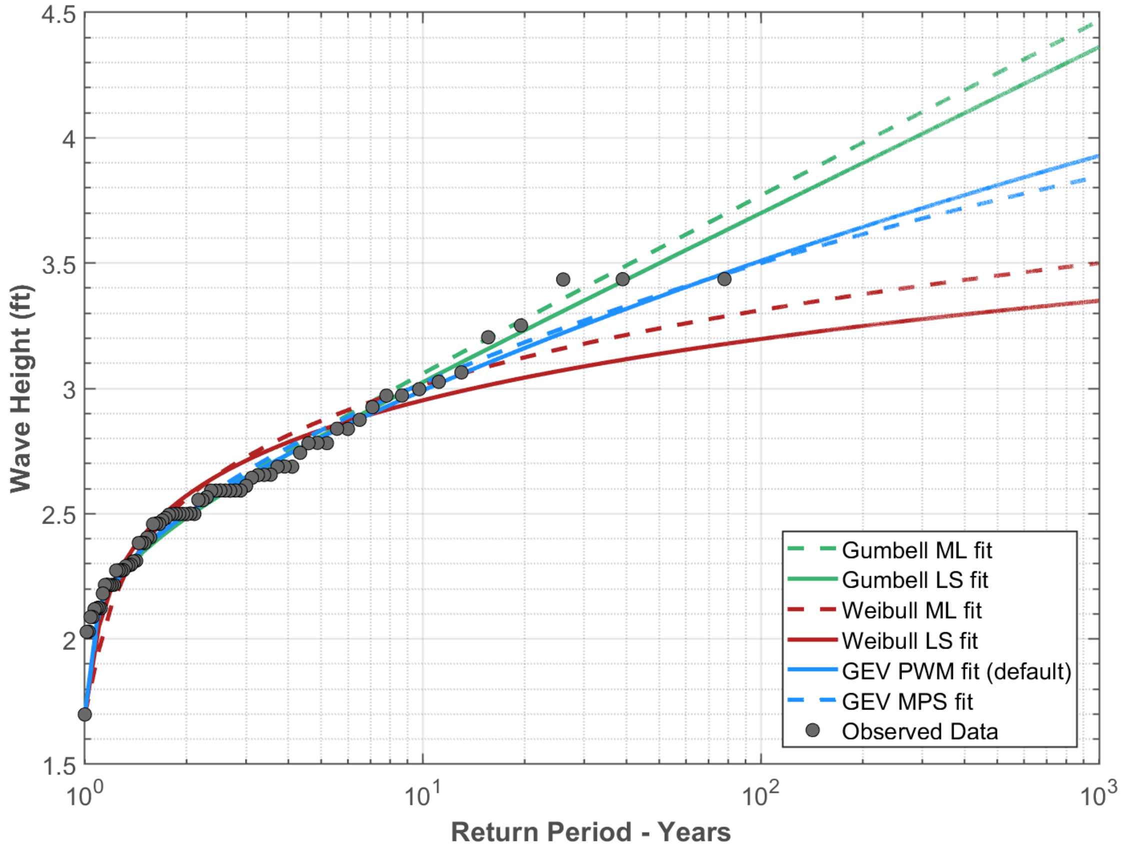
SOURCE: ESA (2023)

TNC Maryland Blue Carbon Resilience Credit Analysis

Figure 5-4
Wind Wave Hindcast Using BWI Wind and SWAN Outputs at the Project Site Boundary

5.3 Extreme Wave Height Analysis

An extreme value analysis was conducted on the estimated 77-year wave height time series. The maximum wave height value for each year was found and subsequently fitted to Gumbel, Weibull, and GEV distributions as shown graphically in **Figure 5-5**, with the GEV Maximum Product of Spacings (MPS) distribution showing the best fit. **Table 5-1** summarizes the return periods and annual probability from the GEV MPS distribution. The 100-year (or 1% annual chance) significant wave height is estimated to be 3.5 ft at the project site boundary.



SOURCE: ESA (2023)

TNC Maryland Blue Carbon Resilience Credit Analysis

Figure 5-5
Extreme Analysis of Wave Height at the Project Site Boundary

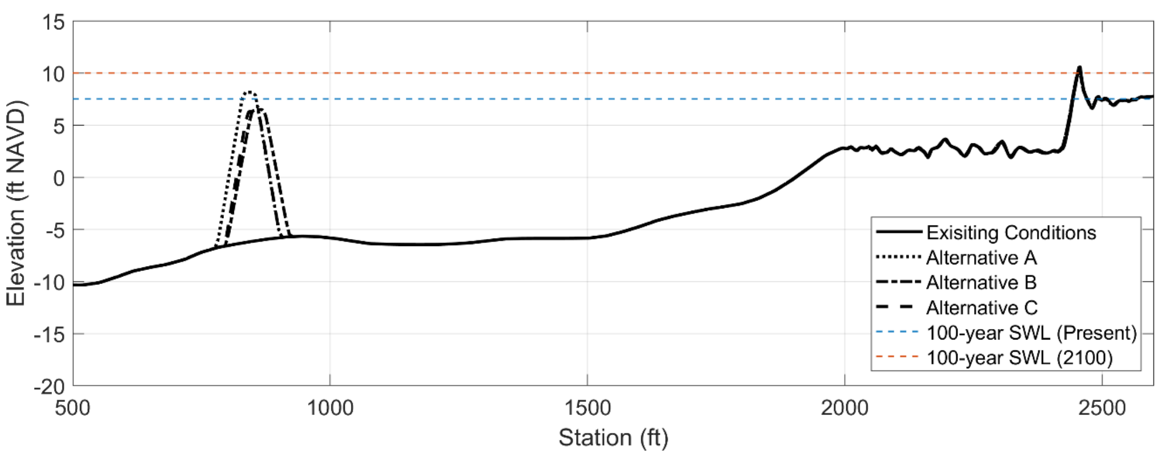
TABLE 5-1
EXTREME WAVE HEIGHTS AT THE PROJECT SITE BOUNDARY(FT)

Return Period (years)	GEV (MPS)
1	1.7
2	2.5
5	2.8
10	3.0
20	3.2
50	3.4
100	3.5

6. COASTAL FLOOD ANALYSIS

To accurately the impact of waves on the shore that takes into account dynamic setup, and complex bathymetry, waves were modeled using a storm response model, XBeach, on non-hydrostatic mode (Roelvink et al., 2009), which allows for a quantitative estimate of complex processes such as the peak wave runup, overtopping flow, and velocity. The 2D version of the XBeach model was used to estimate wave runup, the peak water level, and the landward extent of flooding.

Before running XBeach**,** an analytical assessment was conducted to examine the comparison of the project site topography and extreme water levels. **Figure 6-1** shows the elevation profiles along the cross section (shown in **Figure 2-2**) for the existing conditions and all three alternatives. The 100-year still water levels for present and 2100 from Table 4-2 were also plotted as references. It can be observed that the inland areas behind the marsh are relatively high and would not get flooded during a 100-year event in 2100 under current sea level rise estimations and guidelines. However, higher sea level rise scenarios estimations or guidelines (e.g., xxx scenario in Figure 4-1) will show that coastal inundation will start occurring before year 2100.



SOURCE: TNC (2023), ESA (2023)

TNC Maryland Blue Carbon Resilience Credit Analysis

Figure 6-1
Elevation Profiles along the Cross Section in Figure 2-1

The XBeach model was implemented for an event resembling Hurricane Sandy, with a still water level of 3.8 ft NAVD (approximately a 10-year surge event) and a significant wave height of 3.3 ft (approximately a 50-year wave event). The waves come from a direction of 250 degrees clockwise from the north – the longest fetch at the project site and with a wave period of 4 seconds (**Table 6-1**). The tide signal during Hurricane Sandy was used to generate a time series of water level boundary condition. It should be noted that this event is more extreme than a 50-year storm event but likely not as extreme as a 100-year event.

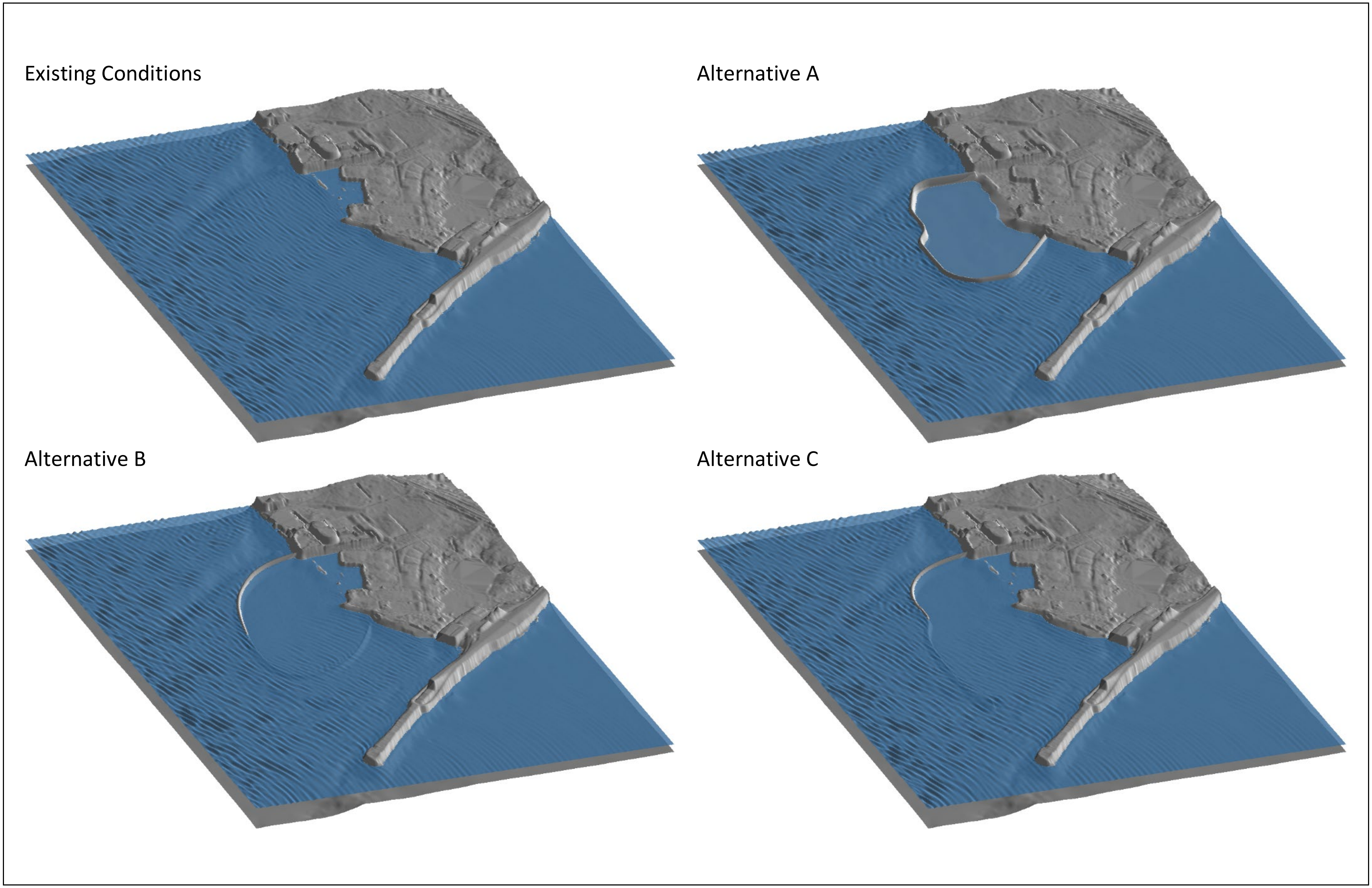
TABLE 6-1
XBEACH MODELED STORM EVENT CONDITIONS

Return Period (years)	SWL (ft NAVD)	Wave Height (ft)	Wave Direction (deg)	Wave Period (s)
50	3.8	3.3	250	4

Figure 6-2 shows the XBeach model implementation for existing conditions and alternatives at a certain time step during the simulation period. Results show waves propagating from the southwest and overtopped the southwest section of the levees for Alternative B and C.

Figure 6-3 shows the coastal flood depth (> 0.5 ft) for each alternative, indicating no significant differences compared to existing conditions during the modeled event. **Figure 6-4** shows the maximum velocities at the site during the storm event. A threshold on coastal erosion is when wave induced currents start exceeding than 3 ft/s . The model results show that all three alternatives reduce wave velocities to close to zero behind the berms. Alternative A shows all the area protected and wave induced currents close to zero except for the entrance on the south were the berm meets the shoreline due to a small gap between the marsh and the existing shoreline. Alternative B is the second alternative with a higher area protected, followed by alternative C.

Overall, the model results show that for existing conditions and all three alternatives, none of the shorelines behind the projected flood except for an area of the marsh due to the relatively high elevations along the shoreline that are not overtopped during the event. Since this event is expected to be larger than the 50-year storm, it suggests that the 10-, 25-, and 50-year events are not expected to flood development with or without the project. Further discussions and recommendations are available in Section 4 of the main report for the TNC Maryland Blue Carbon Resilience Credit Feasibility Study.



SOURCE: ESA (2023)

Figure 6-2
XBeach Model Implementation

ESA

SOURCE: ESA (2023)

TNC Maryland Blue Carbon Resilience Credit Analysis

Figure 6-3
50-year Coastal Flood at the Project Site at Present
Existing Condition and Alternative Designs

ESA

SOURCE: ESA (2023)

Figure 6-4
50-year Max Velocity at the Project Site at Present
Existing Condition and Alternative Designs

ESA

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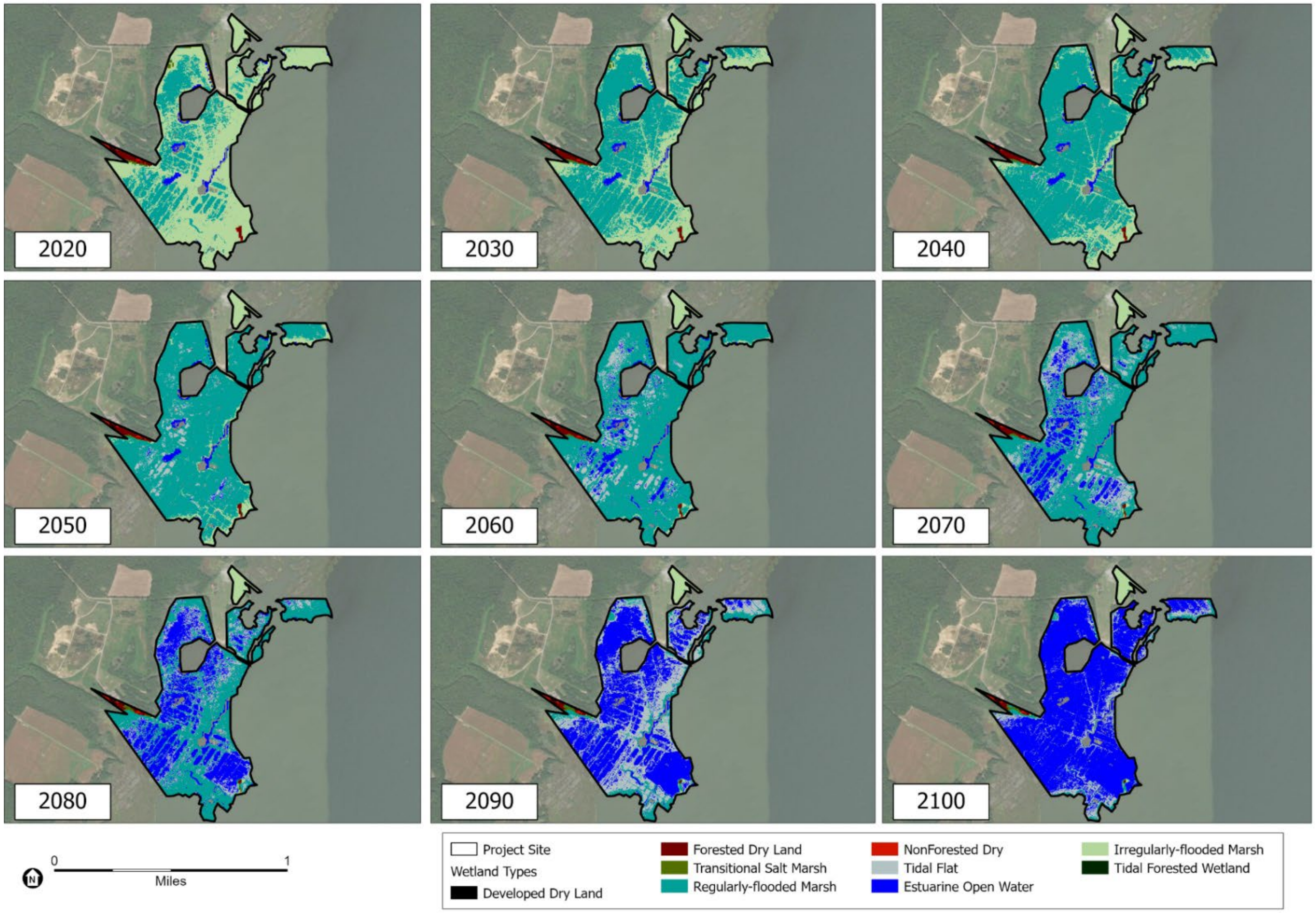
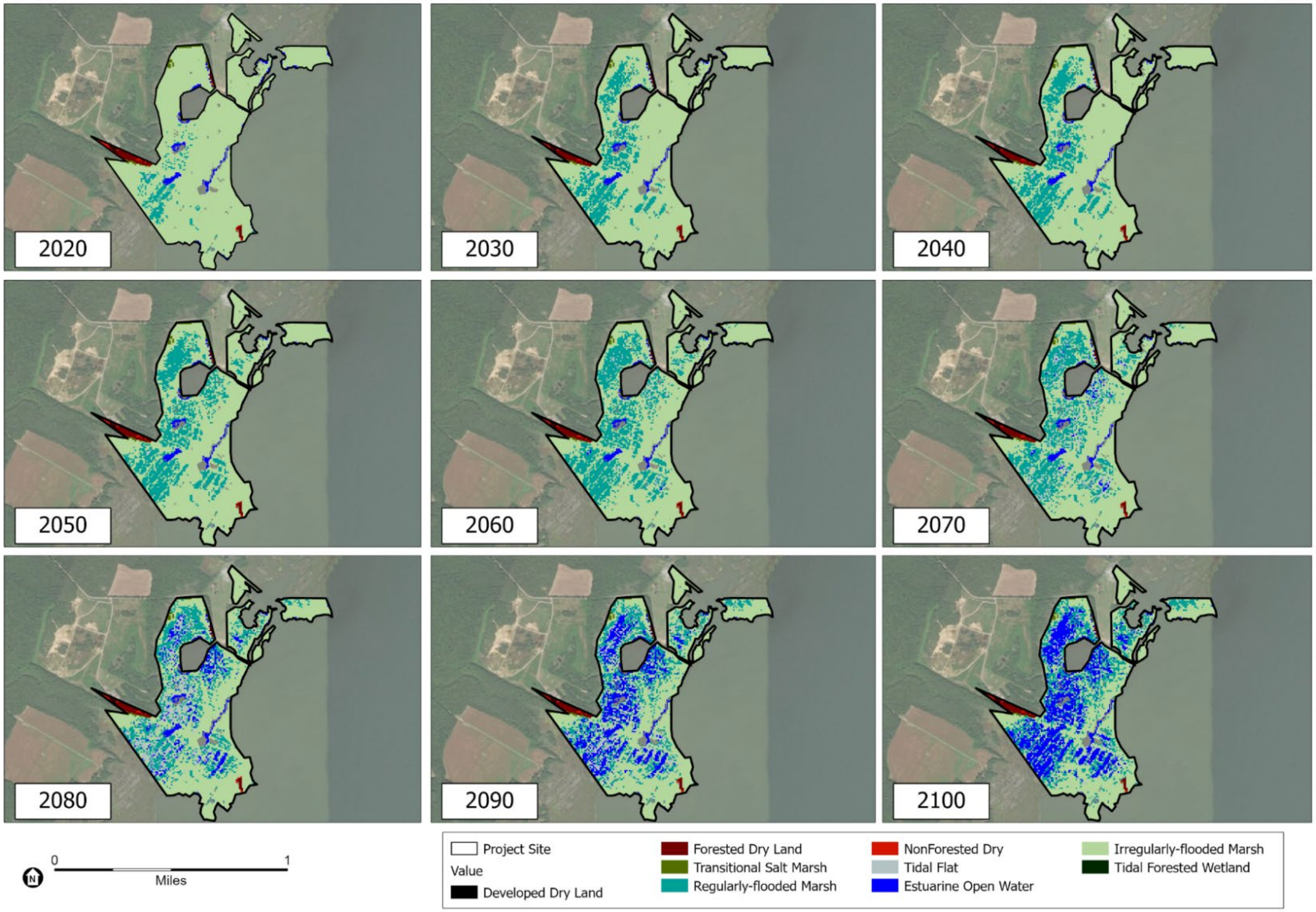
Appendix D
Coastal Bays Habitat Evolution Figures



SOURCE: ESA 2023

Maryland Blue Carbon Resilience Credit Feasibility Study

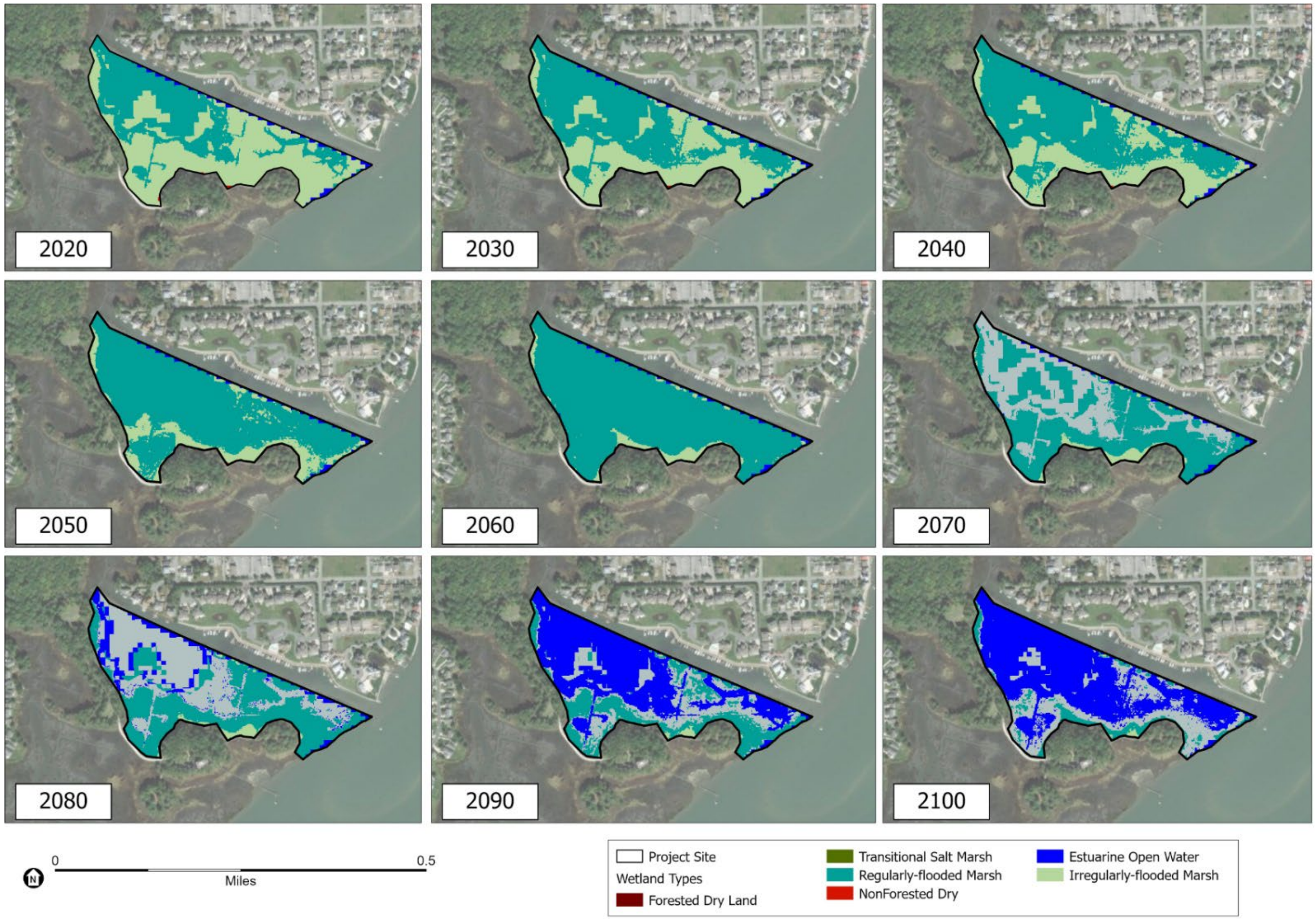
Stark Langmaid Rd. and Worcester County Baseline Scenario



SOURCE: ESA 2023

Maryland Blue Carbon Resilience Credit Feasibility Study

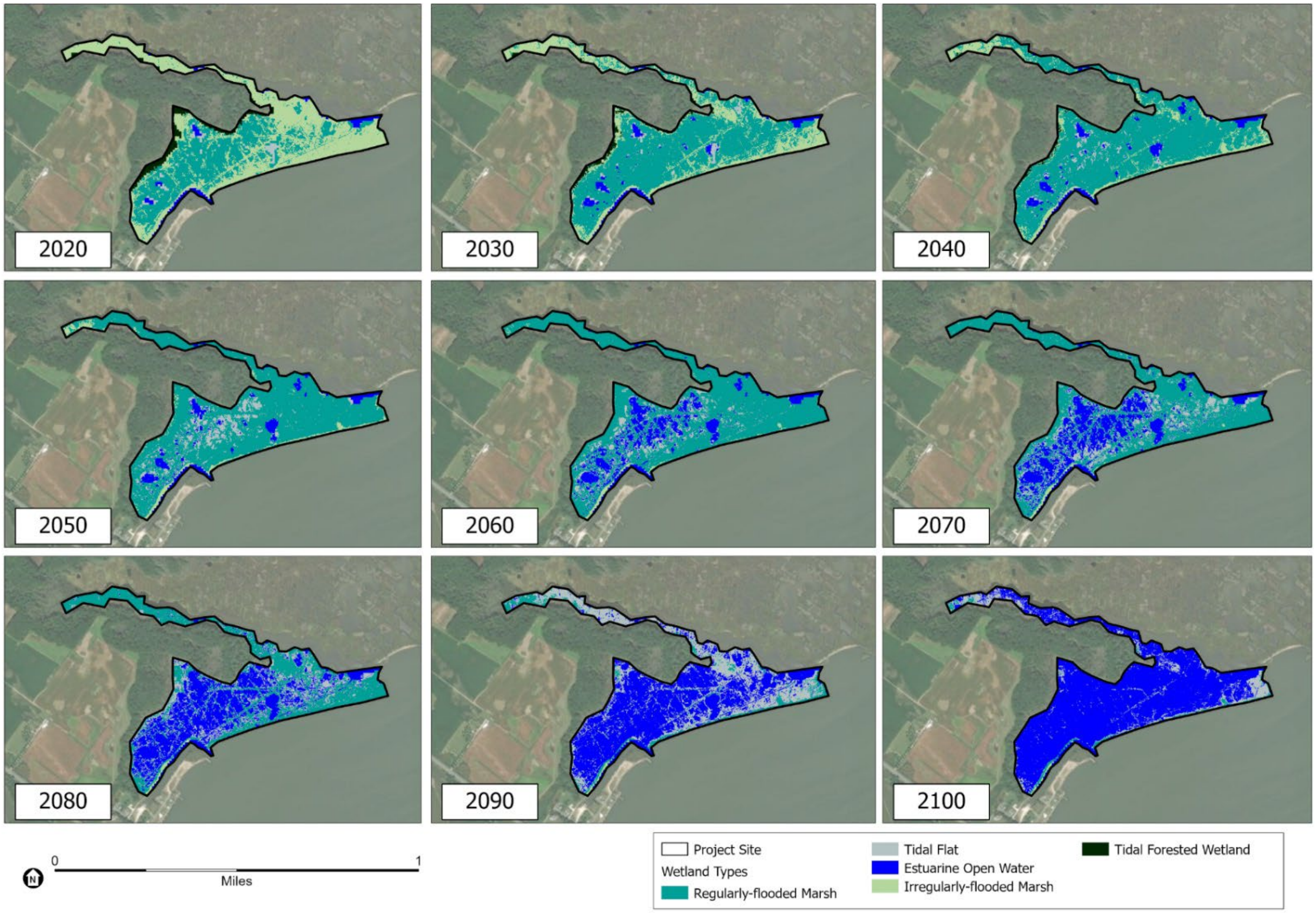
Stark Langmaid Rd. and Worcester County Project Scenario



SOURCE: ESA 2023

Maryland Blue Carbon Resilience Credit Feasibility Study

Marsh Harbor Project Scenario



SOURCE: ESA 2023

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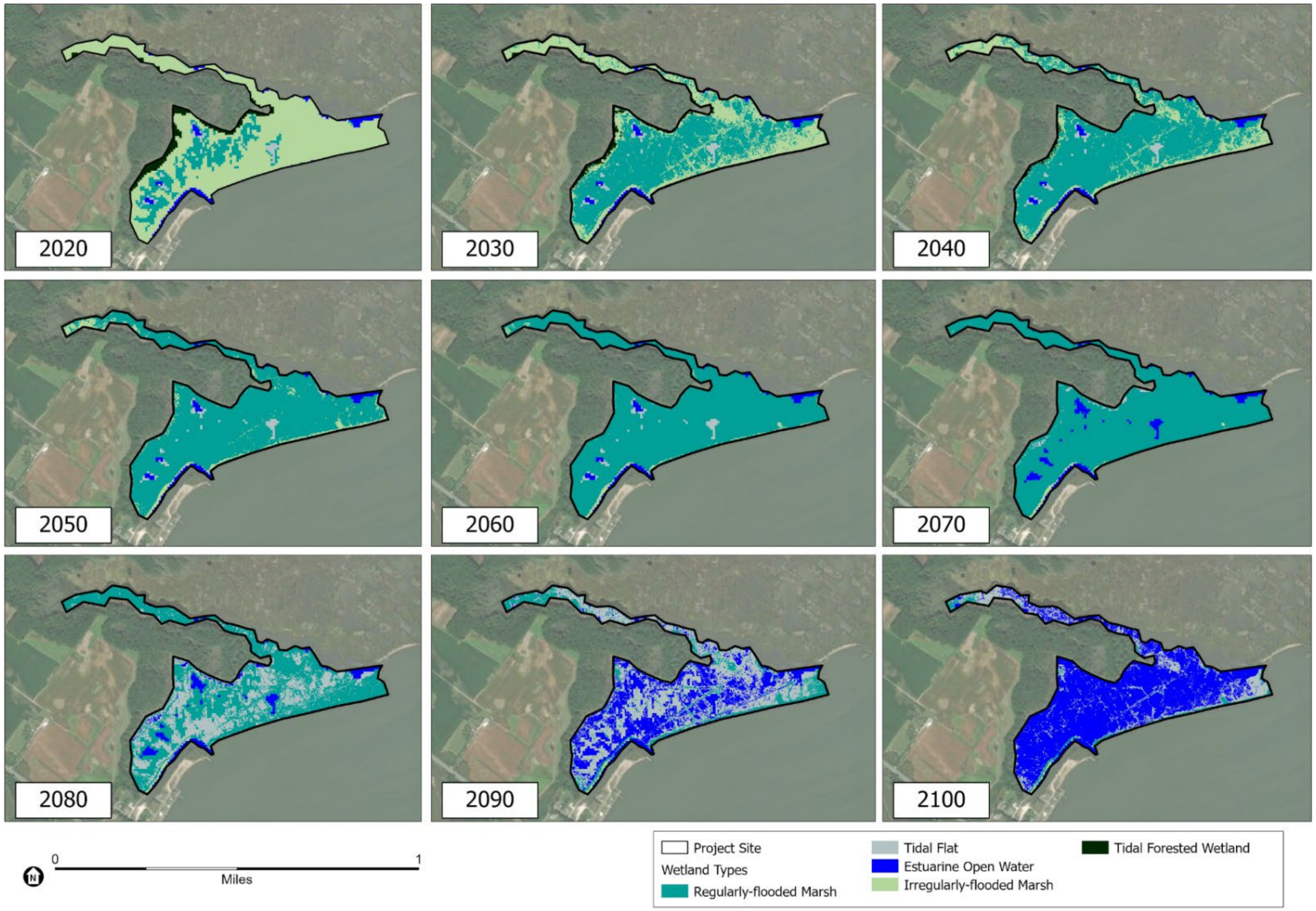
Smithson Baseline Scenario



SOURCE: ESA 2023

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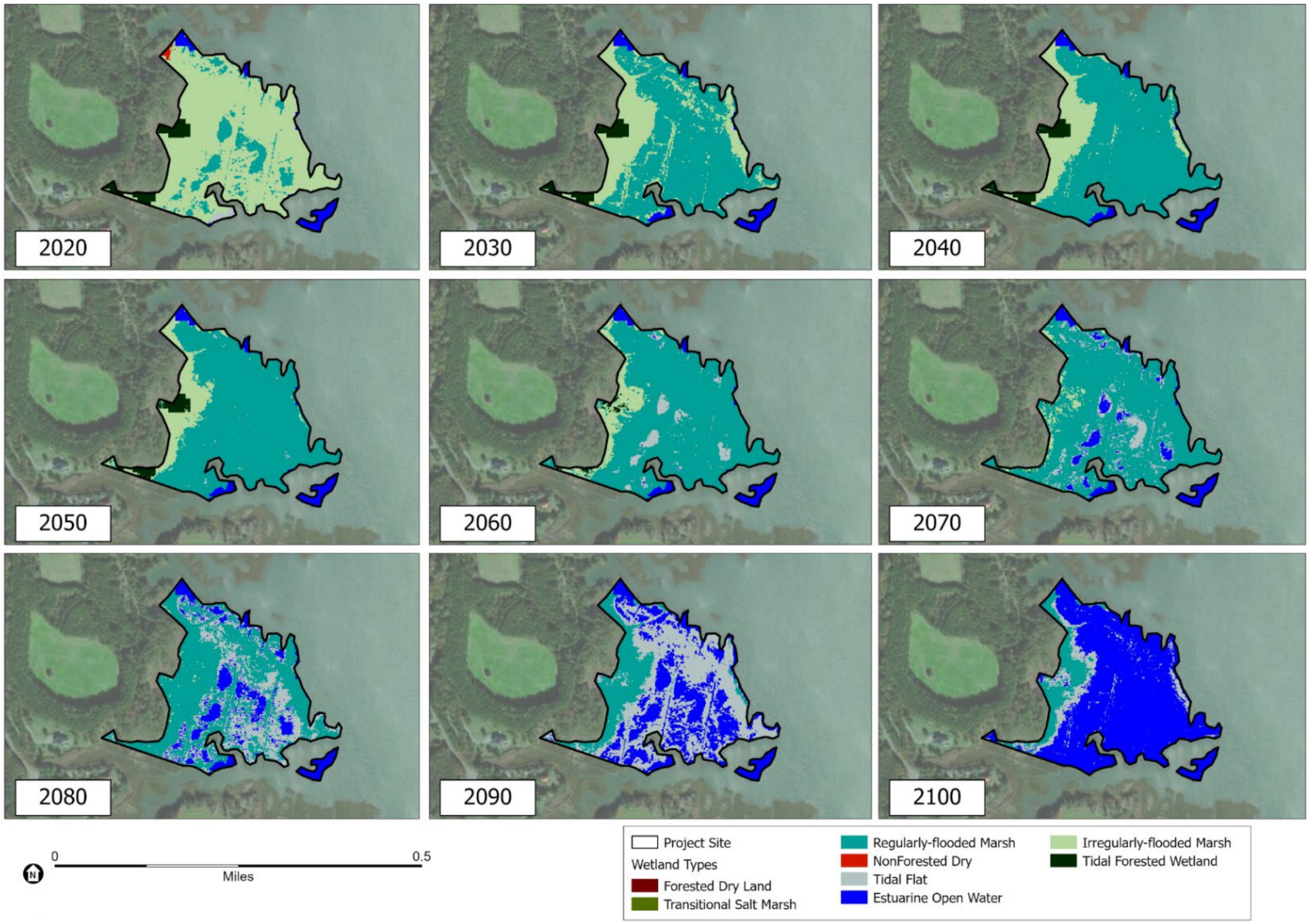
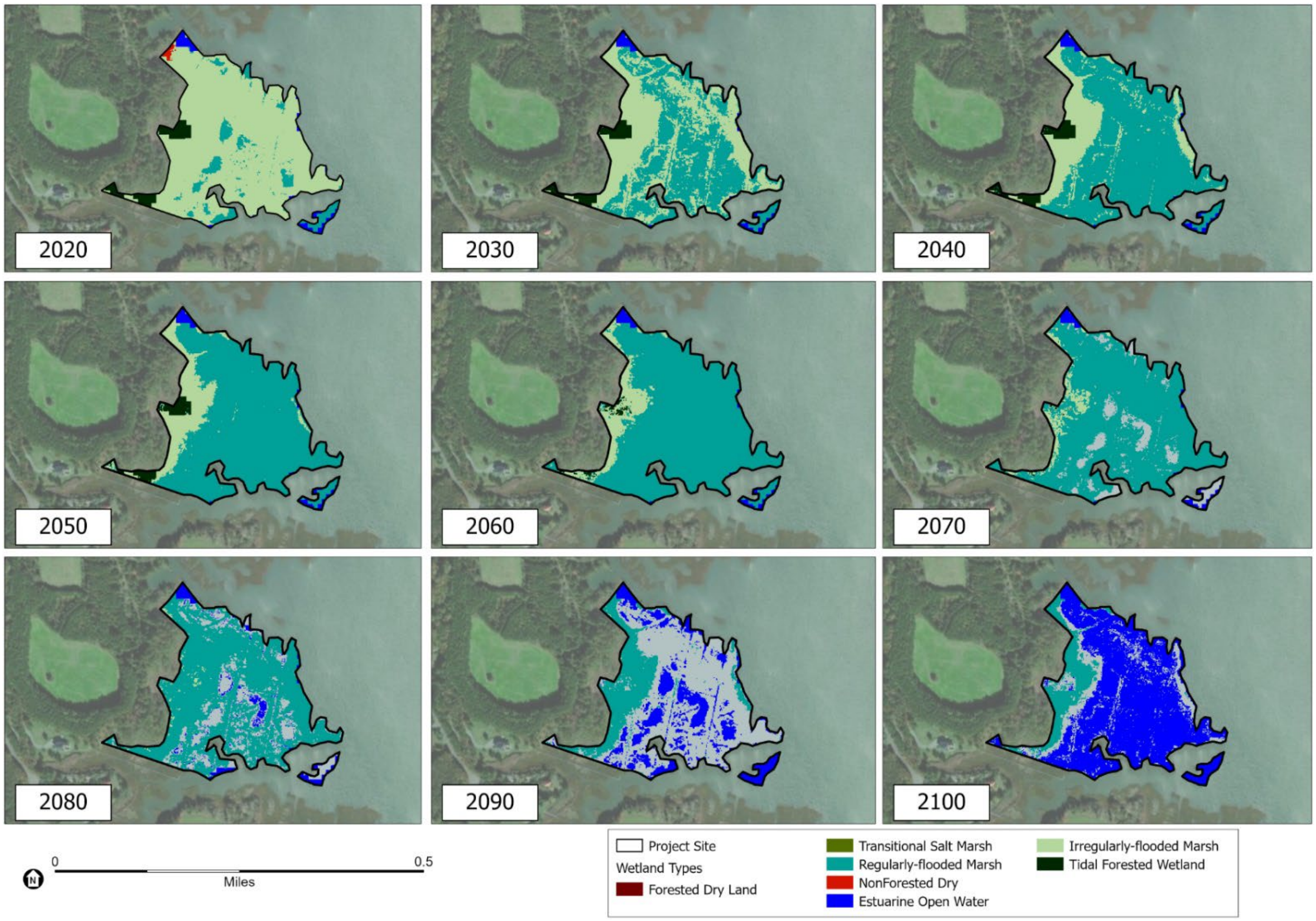
Smithson Project Scenario



SOURCE: ESA 2023

Maryland Blue Carbon Resilience Credit Feasibility Study

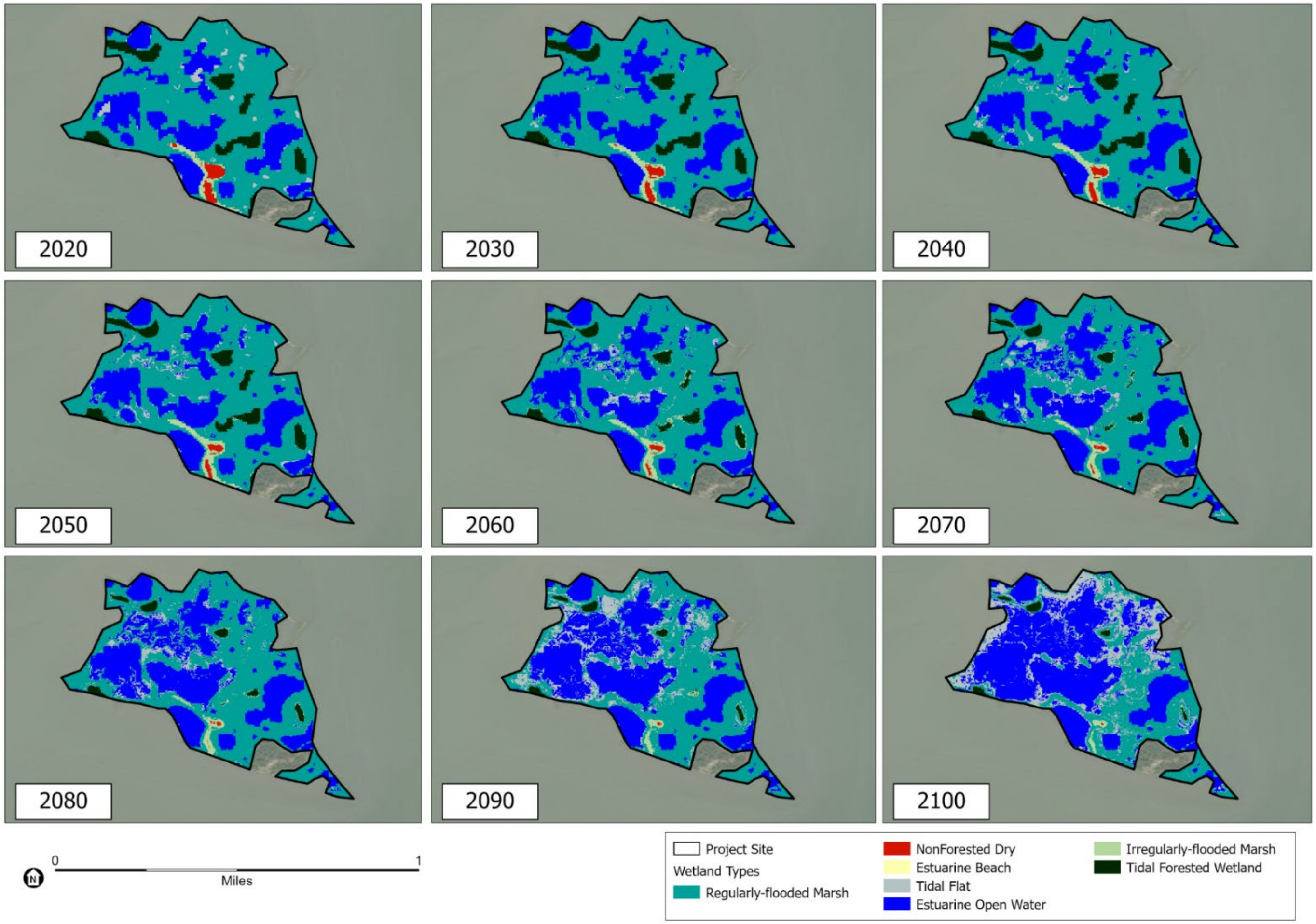
Stark-Bliss Happens Ln. Baseline Scenario



SOURCE: ESA 2023

Maryland Blue Carbon Resilience Credit Feasibility Study

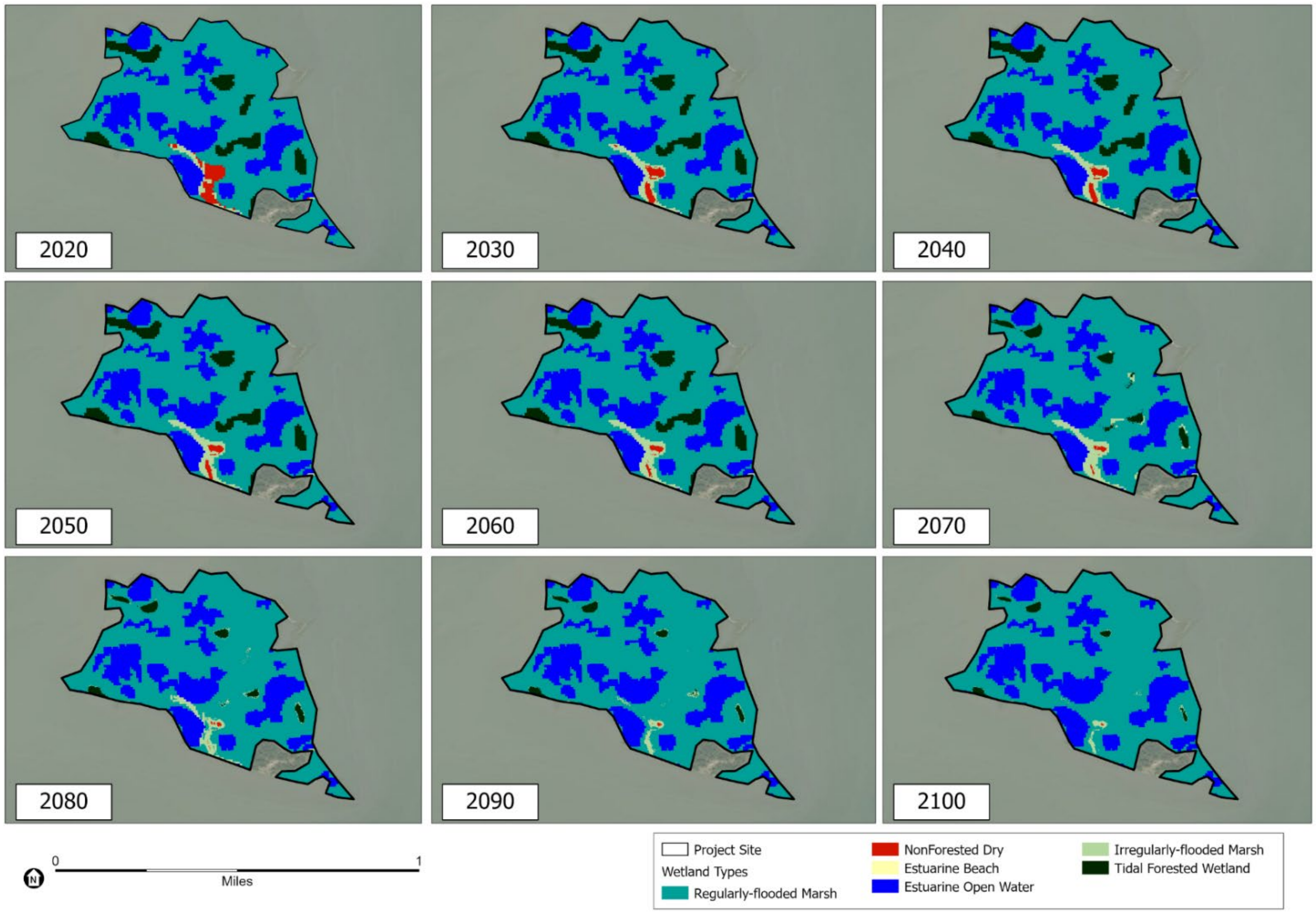
Stark-Bliss Happens Ln. Project Scenario



SOURCE: ESA 2023

Maryland Blue Carbon Resilience Credit Feasibility Study

Tizzard Island Baseline Scenario



SOURCE: ESA 2023

Maryland Blue Carbon Resilience Credit Feasibility Study

Tizzard Island Project Scenario