SOUTH ATLANTIC COASTAL STUDY (SACS)

Measures & Cost Library Report

FINAL REPORT

AUGUST 2022

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SECTION 1
Introduction

The purpose of this report is to provide information about the South Atlantic Coastal Study Measures and Cost Library (MCL). Topics covered include the purpose and definition of the MCL, its development and intended use, methods, underlying assumptions, data sources, conceptualization of risk, and the relationship between risk and the MCL.

1.1 What is the SACS Measures and Cost Library (MCL)?

The SACS MCL is intended to be a detailed and standardized repository of U.S. Army Corps of Engineers (USACE) South Atlantic Division (SAD) coastal storm risk management (CSRM) options to assist Project Delivery Teams (PDT) and stakeholders in CSRM planning efforts. Efforts could include developing an array of measures to be used in alternative formulation for feasibility studies, Continuing Authorities Program (CAP) studies, and other planning support efforts. While the applicability of the library's measures and costs for specific project locations will need to be assessed by PDTs, the general purpose is to reduce time and effort needed by PDTs to develop this information on a project-by-project basis.

1.2 Document Layout Outline

1.2.1 Section 1 Measures and Cost Library Introduction

Section 1, with reference to the SACS authority and implementation guidance, discusses the purpose of the SACS MCL and why it was developed. The section also discusses MCL application with respect to the SACS and future CSRM efforts within the SAD Area of Responsibility (AOR), as well as uses and limitations. The list of measures included in the MCL is introduced in this section. An overview of the document layout is also provided.

1.2.2 Section 2 Risk Concepts, Categories, Definitions, and the Four Accounts

This section provides discussions of risk as a conceptual framework, SACS risk categories, risk definitions, and the four national accounts. The four national accounts include national economic development (NED), regional economic development (RED), other social effects (OSE), and environmental quality (EQ). Other topics covered include the relationship between risk categories, risk definitions, the accounts, and the MCL. This section is relevant for users to diagnose CSRM problems, consider what risks are being managed, determine the benefit categories per national account, and estimate costs and potential trade-offs from taking risk management actions.

1.2.3 Section 3 Measures and Cost Library Considerations

Section 3 categorizes the MCL considerations as either non-cost-based or cost-based. Non-cost considerations include discussion about how measures were evaluated for the following: CSRM approaches and methods, performance, and applicability by wave energy characteristics. CSRM effects and linkage with the four national accounts are also discussed. Cost-based considerations include discussion of the SACS planning reaches, costing assumptions, computations, and limitations.

1.2.4 Section 4 Structural Measures

Section 4 details all non-cost-based and cost-based considerations for the 13 structural measures within the MCL. Additional discussion on measure design, cost components, cost drivers, assumptions, information sources, uncertainties, and limitations is also provided.

1.2.5 Section 5 Natural and Nature-Based Features

Section 5 provides details on all non-cost-based and cost-based considerations for the 12 natural and nature-based feature measures within the MCL. Additional discussion on measure design, cost components, cost drivers, assumptions, information sources, uncertainties, and limitations is also provided.

1.2.6 Section 6 Nonstructural Measures

Section 6 provides details about all non-cost-based and cost-based considerations for the 15 nonstructural measures within the MCL. Additional discussion on measure cost components, cost drivers, assumptions, information sources, uncertainties, and limitations is also provided.

1.2.7 Section 7 Conclusions / Key Points

Section 7 summarizes the MCL and explains how to use the MCL in conjunction with the SACS Tier 2 Economic Risk Assessment to appropriately scale CSRM measures to CSRM problems. Also provided is discussion of CSRM strategy considerations.

SECTION 2
Rationale for Development

2.1 Basis for Development

2.1.1 Authority and Implementation Guidance

The SACS MCL was developed in compliance with Public Law 114-322 dated December 16, 2016, Section 1204 of the Water Resources Development Act of 2016[1] (WRDA 2016), and with implementation guidance released November 16, 2017 for Section 1204, which directs that the SACS must include a framework for identifying flood and coastal flood risk management measures and the associated rough order of magnitude (ROM) cost estimates.

2.1.2 Usage in the South Atlantic Coastal Study

Furthermore, SACS study goals include identification and assessment of CSRM actions, along with the promotion of sustainable communities, projects, and programs. As such, this library is intended for use by USACE or any stakeholders seeking to perform affordability analysis for CSRM planning. As part of the SACS, the MCL was used in development of SACS Focus Area Action Strategies (FAAS), and will be used in future planning efforts throughout the SAD AOR. However, the cost estimates are to be used for conceptual affordability analysis for measures, and not for alternative selection.

2.1.3 Applicability to Future Coastal Storm Risk Management Planning Efforts in the South Atlantic Division

PDTs are required to develop a focused array of alternatives within 90 days of initiating any USACE CSRM study effort. The MCL is intended to be a consistent resource to save PDTs time and effort in developing ROM cost ranges for the CSRM measures for use in future study efforts. The goal is to help users match problems with measures by providing cost-based and non-cost-based considerations. In some cases the MCL can be used to compare the ROM expected annual cost of measures with the ROM expected annual damages for a given problem.

2.2 MCL: Intended Use and Limitations

The MCL encompasses a range of unit costs distributed across the SAD AOR for each measure. The user will need to apply additional information, such as the location, site variability, length, and/or size of the measure to estimate the range of either total costs or annualized life cycle costs.

Because of the regional nature of the data developed, it is impossible to address the scope and site specificity issues prevalent in all CSRM projects. Items such as environmental and real estate impacts, as well as their influence on the cost of measure implementation, will not be addressed in the library. The MCL is intended for use as a starting point for identifying applicable measures and costs to be developed into alternatives. Expert

[1] An ancillary authority pertains to Section 1184 of WRDA 2016 and its respective implementation guidance released November 16, 2017, which directs the ASACW "with consent of the non-Federal sponsor, to consider natural features, nature-based features, nonstructural measures, and structural measures, as appropriate, when studying the feasibility of projects for flood risk management, hurricane and storm risk management, and ecosystem restoration." The MCL will facilitate compliance with this directive.

opinion will be needed to determine whether modification to the MCL data is necessary to account for site-specific considerations.

Although the list of measures is standardized, the costs should not be considered standard costs. The application of additional information, such as more specific cost data or a rapid assessment of a measure, may result in a cost different from those presented in the body of this report. This MCL is not intended to be a benchmark for comparing the 'correctness' of costs developed with site-specific information within the AOR. Nor is it intended to address the full range of all possible engineering solutions to manage coastal storm risk. Engineers, planners, and other stakeholders should still strive to identify innovative solutions to coastal storm risk. MCL cost estimates do not include interest during construction (IDC) costs, lands, real estate, or mitigation. Costs of each of these items could be significant and prohibitive depending on project conditions. Users have a responsibility to consider the impact of IDC, lands, real estate, and/or environmental mitigation when formulating risk management alternatives for CSRM planning applications.

Measures' costs are represented in 2020 price levels. The method for updating the price levels on these costs is outlined in Section 3.2.7 Costs Price Level Adjustment Recommendations. Adjusting measure costs to the desired price levels will diminish the accuracy of the cost estimate over time.

2.3 Measures and Cost Library Measures and Classification

Measures are categorized as either structural, natural and nature-based features (NNBF),[2] or nonstructural. Structural measures consist of man-made structures designed to reduce the occurrence and/or severity of an event that leads to harm. NNBF also achieve risk-management-like structural measures but are designed to be more consistent with and conducive to the natural environment. Nonstructural measures manage risk by either removing the item(s) of concern from the exposure or reducing said item(s) degree of vulnerability to the harm. This list represents commonly implemented measures within the AOR. However, this list is not all encompassing. PDTs should consider site-specific conditions during the brainstorming phase of a project to determine whether any other measures, which may not be listed, may be appropriate.

[2] Use of the MCL NNBF measures should not be construed as compliance with the WIIN Act, which directed USACE to evaluate NNBF and nonstructural measures as part of the agency's planning of flood risk reduction and ecosystem restoration projects.

Table 2-1: Table of Measures

Measure Category	Measure Code	Measure Group Name	Measure Unit
Structural	S-1	Groins	$/Linear foot (LF)
	S-2	Seawall	$/LF
	S-3	Revetment	$/LF
	S-4	Bulkhead	$/LF
	S-5	Breakwaters	$/LF
	S-6	Floodwalls	$/LF
	S-7	Deployable Floodwalls	$/LF
	S-8	Levees / Dikes	$/LF
	S-9	Surge Barrier	$/LF
	S-10[3]	Beach Nourishment	$/LF
	S-11[4]	Nearshore Nourishment	$/LF
	S-12	Road Elevation	$/LF
	S-13	Ring Walls	$/LF
Natural and Nature-Based Features (NNBF)	NNBF-1	Barrier Island	$/Acre (AC)
	NNBF-2	Tidal Flats	$/Square foot (SF)
	NNBF-3	Wetland	$/AC
	NNBF-4	Maritime Forest	$/AC
	NNBF-5	Wet Pine Savannah	$/AC
	NNBF-6	Mangroves	$/LF
	NNBF-7	Living Shoreline Vegetation	$/LF
	NNBF-8	Submerged Aquatic Vegetation (SAV)	$/AC
	NNBF-9	Coral Reef Breakwater	$/LF
	NNBF-10	Oyster Reef Breakwater	$/LF
	NNBF-11	Living Shoreline Reefs	$/LF
	NNBF-12	Living Shoreline Sills	$/LF
Nonstructural	NS-1	Buyout & Acquisition	$/Asset
	NS-2	Building Elevation	$/Asset
	NS-3	Dry Floodproofing	$/Asset
	NS-4	Wet Floodproofing	$/Asset
	NS-5	Relocation	$/Asset
	NS-6	Flood Warning Systems	No Cost Included
	NS-7	Flood Insurance	No Cost Included
	NS-8	Floodplain Mapping	No Cost Included
	NS-9	Flood Emergency Preparedness Plans	No Cost Included
	NS-10	Land Use Regulations	No Cost Included
	NS-11	Zoning	No Cost Included
	NS-12	Evacuation Plans	No Cost Included
	NS-13	Risk Communication	No Cost Included
	NS-14	Risk Analysis	$/Study*
	NS-15	Land Conservation	No Cost Included

[3] Beach nourishment is also considered to be a nature-based feature.
[4] Nearshore nourishment is also considered to be a nature-based feature.

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SECTION 3

Conceptual Risk Framework, Definitions, and the Four National Accounts

This section describes the conceptual risk framework, SACS risk categories, the four national accounts, decision context, and the implications for risk characterization. Understanding the linkage between these ideas is important for application of the MCL.

3.1 Conceptual Risk Framework

Figure 3-1 is an illustration of the conceptual risk framework. The measures highlighted in the MCL manage risk by adjusting one or more of the elements of the conceptual risk framework. Each element is described in the following sections.

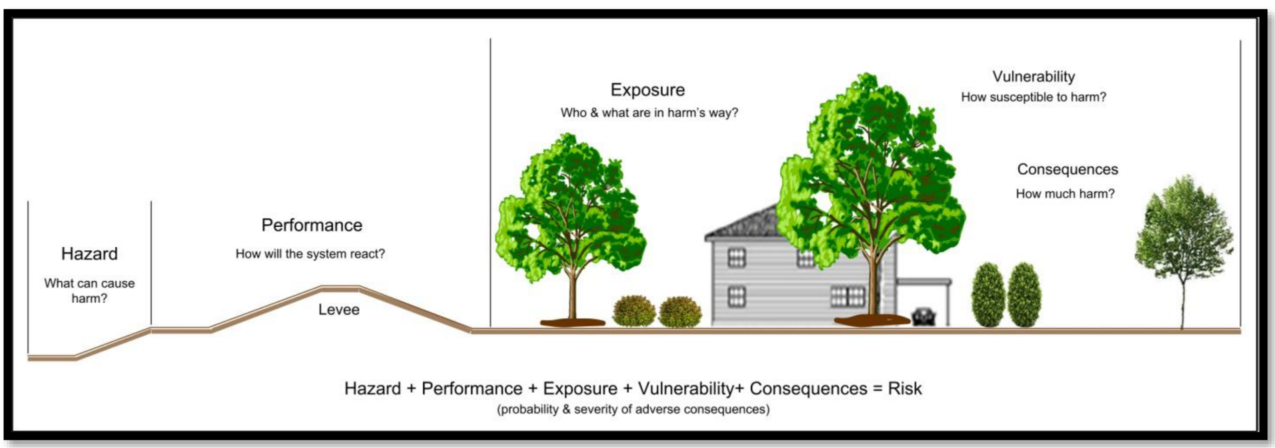

Figure 3-1: Conceptual Risk Framework (ER 1105-2-101)

3.1.1 Conceptual Risk Framework and SACS Risk Definitions

This section explains how the conceptual risk framework used in the SACS relates to the MCL. Risk is conceptualized as a function of hazard, performance, exposure, vulnerability, and consequences (ER 1105-2-101). Within the context of the MCL effort, the descriptions in this section are intended to provide a conceptualization of risk as a precursor to the risk management measures that form the basis of the MCL. If coastal storm risk is a function of hazard, system/physical setting, exposure, and vulnerability, then risk management measures should influence the physical setting (e.g., structural, NNBF), exposure (e.g., temporary or permanent relocation), or vulnerability (e.g., retrofitting).

3.1.1.1 Hazard

For the purposes of the MCL, hazards are considered coastal storm events associated with a probability distribution that leads to adverse impacts through inundation, wave attack, and erosion—the primary hazards of concern within the SACS and the MCL. Coastal storms also create hazardous wind conditions as well as precipitation-based flood conditions. However, these issues were not directly evaluated in the SACS or the MCL.

3.1.1.1.1 Inundation

On the Atlantic and Gulf of Mexico coasts, tropical cyclones and extratropical storms produce elevated water levels (storm surge) that inundate and damage coastal property, as well as cultural and environmental resources. Typically, the inundation would be characterized by the frequency and stage of the flooding from the storm event. Storm surge inundation causes damage to structures in the following ways:

- Lateral forces from moving water on load-bearing asset walls
- Hydrostatic pressure differentials between the exterior and interior of the asset
- Water damage to interior utilities, mechanicals, drywall, trim, and furniture
- Conditions for mold and other health hazards

Figure 3-2: Storm Surge Inundation (Photo Source: USACE)

3.1.1.1.2 Wave Attack

Coastal storms can also bring higher wave energy inland to damage upland development. Wave attack damage, which is a nonlinear function of wave height, can occur with and/or without storm surge. Wave attack hazards can be characterized by the frequency and crest elevation of the waves generated by the storm event. Wave attack creates a high risk of structure failure through the weight and force of the wave battering and by undermining the load-bearing exterior walls of the asset.

Figure 3-3: Wave Attack Damage (Photo Source: USACE)

Erosion hazards are characterized by a combination of the frequency of erosional storm events, post-storm recovery, and seasonal fluctuations. Erosion causes damage by removing load-bearing soil and material from around and underneath assets, undermining their foundations.

Figure 3-4: Long-Term and Storm-Induced Beach Erosion (Photo Source: USACE)

3.1.1.2 System Performance (Physical Setting)

For the purposes of the MCL, the 'system' refers to the combination of offshore, nearshore, foreshore, and backshore components. These elements of the physical setting bear the brunt of the coastal storm hazard. System performance is the system's ability to absorb inundation, wave attack, and/or erosive effects caused by the coastal storm event without harm to exposed assets. Relevant system components include the topography, ground elevation, shoreline type, and the presence of existing risk management measures. Stage volume or fragility curves are representations of system performance. Structural and NNBF measures manage risk by increasing the system's capacity to handle the hazard-loading conditions.

3.1.1.3 Exposure

Exposure describes who and/or what may be harmed by coastal storm hazards. It incorporates the object of desired risk management, such as asset/structure inventories, population at risk, and habitat acreage. **Table 3-1** provides additional details about the SACS exposure categories.

Table 3-1: Risk Categories

SACS Exposure Category	Exposure Category Description
Assets and Infrastructure	Public and private property and critical infrastructure subject to harm from coastal storms, including residential, commercial, and public sector buildings, their associated contents, vehicles, utilities, and any other systems necessary to sustain development
Populations	Representative of exposed populations, including vulnerable populations, that are more susceptible to increased life safety harm due to coastal storms
Environmental Resources	Acres of valuable habitat and/or species subject to harm from coastal storms
Cultural Resources	Cultural resource buildings or sites subject to harm from coastal storms

Nonstructural measures, such as temporary or permanent evacuation, manage risk by reducing the number of exposed resources within the floodplain.

3.1.1.4 Vulnerability

Vulnerability is the relationship between the hazard and the extent of the harm from the exposure. Depth damage functions and depth mortality functions are examples of vulnerability from a conceptual standpoint. Retrofit measures such as floodproofing and elevating assets reduce vulnerability by adjusting or shifting the hazard to harm relationship such that each increment of hazard results in less harm to the exposed asset or population.

3.1.1.5 Consequences

Consequence is a characterization of the harm given an occurrence of the hazard. Consequences should be described in terms and/or units that are meaningful to decision-makers, risk assessors, risk managers, and stakeholders. Understanding the decision context should provide insight as to which metrics should be used to characterize risk. Consider the following questions:

- What CSRM decisions need to be made?
- Who makes the CSRM decisions?
- What kind of information will be needed to inform these decisions?
- Who and/or what is impacted by the risk?
- What is needed to communicate the costs, trade-offs, and value of risk management action?

Understanding these decision context questions will lead to a more meaningful risk characterization and provide a more compelling impetus for action.

3.1.1.6 SACS Risk Definitions

Table 3-2 provides information on the SACS risk categories and definitions based on the conceptual risk framework.

Table 3-2: SACS Risk Categories and Definitions

Risk Category	SACS Exposure Type	Risk Category Description
Population Risk	Populations at Risk (PAR)	A combination of likelihood and harm resulting from adverse life safety impacts due to coastal storm events. The MCL coastal engineering sub-team evaluated measures for population risk by considering whether a measure triggers an Independent External Peer Review (IEPR) based on significant life safety issues.
Economic Risk	Assets and Infrastructure; Regional Economic Activity	Economic risk is the combination of likelihood and harm to public and private property, critical infrastructure, and regional economic activity due to coastal storm events. The primary dimension of economic risk considered in SACS is risk to infrastructure, and public and private property.
Environmental Resource Risk	Acres of Valuable Habitat, Threatened and Endangered Species	Environmental resource risk is the combination of likelihood and the harm resulting from the loss of acres of environmental resources due to coastal storm events.
Cultural Resource Risk	Cultural Resource Buildings and Sites	Cultural resource risk is a combination of likelihood and the harm resulting from lost/damaged cultural resource buildings and/or sites due to coastal storm events.

3.2 Risk Categories and the Four National Accounts

This section provides details on the four national accounts and how they apply to the MCL. The four accounts are established to facilitate evaluation and display alternative plan effects. The accounts are NED, RED, OSE, and EQ. In compliance with the Policy Directive – Comprehensive Documentation of Benefits in Decision Document, signed by the Assistant Secretary of the Army for Civil Works (ASACW) on January 5, 2021, all four accounts must be documented, analyzed, and considered in the USACE decision framework. The NED account displays changes in the economic value of the national output of goods and services. The RED account registers changes in the distribution of regional economic activity that result from each alternative plan. Evaluations of regional effects are to be carried out using nationally consistent projections of income, employment, output, and population. The EQ account displays nonmonetary effects on significant natural and cultural resources. The OSE account registers plan effects from perspectives that are relevant to the planning process, but not reflected in the other three accounts.

Table 3-3: Risk Categories, Exposure Types, and National Accounts

Risk Category	SACS Exposure Type	National Accounts
Population Risk	Populations at Risk	Other Social Effects (OSE)
Economic Risk	Assets and Infrastructure, Regional Economic Activity	National Economic Development (NED) / Regional Economic Development (RED)
Environmental Resource Risk	Acres of Valuable Habitat, Threatened or Endangered Species	Environmental Quality (EQ)
Cultural Resource Risk	Cultural Resource Buildings and Sites	EQ

3.2.1 National Economic Development Account

The NED account displays changes in the economic value of the national output of goods and services. In the NED context, benefits and costs are increases and decreases (respectively) in the national output of goods and services described in monetary units. NED is used to account for the following:

- **NED Benefits:** Any positive change in NED resulting from the implementation of a risk management alternative. This means the economic value lost from coastal storms without a risk management alternative in place minus the economic value lost from coastal storms with a risk management alternative in place.

- **NED Costs:** Any negative change in NED resulting from the implementation of a risk management alternative. This includes any costs associated with implementation of a risk management alternative. The Federal perspective is to be used when valuing project outputs (benefits) or project inputs (costs). A typical USACE CSRM economic evaluation should answer the following two questions:

Question 1: From an economics perspective, should we invest in a CSRM solution?

Question 2: If so, then how much should we invest in a CSRM solution?

Project economic justification is achieved when the project NED benefits exceed project NED costs (Question 1). In the context of USACE CSRM planning, the NED plan is the alternative that most reasonably maximizes the net NED benefits[5] (Question 2). The MCL does not include damages or benefits. However, the costs included within the MCL estimates provided can be used as approximations of portions of the NED costs. It should also be noted that these costs are not reflective of a total project cost and are in 2020 price levels.

3.2.1.1 CSRM NED Metrics

Characterization of a measure's NED impacts means selecting metric(s) that are meaningful for decision-making and useful for evaluating and comparing a measure's effects. In the context of CSRM, NED is used to account for losses in the function of economic resources, such as storm damage to a residence. The economic value of the storm damage loss is equal to the cost of restoring the economic function of the resource. From a national perspective, this loss in physical property is a cost to the nation, and not a transfer of value between different regions. **Table 3-4** provides details about the potential NED CSRM benefit categories and metrics.

[5] Net NED Benefits are the difference between NED benefits and NED costs. The NED plan is the alternative that most reasonably maximizes this difference.

Table 3-4: Coastal Storm Risk Management National Economic Development Metrics

National Economic Development (NED) Category	NED Category Description	Coastal Storm Risk Management (CSRM) NED Metrics
Property and Critical Infrastructure Damage	Structural Damage to Buildings: homes, commercial or public buildings, sheds, lumberyards, etc. Loss of Contents: this includes any loose items inside any structures, but could also include outside items such as lumber from a lumberyard	$ value of depreciated replacement losses
Agricultural Losses	Agricultural Losses: crops and equipment (see the Agricultural Flood Damage NED Manual IWR Report 87-R-10 for more details)	$ value of agriculture losses
Vehicle Damages	Vehicle damages: personal, public, or commercial vehicles that are not evacuated (NED Procedures Manual: NED Costs)	$ value of vehicle damages
Land Loss Damage	The value of nearshore land lost from coastal erosion	$ value of land loss
Net Income Loss	Income Loss: loss of wages or profits to business over physical damages that cannot be deferred or transferred regionally. Prevention of income losses result in a contribution to NED only to the extent that the losses cannot be compensated for by postponement of an activity or transfer of the activity to other establishments. Estimates of these losses must be derived from specific independent economic data for the interests and properties affected.	$ value of income lost
Emergency Cost Avoided	Emergency Costs: expenses from the risk of a storm and expenses from the storm itself, includes expenses for monitoring, forecasting storm problems, emergency evacuation, storm fighting efforts such as sandbagging or building closures, administrative costs of disaster relief, public clean-up costs, and increased costs for fire, police and/or military patrols.	$ value of emergency costs avoided
Public and Private Protective Measures	Public and Private Protective Measures: reduced cost in the future from a proposed project for avoiding public and private expenditures on measures to reduce damages to coastal property.	$ value of protective measures undertaken
Temporary Evacuation and Relocation	Public and private expenses from relocating residents to habitable areas temporarily because their homes are severely damaged, have sediment deposits, or disruption in utility services.	$ value of evacuation/ relocation costs
Transportation Delay Costs	Public and private delay expenses from cars, rail, air or other transportation means; for example, a road could be closed for public safety reasons due to the flooding, delays and traffic rerouting that can be avoided by a proposed project would be counted as NED benefits.	$ value of transportation delay costs
Associated Agricultural Losses	Associated agricultural crop or other losses from delays in planting or lack of access to land.	$ value of associated agricultural losses
Reduced Maintenance on Existing Structures	Extent to which maintenance costs are reduced.	$ value of maintenance on existing structures
Recreation	Incidental economic value of recreation in terms of the supply, demand, and value of recreation events.	$ value of recreation

3.2.2 Regional Economic Development Account

The regional economic development account displays changes in the distribution of regional economic activity due to the measure/alternative implementation. It is distinct from the NED account in that it examines the potential impacts mainly to the localized or regional economic area instead of the nation.

Measure RED impacts are attributable to the effect of the measure on the economic activity of the impacted region. These impacts are due to either measure construction expenditure, or as a result of measure implementation. Measure construction expenditure RED impacts create multiplier effects as the proportion of the expenditure cycles through the regional economy. Measure implementation can affect regional economic activity by influencing the likelihood and/or severity of coastal-storm-based disruptions to area commercial businesses.

3.2.2.1 Direct, Indirect, and Induced Effects

RED impacts are typically categorized as direct, indirect, or induced effects. Direct effects are changes in regional economic activity due to measure construction expenditure or implementation. The proportion of project construction expenditures that flow to material and service providers within the impact region constitute a 'direct effect' to regional economic activity. Indirect effects are the changes in regional economic activity from changes in interindustry purchases in response to new demand from directly affected industries. Induced effects are the resulting changes in spending patterns of increases in income to directly and indirectly affected industries.

These impacts can be positive or negative depending on the situation. Measure construction expenditures and implementation can increase the value of RED through short-term multiplier effects and long-term reductions in local economic disruptions. However, it is possible that measure construction and implementation could result in either temporary or permanent relocation of some commercial activities.

3.2.2.2 Regional Economic Development Metrics

While CSRM NED impacts tend to describe the value of storm damage to property, RED impacts describe the change in regional economic activity either as a result of the damage, or from expenditures on risk management solutions. **Table 3-5** provides details about different RED categories, descriptions, and potential metrics. It is important to select metric(s) that are meaningful for decision-making, and useful for evaluating and comparing measure effects when characterizing RED impacts.

Table 3-5: Regional Economic Development Metrics

Regional Economic Development (RED) Category	Description	Recommended Metric/Unit
Employment	Employment reflects the number of additional jobs created by economic growth or the losses by contraction. This is one of the most popular measures of economic impacts because it is the easiest for the public to understand. However, job counts do not always reflect the quality or permanency of employment opportunities. In the context of RED modeling, one annual job is equivalent to one person being employed during a single year. One person being employed for 5 years is equivalent to five annual jobs. Employment impacts may be measured in several 'person years.'	Number of person years (which is equal to number of people employed multiplied by the number of years)

Regional Economic Development (RED) Category	Description	Recommended Metric/Unit
Income	Labor income / personal income rises as salaries rise and/or additional workers are hired. Either or both of these conditions can occur as a result of business revenue growth. As long as nearly all of the affected workers live in the study area, this is a reasonable measure of the personal income benefit of a project or program. Sponsors often publicize the additional income and the tax receipts as a means of selling the project to the public.	$ in income
Value Added	'Value Added,' also referred to as Gross State Product (GSP), Gross Regional Product (GRP), or Gross Metropolitan Product (GMP) provides a broader measure of the impact of a large-scale project (e.g., port projects) that reflects the sum of wage income and corporate profit generated in a large study area. However, as today's economy is increasingly global, the GSP or GRP/GMP can overestimate the true income impact on a local area, since it often includes dividends to business owners who may not reside in the study area, as well as reinvestments in corporate facilities outside of the study area. Thus, while GSP/GRP/GMP may best describe the total impact on overall economic activity in a geographic area, the personal income (wage) measure is often preferred as a more conservative measure of income benefit to residents of the area. Value added includes employee compensation, proprietary income, other proprietary income and indirect business taxes. Employee compensation includes wage and salary payments as well as benefits, including health and life insurance, retirement payments, and any other non-cash compensation. It includes all income to workers paid by employers. Proprietary income consists of payments received by self-employed individuals as income. This is income recorded on Federal Tax Form 1040C. Proprietary income includes income received by private business owners, doctors, lawyers and so forth. Any income a person receives for payment of self-employed work is counted. Other proprietary type income consists of payments from interest, rents, royalties, dividends, and profits. This includes payments to individuals in the form of rents received on property, royalties from contracts, and dividends paid by corporations. This also includes corporate profits earned by corporations. Indirect business taxes consist primarily of excise and sales taxes paid by individuals to businesses. These taxes occur during the normal operation of these businesses but do not include taxes on profit or income (MIG, Inc).	$ value in GSP/GRP/GMP
Business Revenues	Business Revenues (also referred to as business output or sales volume) is the broadest measure of economic activity, as it encapsulates the most categories and provides the largest numbers. Revenues include the full (gross) level of business revenue, which pays for costs of materials and costs of labor, as well as generating net business income (profits). This can be a misleading measure of economic development since it does not distinguish between a high value-added activity (generating substantial local profit and income) and a low value-added activity (generating relatively little local profit or income from the same level of sales).	$ value of business revenue or output
Indirect Business Taxes	Indirect Business Taxes consist primarily of excise and sales taxes paid by individuals to businesses. Non-Federal sponsors often have a keen interest in this metric since it measures the project's repayment to the local economy. As with increased income, sponsors often publicize the additional tax receipts as a means of promoting the project to the public.	$ value in taxes

Regional Economic Development (RED) Category	Description	Recommended Metric/Unit
Public Assistance Distribution	The quantity and population distribution in need of public assistance can be a compelling argument for RED. If a group of disadvantaged people are made better off in a local area as a result of a project, then the reduction in the number of people requiring public assistance could arguably be considered a RED benefit. Executive Order 12898, Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations, was issued to combat the fact that poor and minority groups often have been exposed to greater human health and safety risks than society at large and have borne more than their share of the negative effects of development.	Number of persons requiring assistance and /or $ value of public assistance

3.2.3 Other Social Effects Account

Most water and land resource plans have beneficial and adverse effects on social well-being. The OSE account is a means of displaying and integrating perspectives that are not reflected in the other three accounts into water resource planning information on alternative plan effects. The categories of effects in the OSE account include the following: urban and community impacts; life, health, and safety factors; displacement; long-term productivity; and energy requirements and energy conservation. **Table 3-6** provides details on some potential OSE metrics.

Table 3-6: Other Social Effects Metrics

Other Social Effects (OSE) Category	OSE Category Description
Urban and Community Socioeconomic Impacts	Effects on real incomes: Beneficial effects on real income occur when designated persons or groups receive income generated as a result of the plan. Current guidelines defining the family poverty line may be used as the data from which to measure and portray the estimated absolute and percentage increase toward meeting or exceeding this standard for specific geographic planning areas. Effects on employment distribution, especially the share to minorities Effects on population distribution and composition Effects on the fiscal condition of the state and local sponsor
Effects on Educational, Cultural, and Recreational Opportunities	Beneficial effects to this component include contributions to (1) improved opportunities for community services such as utilities, transportation, schools, and hospitals, and (2) more cultural and recreational opportunities such as historic and scientific sites, lakes, and reservoirs, and recreations areas. Beneficial effects to improved community services may be described in appropriate quantitative terms, while increased cultural and recreational opportunities will be set forth as the numerical increase in the relevant facilities, otherwise accounting for size, use potential, and quality. Beneficial effects to improved community services may be described in appropriate quantitative terms, while increased cultural and recreational opportunities will be set forth as the numerical increase in the relevant facilities, otherwise accounting for size, use potential, and quality. Conversely, adverse effects are identified and measured or described as detrimental effects on education, cultural, and recreational opportunities.

Other Social Effects (OSE) Category	OSE Category Description
Effects on Security of Life, Health, and Safety	Beneficial effects include contributions to (1) reducing risk of flood, drought, or other disaster affecting the security of life, health, and safety; (2) reducing the number of disease-carrying insects and related pathological factors; (3) reducing the concentration and exposure to water and air pollution; and (4) providing a year-round consumer choice of food that contributes to the improvement of national nutrition. In those limited situations where, historical experience is sufficiently documented to provide confidence in projecting likely future hazards, an estimate of the number of lives saved or the number of persons affected may be provided. In most instances, however, a descriptive-qualitative interpretation and evaluation of the improvement and expected results will be applicable.
Displacement Effects	Displacement effects include the displacement of people, businesses, and farms
Long-Term Productivity Effects	Long-term productivity effects include maintenance and enhancement of the productivity of resources, such as agricultural land, for use by future generations.
Effects on Emergency Preparedness	Beneficial effects include contributions to (1) extending, maintaining, and protecting major components of the national water transportation system; (2) provision of flexible reserves of water supplies; (3) provision of critical power supplies (ample, stable, quickly responsive); (4) provision of reserve food production potential; (5) provision for the conservation of scarce fuels; (6) provision for dispersal of population and industry; and (7) supplying international treaty requirements. While these beneficial effects will be measured in appropriate quantitative units where readily practicable, they will be largely characterized in descriptive-qualitative terms. Conversely, adverse effects are identified and measured or described as overloading capacities of water resource systems and increasing the risk of interruption in the flow of essential goods and services needed for special requirements of national security.

3.2.4 Environmental Quality Account

The EQ account displays nonmonetary effects on ecological, cultural, and aesthetic resources, including the positive and adverse effects of ecosystem restoration plans. EQ impacts are generally not monetized and appear in the form of additional acres, habitat units, fish counts, biodiversity indices, or cultural resource buildings or sites.

Table 3-7: Environmental Quality Metrics

Environmental Quality (EQ) Category	EQ Category Description
Endangered and Threatened Wildlife and Plants Including Associated Critical Habitats	Beneficial effects to this component include opportunities under the Endangered Species Act with reductions in loss and/or restoration of critical habitat necessary for endangered and threatened wildlife and plants.
Essential Fish Habitat	Beneficial effects to this component include opportunities under the Magnuson-Stevens Fishery Conservation and Management Act with reduction in loss and/or restoration of essential fish habitats that are necessary to the species for spawning, breeding, feeding or growth to mature.
Marine Mammals	Beneficial effects to this component include opportunities under the Marine Mammal Protection Act with reductions in loss of habitat necessary for bird survival.
Migratory Birds	Beneficial effects to this component include opportunities under the Migratory Bird Treaty Act with reductions in loss of habitat necessary for bird survival.
Wildlife and Wildlife Resources	Beneficial effects to this component include opportunities under the Fish and Wildlife Coordination Act and the Coastal Zone Management Act with reductions in loss and/or restoration of natural systems in the coastal zone.

Environmental Quality (EQ) Category	EQ Category Description
Air Quality	Beneficial effects to this component include opportunities under the Clean Air Act with reductions in loss or restoration of habitats the contribute to air quality values.
Water Quality	Beneficial effects to this component include opportunities under the Clean Water Act with reduction in loss or restoration of aquatic habitats that provide healthy habitat for fish, plants, and wildlife.

3.3 Problems, Opportunities, Decision Context, and Risk Characterization

The preceding sections discussed the components of risk and the relationship between different risk categories and the four national accounts. This is relevant because it provides a framework for the specifying problems and opportunities, understanding decision context, and characterizing the risks. A clear understanding of the problem and the risk should always precede any risk management measure formulation exercise.

3.3.1 Problems versus Opportunities

A problem can be thought of as an existing negative condition. If the harm has already occurred and/or is currently occurring and there is evidence to prove it, it is a problem. If all relevant exogenous and endogenous factors keep the same trajectory, the risk is expected to occur in the future and is less speculative.

Opportunities are future positive conditions. The harm has not occurred but is expected to occur in the future if all relevant exogenous and endogenous factors keep the same trajectory. There is an opportunity to manage a future risk.

The difference between the two concepts is relevant when considering risk management actions. Risks based on existing problems involve resources that are under immediate threat. Potential future risks are more speculative in nature and there may be more time to address the risk. This information should be considered when developing an array of CSRM measures.

3.3.2 Diagramming Problems and Opportunities

Diagramming involves developing problem and opportunity statements in a way that eases the selection of an array of risk management measures. The CSRM problem should be described in terms of how the harm occurs, who and/or what is being harmed, and where the harm is anticipated to occur. Problem and/or opportunity statements should incorporate the following dimensions:

Who/What – Describe who and/or what is being harmed (property, population at risk, environmental, and/or cultural resources).

How – Describe the coastal storm hazard(s) and how they produce harm (inundation, wave attack, and/or erosion).

Where – Describe the location and spatial extent of the harm.

When – Is the harm happening now and expected to get worse? Is the harm expected to occur in the future?

SECTION 4
Measures and Cost Library Considerations and Use

4.1 Non-Cost Considerations

4.1.1 Coastal Storm Risk Management Approaches and Methods

For the purposes of the MCL, a CSRM approach describes which factor gets changed within the conceptual risk framework to manage the risk. A CSRM method describes how that factor gets changed. **Figure 4-1** provides an illustration of the different CSRM approaches and the methods. **Table 4-1** provides detail about each measure in the MCL along with the measure's assigned CSRM approach and CSRM method.

An understanding of the risk as laid out in the previous sections; **Figure 4-1** includes three potential risk management approaches: performance-based, exposure-based, and vulnerability-based. In addition, consideration of nonphysical, nonstructural CSRM methods gives rise to a fourth: a decision-based approach. A brief description of these approaches is as follows:

- **Performance-based:** Reduce the occurrence and/ or severity of the coastal storm-based harm.
- **Exposure-based:** Reduce the size of the exposure.
- **Vulnerability-based:** Increase the resiliency of the exposure.
- **Decision-based:** Influence individual and collective decision-making to manage risk in the intermediate to long term.

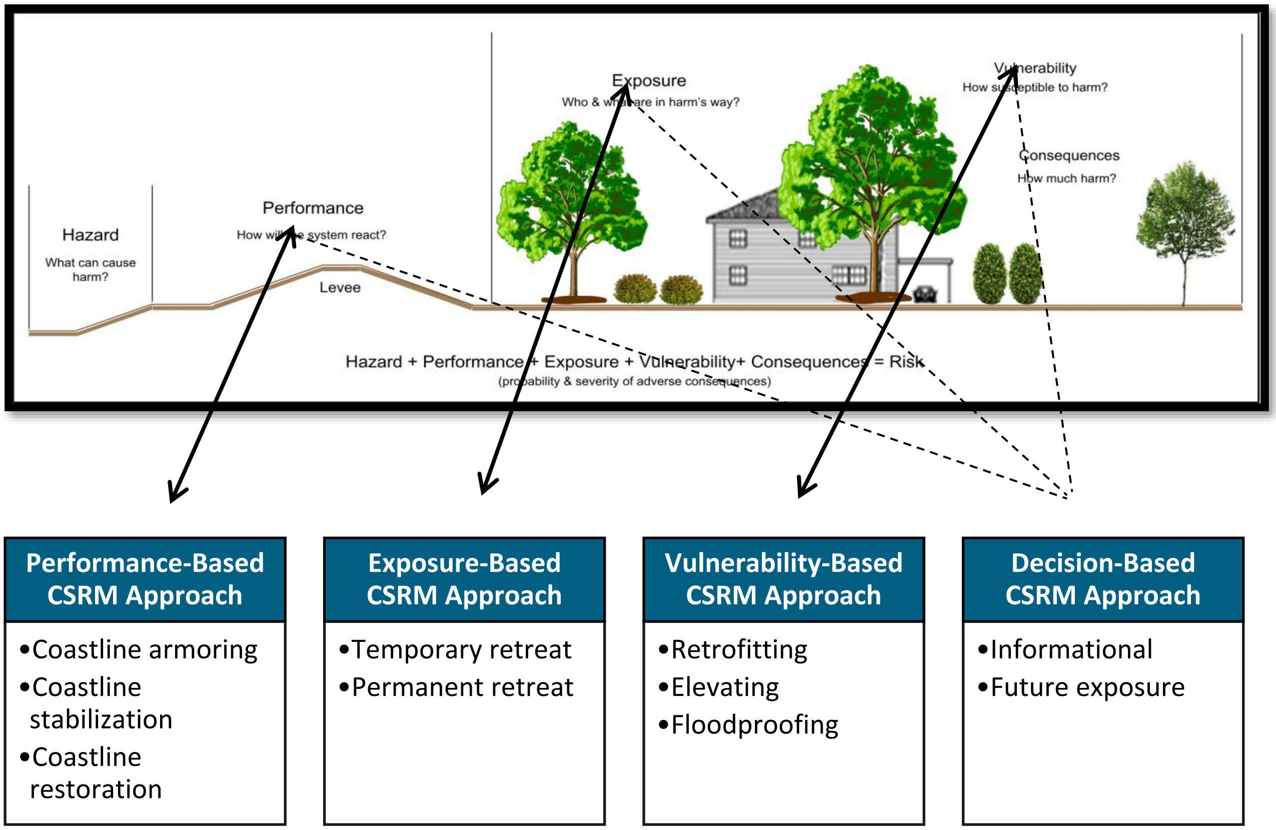

Figure 4-1: Coastal Storm Risk Management Approaches and Methods

The primary purpose of the MCL is to outline measures, which are considered individual actions that can be taken to address a CSRM problem or realize an opportunity. These are different from alternatives, which are one or more risk management measures employed at a specific location for the purpose of accomplishing one or more planning objectives. While measures are specific to an approach, alternatives can cover multiple approaches. The MCL is intended to deal with measures, and not alternatives. The ensuing sections provide additional description of the different CSRM approaches and methods.

4.1.1.1 Performance-Based Coastal Storm Risk Management Approaches

Performance-based approaches manage risk by reducing the occurrence and/or severity of coastal storm hazard adverse impacts in the floodplain. The risk management methods employed with this strategy include armoring the shoreline, moderating the erosion rate, and/or restoration of the shoreline. These methods are employed via hard-structural, soft-structural, and NNBF measures.

4.1.1.1.1 Coastline Armoring

The method behind armoring is to reduce the frequency and/or severity of the interactions between coastal storm hazards and exposure with a man-made physical barrier. These measures are prevalent in situations where the amount of land between hazard and exposure is relatively narrow, and there is enough development to warrant the cost of the risk management measure. Coastline armoring measures consist of seawalls (S-2), revetments (S-3), bulkheads (S-4), floodwalls (S-6,S-7), levees (S-8, S-12[6]), and surge barriers (S-9).

[6] Road elevation (S-12) can function similarly to a levee in that it can impede the movement of water within the floodplain.

4.1.1.1.2 Coastline Stabilization

Coastline stabilization manages coastal storm risk by moderating the shoreline change rate to sustain a natural shoreline barrier between the hazard and the exposure. This approach moderates the coastal sediment transport process and reduces the local erosion rate. These structures should be considered where chronic erosion is a problem due to the diminished sediment supply. Coastline stabilization measures include groins, breakwaters, and living shoreline type measures (S-1, S-5, NNBF-7 through NNBF-12). They are often combined with beach nourishment (S-10) to reduce downdrift impacts.

4.1.1.1.3 Coastline Restoration

Restoration manages risk by maintaining a minimum shoreline width between the hazard and the exposure. Its purpose is to provide risk management to upland development. Sediment material can be placed on the sub-aerial beach, as underwater mounds, across the subaqueous profile, or as dunes (S-10, S-11). Material can also be placed in a manner that restores barrier islands, maritime forests, or other coastal wetlands (NNBF-1 through NNBF-6).

4.1.1.2 Exposure-Based Coastal Storm Risk Management Approaches

Exposure-based CSRM approaches manage risk by reducing the size of the exposure. The method for achieving this is primarily adaption through temporary or permanent evacuation of the floodplain (retreat). Exposure-based CSRM methods are considered nonstructural measures because they are not intended to influence the frequency or severity of the coastal storm hazard(s) in the floodplain.

4.1.1.2.1 Temporary Retreat

Temporary retreat is a temporary reduction in the size of the exposure. Temporary retreat is the temporary evacuation of a population at risk during a coastal storm event. Some examples include flood warning systems (NS-6), flood emergency preparedness plans (NS-9), and evacuation plans (NS-12).

4.1.1.2.2 Permanent Retreat

Permanent retreat involves relocating assets, asset function and/or the population at risk in a way that eliminates all interaction with coastal-storm-induced hazards such as buyout/acquisition (NS-1) and relocation (NS-5). While permanent retreat CSRM measures effectively eliminate residual risk, they can inflict a significant social cost on a community.

4.1.1.3 Vulnerability-Based Coastal Storm Risk Management Approach

Vulnerability-based CSRM approaches manage risk by increasing the resiliency of existing or future exposure to harm from coastal storms. Methods for reducing vulnerability include retrofitting existing exposure and influencing decision-making with respect to future exposure development. Vulnerability-based CSRM methods are also considered nonstructural measures because they are not intended to influence the frequency or severity of the coastal storm hazard(s) in the floodplain. Retrofitting manages risk by reducing exposure vulnerability to coastal storm hazards. Elevating structures (NS-2, S-12[7]) and floodproofing (NS-3, NS-4) are retrofitting methods that make up a vulnerability-based CSRM approach.

4.1.1.4 Decision-Based Coastal Storm Risk Management Approach

While the CSRM approaches are characterized by physical actions taken to manage existing risk, a decision-based CSRM approach consists of methods that manage risk by influencing individual and collective choices or decisions. These decisions can be characterized by their direct or indirect effects, and the time frame for

[7] In addition to impeding the movement of floodwater in the floodplain, road elevation (S-12) is also an example of vulnerability-based retrofitting because it elevates critical infrastructure, making it less vulnerable to flood harm.

achieving those effects. Performance-, exposure-, and vulnerability-based CSRM approaches manage risk by reducing the likelihood or the degree of harm to existing exposure, while decision-based approaches manage risk by avoiding harm to future exposure. Though decision-based methods can address aspects of risk in the present, they tend to be more focused on the intermediate to long-term risk picture. Decision-based approaches can incorporate elements from performance-, exposure-, and vulnerability-based CSRM methods. Decision-based CSRM methods include informational and future exposure, as described below.

4.1.1.4.1 Informational

Information CSRM methods manage and/or avoid risk by influencing individual and collective behavior in the immediate, intermediate, and/or long-term time frames. Information and analysis are provided to individuals, businesses, and government entities to inform decisions with respect to protective action initiation, risk management, or future development. Some informational risk management measures are floodplain mapping (NS-8), risk communication (NS-13), and risk analysis (NS-14).

4.1.1.4.2 Future Exposure

Future exposure CSRM methods manage risk by shaping the future composition and character of the exposure. These nonphysical, nonstructural measures are intended to change the exposure over time in a way that minimizes future coastal storm risk. Measures that use this method include flood insurance (NS-7), land use regulations (NS-10), zoning (NS-11), and land conservation (NS-15).

4.1.2 Coastal Storm Risk Management Prepare, Absorb, Recover, and Adapt Principles

Community-level Prepare, Absorb, Recover, and Adapt (PARA) principles were used to qualitatively assess each measure for its ability to contribute to community resiliency. **Table 4-1** provides detail about each measure in the MCL, along with the measure's assigned CSRM approach and CSRM method. PARA principles used are based on ECB 2020-6.

4.1.2.1 Prepare

The prepare principle considers a measure's ability to meet the needs of a project component or system, including managing risks or costs under loading conditions beyond those required by technical standards or norms (e.g., USACE, International Code Council, American Society of Civil Engineers, American Society of Mechanical Engineers).

With respect to the MCL, measures were assessed based on contribution to community resiliency by taking advance actions that limit coastal storm risks in the immediate term. Measures that manage risk by temporary and permanent evacuation, or risk communication enhance community preparedness.

4.1.2.2 Absorb

The absorb principle considers a measure's ability to limit damage to, or loss of function of, a project component or system due to both acute and chronic loading conditions, including conditions beyond those used for the design. This principle can also be used as an opportunity to consider adding system component robustness, redundancy, and increased reliability.

With respect to the MCL and the absorb principle, measures were assessed based on contribution to community resiliency by enhancing the communal ability to withstand storm event loading conditions. Measures using performance-based and vulnerability-based risk management approaches enhance a community's ability to absorb the storm event and limit damages and loss of function.

4.1.2.3 Recover

The recover principle stresses wise and rapid repair or functional restoration of a project component or system. With respect to the MCL and the recover PARA principle, measures were evaluated based on contribution to community resiliency by facilitating recovery from coastal storm events. Flood insurance is the only measure in the MCL that enhances community resiliency by facilitating recovery.

4.1.2.4 Adapt

The adapt principle considers modifications to a project component or system that maintains or improves future performance based on lessons learned from a specific loading condition or loadings associated with changed conditions.

With respect to the MCL and the adapt principle, measures were assessed based on contribution to community resiliency by improving future and/or long-term ability to withstand coastal storm events.

Table 4-1: Measures and Cost Library Coastal Storm Risk Management Approaches, Methods, and Community PARA Principles

Measure Category	Measure Code	Measure Group Name	Coastal Storm Risk Management (CSRM) Approaches	CSRM Method(s)	Community-Level Prepare, Absorb, Recover, and Adapt (PARA) Principles
Structural	S-1	Groins	Performance-Based	Coastline Stabilization	Absorb
	S-2	Seawall	Performance-Based	Coastline Armoring	Absorb
	S-3	Revetment	Performance-Based	Coastline Armoring	Absorb
	S-4	Bulkhead	Performance-Based	Coastline Armoring	Absorb
	S-5	Breakwaters	Performance-Based	Coastline Stabilization	Absorb
	S-6	Floodwalls	Performance-Based	Coastline Armoring	Absorb
	S-7	Deployable Floodwalls	Performance-Based	Coastline Armoring	Absorb
	S-8	Levees / Dikes	Performance-Based	Coastline Armoring	Absorb
	S-9	Surge Barrier	Performance-Based	Coastline Armoring	Absorb
	S-10	Beach Nourishment (Initial)	Performance-Based	Coastline Restoration	Absorb
	S-10	Beach Nourishment (Renourishment)	Performance-Based	Coastline Restoration	Absorb
	S-11	Nearshore Nourishment	Performance-Based	Coastline Restoration	Absorb
	S-12	Road Elevation	Performance-Based	Coastline Armoring/Retrofit*	Absorb
	S-13	Ringwalls	Vulnerability-Based	Retrofit	Absorb

Measure Category	Measure Code	Measure Group Name	Coastal Storm Risk Management (CSRM) Approaches	CSRM Method(s)	Community-Level Prepare, Absorb, Recover, and Adapt (PARA) Principles
NNBF	NNBF-1	Barrier Island	Performance-Based	Coastline Restoration	Absorb
	NNBF-2	Tidal Flats	Performance-Based	Coastline Restoration	Absorb
	NNBF-3	Wetland	Performance-Based	Coastline Restoration	Absorb
	NNBF-4	Maritime Forest	Performance-Based	Coastline Restoration	Absorb
	NNBF-5	Wet Pine Savannah	Performance-Based	Coastline Restoration	Absorb
	NNBF-6	Mangroves	Performance-Based	Coastline Restoration	Absorb
	NNBF-7	Living Shoreline Vegetation	Performance-Based	Coastline Stabilization	Absorb
	NNBF-8	Submerged Aquatic Vegetation (SAV)	Performance-Based	Coastline Stabilization	Absorb
	NNBF-9	Coral Reef Breakwater	Performance-Based	Coastline Stabilization	Absorb
	NNBF-10	Oyster Reef Breakwater	Performance-Based	Coastline Stabilization	Absorb
	NNBF-11	Living Shoreline Reefs	Performance-Based	Coastline Stabilization	Absorb
	NNBF-12	Living Shoreline Sills	Performance-Based	Coastline Stabilization	Absorb
Nonstructural	NS-1	Buyout and Acquisition	Exposure-Based	Permanent Retreat	Adapt
	NS-2	Building Elevation	Vulnerability-Based	Retrofit	Absorb
	NS-3	Dry Floodproofing	Vulnerability-Based	Retrofit	Absorb
	NS-4	Wet Floodproofing	Vulnerability-Based	Retrofit	Absorb
	NS-5	Relocation	Exposure-Based	Permanent Retreat	Adapt
	NS-6	Flood Warning Systems	Exposure-Based	Temporary Retreat	Prepare
	NS-7	Flood Insurance	Decision-Based	Future Exposure	Recover
	NS-8	Floodplain Mapping	Decision-Based	Informational	Adapt
	NS-9	Flood Emergency Preparedness Plans	Exposure-Based	Temporary Retreat	Prepare
	NS-10	Land Use Regulations	Decision-Based	Future Exposure	Adapt
	NS-11	Zoning	Decision-Based	Future Exposure	Adapt
	NS-12	Evacuation Plans	Exposure-Based	Temporary Retreat	Prepare
	NS-13	Risk Communication	Decision-Based	Informational	Prepare
	NS-14	Risk Analysis	Decision-Based	Informational	Adapt
	NS-15	Land Conservation	Decision-Based	Future Exposure	Adapt

4.1.3 Coastal Storm Risk Management Measure Performance

For the purposes of the MCL, measure performance designation is based on whether a measure's ability to reduce inundation, wave attack, and erosion harm is a primary, secondary or not a function of the measure. This distinction is based on published USACE guidance including the Coastal Engineering Manual (USACE 2002), Coastal Risk Reduction and Resilience: Using the Full Array of Measures (USACE 2013a), and Use of Natural and Nature-Based Features (NNBF) for Coastal Resilience (USACE 2015b). The performance measure characterization based on the published guidance may not include more recently developed innovative engineering solutions. For these performance measures, inundation refers to the total water level contribution including wave setup, but not including wave run-up effects. Wave attack considers the energy of the waves as well as the water level contribution from the waves in the form of run-up and overtopping. Erosion considers the problem of a reduced sediment supply due to waves and/or currents.

4.1.4 Coastal Storm Risk Management Measure Applicability

Waves can generate a significant amount of energy along a coast. This energy shapes the coastline and is a primary factor considered in the application of any CSRM measure (**Figure 4-2**). High-energy coastlines are regularly exposed to large waves or strong tidal currents. They most commonly occur along the outermost coastline of a region, where dominant winds cause waves to strike the shoreline directly, or by wave refraction. Along high-energy coastlines, larger structural measures and/or multiple lines of defense are typically chosen. For purposes of the MCL, high-energy coastlines are defined as having design loading conditions from waves equal to or exceeding 3 feet.

Mixed-energy coastlines often have seasonal patterns in storm frequency and wave size. For the purposes of the MCL, mixed-energy coastlines are defined as having design loading conditions from waves generally in the range of 1.5 to 3 feet. Along mixed-energy coastlines, smaller scale coastal structures and coastline stabilization measures are typically chosen to include multiple lines of natural defense.

Low-energy coastlines are sheltered from wave and tidal energy, except during unusual or infrequent events. For the purpose of the MCL, low-energy coastlines are defined as having design loading conditions from waves less than 1.5 feet. Along low-energy coastlines, multiple lines of defense which largely integrate NNBF are common.

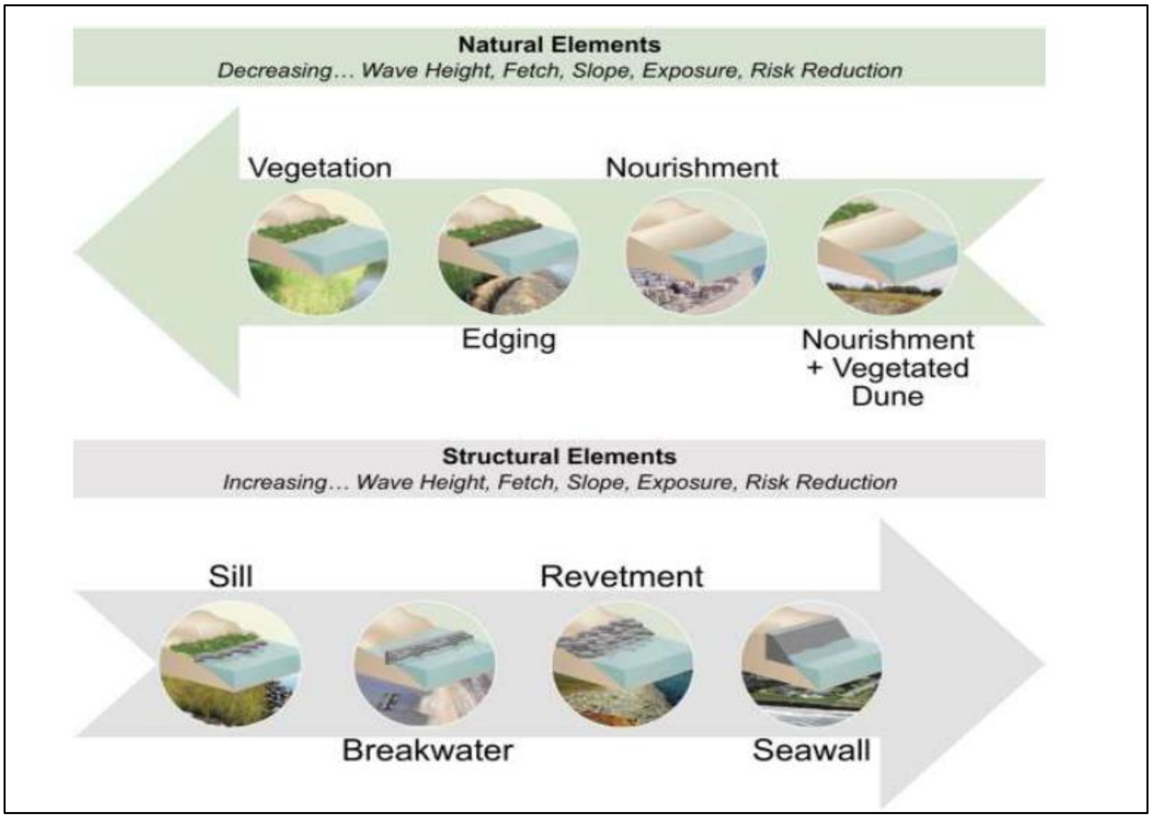

Figure 4-2: Coastal Storm Risk Management Measures Consisting of Varying Degrees of Natural and Nature-Based, and Structural Elements (depending on the setting and exposure to wave action) (Webb et al. 2019)

4.1.5 Coastal Storm Risk Management Measure Effects

4.1.5.1 Physical and Temporal Effects

For MCL purposes, each measure includes a description for how the measure influences the physical condition to achieve risk management effects and a qualitative assessment of when those effects would be realized over time. Immediate CSRM effects occur as soon as the measure is in place. Intermediate effects occur within at least 5 years of the measure being in place. Long-term CSRM effects occur in time frames greater than 5 years.

4.1.5.2 National Economic Development, Regional Economic Development, Environmental Quality, and Other Social Effects

Each measure was evaluated to determine whether it could potentially manage risk to assets and infrastructure, populations, environmental resources, and cultural resources. Measures that manage risk to assets and infrastructure are likely to provide NED benefits. Managing risks to assets and infrastructure can reduce business interruptions, which can result in RED benefits. Measures that manage risks to populations provide public health and safety benefits, which is a positive change in the OSE account. Measures that manage risks to species, habitats, cultural buildings, and/or cultural sites add value to the EQ account.

4.1.6 Coastal Storm Risk Management Measure Sea Level Change Adaptability

USACE guidance ER 1100-2-8162 Incorporating Sea Level Change in Civil Works Programs directs that careful consideration be given to sea level change during formulation and development of any CSRM strategy. This guidance emphasizes that the design or the operations and maintenance be implemented to adapt to sea level change to minimize adverse consequences while maximizing beneficial effects. Once implemented, a CSRM measure can have an actual physical life far beyond the period of economic justification. Therefore, it is important to also consider future adaptability beyond the typical 50-year economic analysis period. With documented historic rates of sea level rise and projected increases in the future, it is vital that adequate resources and real estate be considered upfront for potentially viable adaption strategies.

Each measure was evaluated to determine whether it could potentially be adapted in the future to accommodate sea level change. However, the adaptability of any measure will depend on the relative sea level change and site-specific constraints or opportunities that cannot be determined at the regional scale of the MCL.

4.2 Cost-Based Considerations

4.2.1 SACS Planning Reaches

MCL costs and cost components are organized by planning reach (**Table 4-2)** to ensure design and cost information reflect regional differences. The SACS study area (**Figure 4-3**) falls within the USACE SAD regional boundary and includes the tidally influenced coastal areas of North Carolina, South Carolina, Georgia, Florida, Alabama, Mississippi, Puerto Rico, and the U.S. Virgin Islands. The complete study area covers approximately 65,000 miles of coastline, including tidally connected back bays, estuaries, and wetlands that are vulnerable to hurricane and storm damages.

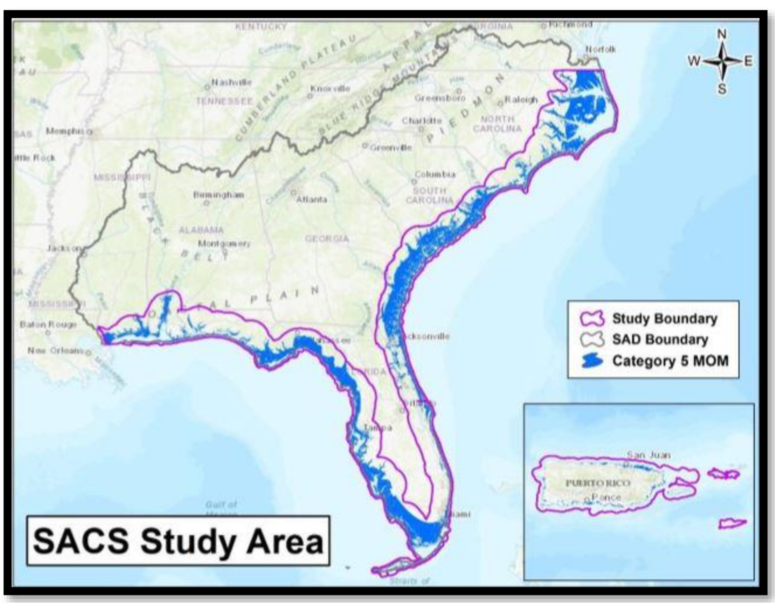

Figure 4-3: SACS Study Area

Table 4-2: SACS Planning Reaches

Planning Reach	Description	State	USACE District	Region
NC_01	Northern North Carolina	North Carolina	Wilmington	CONUS[8]
NC_02	Southern North Carolina	North Carolina	Wilmington	CONUS
SC_03	Northern South Carolina	South Carolina	Charleston	CONUS
SC_04	Southern South Carolina	South Carolina	Charleston	CONUS
GA_05	Georgia Coast	Georgia	Savannah	CONUS
FL_06	Northeast Florida	Florida	Jacksonville	CONUS
FL_07	Central East Florida	Florida	Jacksonville	CONUS
FL_08	Southeast Florida	Florida	Jacksonville	CONUS
FL_09	Florida Keys	Florida	Jacksonville	CONUS
FL_10	Southwest Florida	Florida	Jacksonville	CONUS
FL_11	Central West Florida	Florida	Jacksonville	CONUS
FL_12	Northwest Florida	Florida	Jacksonville	CONUS
FL_13	Florida Panhandle	Florida	Mobile	CONUS
AL_14	Alabama Coast	Alabama	Mobile	CONUS
MS_15	Mississippi Coast	Mississippi	Mobile	CONUS
PR_1	Northwest Puerto Rico	Puerto Rico	Jacksonville	OCONUS[9]
PR_2	North Central Puerto Rico	Puerto Rico	Jacksonville	OCONUS
PR_3	Southern Puerto Rico	Puerto Rico	Jacksonville	OCONUS
PR_4	Northeast Puerto Rico	Puerto Rico	Jacksonville	OCONUS
VI_1	St. Croix	U.S. Virgin Islands	Jacksonville	OCONUS
VI_2	St. Thomas	U.S. Virgin Islands	Jacksonville	OCONUS
VI_3	St. Johns	U.S. Virgin Islands	Jacksonville	OCONUS

4.2.2 Cost Level of Detail, Contingency, and Limitations

Costs for measures were developed to a conceptual level from the engineering data available, based primarily on historical cost data. Because of limitations within the historical record, some of the measures are based on relatively few completed projects. These are conceptual costs for measures, not project-specific costs for alternatives. These estimates are considered similar to Class 5 estimates in accordance with ER 1110-2-1302 and AACEI 56R-08. Typical variations in low and high ranges for Class 5 estimates are -20 percent to -30 percent on the low side and 30 percent to 50 percent on the high side (AACE-International 2020). Contingency is included in each estimate at 20 percent for the low end and 40 percent for the high end of the range. Because the majority of the costs are parametric in nature, they already contain some magnitude of contingency. As a result, these percentages were thought to be reasonable enough to present a user with a general idea of the cost of a measure. Costs do not include IDC costs, lands, real estate, or mitigation. Operation and maintenance costs are also not included at this time. Costs of each of these items could be significant and prohibitive depending on project conditions. Users have a responsibility to consider the impact of IDC, lands, real estate, operation and maintenance, and/or environmental mitigation when formulating risk management measures.

[8] CONUS – Continental United States. Consists of the 48 contiguous states between Canada and Mexico

[9] OCONUS – Outside Contiguous United States. Reference to U.S. states and territories that are not part of the CONUS designation (Alaska, Hawaii, Puerto Rico, USVI, American Samoa).

Referencing ER 1110-2-1302, a Class 5 estimate contains preliminary technical information (0 to 5 percent). These estimates are commonly referred to as an ROM. There is considerable risk and uncertainty inherent in a Class 5 estimate, resulting in high contingencies. These estimates are not recommended in reports because the extremely limited information and high risk poses credibility issues in quality and accuracy. Project designs, methods, and quantity development are unclear or uncertain. There is great reliance on broad-based assumptions, costs from comparable projects and data, cost book, cost engineering judgment, and parametric cost data. Development may consist of lump-sum cost. Detailed cost items are not required or captured. Each PDT must identify areas of risk and uncertainty in the project and describe them clearly to improve quality and confidence to a Class 4 estimate level for external reporting purposes. Establishing a credible contingency with qualifications is necessary. A typical contingency range could be 40 percent to 200 percent.

4.2.3 Cost Ranges

Ranges for costs were developed by using the varying sizes of measures applicable for a planning reach while also accounting for the unit cost range with respect to the measures' minimal constructible increment. Area cost factor (ACF) adjustments were not included in these estimates as the range of the ACFs for the AOR is 0.89 to 0.91 per EM 1110-2-1304, except Puerto Rico, which is 1.12. The cost-estimating team considered this small variation to be outweighed by the assumptions required for the scale of the planning reach. Specifically, the 2-percent variation for ACF within CONUS is well within the expected accuracy range of the estimates. These estimates are intended as a conceptual level estimate in the absence of site-specific cost data.

4.2.4 Engineering and Design / Supervision and Administration Costs

Engineering and Design (E&D) costs (15 percent) and Supervision and Administration (S&A) costs (12 percent) are included in each estimate. These costs are applied as a simple markup percentage. These percentages can vary dramatically depending on project complexity, designer of record, and the organization administering the contract. Historically the combined percentages could exceed 30 percent of project costs. These costs are combined with the estimated construction cost and contingency to calculate the Total Estimated First Cost. All costs are presented in FY20 dollars.

4.2.5 Life Cycle Cost Computations

Life cycle costs are reflected as equivalent annual costs (EAC), which reflect the cost of owning, operating, and maintaining an asset over its lifespan represented on an annual basis. NED costs are typically represented in EAC terms. Life cycle costs consist of the sum of all costs necessary to realize the benefits of the measure being constructed/implemented. These costs include all the total measure investment costs[10] reflected in EAC terms plus any operation and maintenance (O&M)[11] or monitoring and adaptive management (M&AM)[12] costs reflected in annual terms. O&M and M&AM costs are reflected in annual terms and for the purposes of the MCL are calculated as a percentage of the total measure cost.[13] Total measure investment costs are annualized using a capital recovery factor (CRF). CRF computation is as follows:

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[10] Total measure investment costs include all construction, construction management, PED (Pre-construction, Engineering, and Design), IDC (Interest During Construction), land, real estate, mobilization and demobilization, demolition, monitoring, and mitigation costs.

[11] O&M Costs – Currently there is a 0-percent placeholder in the MCL. This means that O&M costs are not reflected in the estimates at this time due to insufficient time to procure data.

[12] M&AM Costs – Currently M&AM cost is assumed to range between 3 and 4 percent of the total measure costs for S-10, S-11, and all NNBF measures.

[13] Total measure costs reflect the measure cost and contingency.

$$CRF = (i * (1+i)^n)/(((1+i)^n) - 1)$$

Where

i = Federal water resources discount rate (2.75 percent) and *n*= the number of years in the period (50)

4.2.6 Cost Computation Structures

All costs are converted to ROM unit costs using different cost computation processes or approaches. Those are as follows:

- Cost Approach-1: Hard-structural measures
- Cost Approach-2: Soft-structural measures
- Cost Approach-3: NNBF measures
- Cost Approach-4: Nonstructural measures (unique)

4.2.6.1 Cost Approach-1: Hard-Structural Measure Cost Computations

Cost computations for measures S-1, S-2, S-3, S-4, S-5, S-6, S-7, S-8, S-9, S-12 for both low and high ranges are based on the bulleted list below:

1. Total Measure Investment Cost Computations
   a. Measure Cost = Sum (Unit Quantity × Unit Price) for each cost component in the measure
   b. Contingency Cost = Measure Cost × Contingency (%)
   c. Total Measure Cost = Measure Cost + Contingency Cost
   d. E&D Cost = Total Measure Cost × E&D (%)
   e. S&A Cost = Total Measure Cost × S&A (%)
   f. Total Measure Investment Cost = Total Measure Cost + E&D Cost + S&A Cost
2. Measure Unit Cost & ROM Cost Computations
   a. Measure Unit Cost = (Total Measure Investment Cost – Mob/Demob Cost)/ Measure Unit
   b. ROM Cost Computation w/ User Input14 = (Measure Unit Cost x Measure Units) + Mob/Demob Cost
3. EAC Computations
   a. O&M Cost = Total Measure Cost × O&M (%)
   b. Annualized Total Measure Investment Cost = Total Measure Investment Cost × CRF
   c. EAC ($) = Annualized Total Measure Investment Cost ($) + O&M ($)

4.2.6.2 Cost Approach-2: Soft-Structural Measure Cost Computations

Cost Approach-2 differs from Cost Approach-1 in that there are renourishment events (S-10) or multiple construction events (S-11) throughout the life cycle. This approach accounts for this in a simplified fashion. This approach accounts for the total and annualized cost of each event and then sums them. The present value of these costs as they occur throughout the life cycle is not factored into the cost to account for the level of detail used in the MCL. This cost approach also uses the M&AM cost assumption of between 3 and 4 percent of measure's total cost. Cost computation for measures S-10 and S-11 for both low and high ranges are based on the bulleted list below:

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[14] Each measure within this document has a Unit Cost Ranges by Planning Reach table. The included formula should be used to compute the ROM cost ranges for the measure.

1. Total Measure Investment Cost Computations for Initial Nourishment Events
   a. Measure Cost = Sum (Unit Quantity × Unit Price) for each cost component in the measure
   b. Contingency Cost = Measure Cost × Contingency (%)
   c. Total Measure Cost = Measure Cost + Contingency Cost
   d. E&D Cost = Total Measure Cost × E&D (%)
   e. S&A Cost = Total Measure Cost × S&A (%)
   f. Total Measure Investment Cost = Total Measure Cost + E&D Cost + S&A Cost
2. Total Measure Investment Cost Computations for Renourishment Events
   a. Measure Cost = Sum (Unit Quantity × Unit Price) for each cost component in the measure
   b. Contingency Cost = Measure Cost × Contingency (%)
   c. Total Measure Cost = Measure Cost + Contingency Cost
   d. E&D Cost = Total Measure Cost × E&D (%)
   e. S&A Cost = Total Measure Cost × S&A (%)
   f. Total Measure Investment Cost = Total Measure Cost + E&D Cost + S&A Cost
3. Measure Unit Cost & ROM Cost Computations
   a. Initial Measure Unit Cost = (Total Measure Investment Cost – Mob/Demob Cost)/ Measure Unit
   b. Renourishment Measure Unit Cost = (Total Measure Investment Cost ($) – Mob/Demob Cost)/Measure Unit
   c. ROM Cost Computation w/ User Input
      i. S-10 = ((Initial Event Measure Unit Cost ($) × Measure Units) + (Initial Mob/Demob Cost)) + Estimated # Renourishment Events × ((Renourishment Event Measure Unit Cost ($) × Measure Units) + (Renourishment Mob/Demob Cost))
      ii. S-11 = ((Measure Unit Cost × Measure Units) + (Mob/Demob Cost)) × Estimated # Nourishment Events
4. EAC Computations
   a. M&AM Cost = Total Measure Cost x M&AM (%)
   b. Annualized Total Measure Investment Cost = Total Measure Investment Cost × CRF
   c. EAC = Annualized Total Measure Investment Cost + M&AM Cost

4.2.6.3 Cost Approach-3: Natural and Nature-Based Features Cost Computations

Cost Approach-3 is similar to Cost Approach-1 but it uses the M&AM cost assumptions. Cost computation for all NNBF measures are based on the bulleted list below:

1. Total Measure Investment Cost Computations
   a. Measure Cost = Sum (Unit Quantity × Unit Price) for each cost component in the measure
   b. Contingency Cost = Measure Cost × Contingency (%)
   c. Total Measure Cost = Measure Cost + Contingency Cost
   d. E&D Cost = Total Measure Cost × E&D (%)
   e. S&A Cost = Total Measure Cost × S&A (%)
2. Total Measure Investment Cost = Total Measure Cost + E&D Cost + S&A Cost
   a. Measure Unit Cost & ROM Cost Computations
   b. Measure Unit Cost = (Total Measure Investment Cost – Mob/Demob Cost)/ Measure Unit
   c. ROM Cost Computation w/ User Input = (Measure Unit Cost × Measure Units) + Mob/Demob Cost
3. EAC Computations
   a. M&AM Cost = Total Measure Cost × M&AM (%)
   b. Annualized Total Measure Investment Cost = Total Measure Investment Cost × CRF
   c. EAC ($) = Annualized Total Measure Investment Cost ($) + O&M ($)

4.2.6.4 Cost Approach-4: Nonstructural Measures Cost Computations

Cost computation for measures NS-1, NS-2, NS-3, NS-4, NS-5, and NS-6 are reflected in the section for each measure and converted to annualized costs using the same CRF used in the other cost approaches.

4.2.7 Costs Price Level Adjustment Recommendations

Measure costs are represented in 2020 price levels. Refer to Section 3.2.7.1 for the procedure to update costs to current price levels. **Table 4-3** matches each measure with an index recommendation, from the Civil Works Construction Cost Index System's (CWCCIS) Work Breakdown Structure Feature Codes or the S&P Case-Shiller National Home Price Index, to use in adjusting measure costs to current price levels.

The use of the suggested matches below will reduce cost resolution because the measures do not match the Civil Works Work Breakdown Structure Feature Code Descriptions one for one. The measures are assigned to the most related CWBS (Civil Work Breakdown Structure) category. Additionally, this price level adjustment method decreases measure cost precision with respect to time or duration from initial costing of the measures for use in the MCL. However, this recommendation attempts to capture price changes and reduce uncertainty in the MCL's use.

Table 4-3: Index Recommendations for Price Level Adjustments

Measure Code	Measure Group Name	Index Recommendation
S-1	Groins	CWBS - Feature Code: 16_Bank Stabilization
S-2	Seawall	CWBS - Feature Code: 10_Breakwater & Seawalls
S-3	Revetment	CWBS - Feature Code: 16_Bank Stabilization
S-4	Bulkhead	CWBS - Feature Code: 16_Bank Stabilization
S-5	Breakwaters	CWBS - Feature Code: 10_Breakwater & Seawalls
S-6	Floodwalls	CWBS - Feature Code: 11_Levees & Floodwalls
S-7	Deployable Floodwalls	CWBS – Feature Code: 25 Composite Index
S-8	Levees / Dikes	CWBS - Feature Code: 11_Levees & Floodwalls
S-9	Surge Barrier	CWBS - Feature Code: 05_Locks
S-10	Beach Nourishment	CWBS - Feature Code: 17_Beach Replenishment
S-11	Nearshore Nourishment	CWBS - Feature Code: 17_Beach Replenishment
S-12	Road Elevation	CWBS - Feature Code: 08_Roads, Railroads, and Bridges
S-13	Ringwalls	CWBS - Feature Code: 11_Levees & Floodwalls
NNBF-1	Barrier Island	CWBS - Feature Code: 17_Beach Replenishment
NNBF-2	Tidal Flats	CWBS - Feature Code: 17_Beach Replenishment
NNBF-3	Wetland	CWBS - Feature Code: 06_Fish & Wildlife Facilities
NNBF-4	Maritime Forest	CWBS - Feature Code: 06_Fish & Wildlife Facilities
NNBF-5	Wet Pine Savannah	CWBS - Feature Code: 06_Fish & Wildlife Facilities
NNBF-6	Mangroves	CWBS - Feature Code: 06_Fish & Wildlife Facilities
NNBF-7	Living Shoreline Vegetation	CWBS - Feature Code: 06_Fish & Wildlife Facilities
NNBF-8	Submerged Aquatic Vegetation (SAV)	CWBS - Feature Code: 06_Fish & Wildlife Facilities
NNBF-9	Coral Reef Breakwater	CWBS - Feature Code: 06_Fish & Wildlife Facilities
NNBF-10	Oyster Reef Breakwater	CWBS - Feature Code: 06_Fish & Wildlife Facilities
NNBF-11	Living Shoreline Reefs	CWBS - Feature Code: 06_Fish & Wildlife Facilities
NNBF-12	Living Shoreline Sills	CWBS - Feature Code: 06_Fish & Wildlife Facilities

Measure Code	Measure Group Name	Index Recommendation
NS-1	Buyout and Acquisition	S&P Case-Shiller National Home Price Index[15]
NS-2	Building Elevation	CWBS – Feature Code: 25 Composite Index
NS-3	Dry Floodproofing	CWBS – Feature Code: 25 Composite Index
NS-4	Wet Floodproofing	CWBS – Feature Code: 25 Composite Index
NS-5	Relocation	CWBS – Feature Code: 25 Composite Index
NS-6	Flood Warning Systems	N/A: No Cost Included in MCL
NS-7	Flood Insurance	N/A: No Cost Included in MCL
NS-8	Floodplain Mapping	N/A: No Cost Included in MCL
NS-9	Flood Emergency Preparedness Plans	N/A: No Cost Included in MCL
NS-10	Land Use Regulations	N/A: No Cost Included in MCL
NS-11	Zoning	N/A: No Cost Included in MCL
NS-12	Evacuation Plans	N/A: No Cost Included in MCL
NS-13	Risk Communication	N/A: No Cost Included in MCL
NS-14	Risk Analysis	N/A: No Cost Included in MCL
NS-15	Land Conservation	N/A: No Cost Included in MCL

4.2.7.1 Price Level Adjustment Procedure

Follow the steps below to update each measure's costs to the preferred price level.[16] Follow method 'A' for all measures with the recommendation of using a CWBS Feature Code. Follow method 'B' for price level adjustments on buyouts and acquisitions.

Method A:

- **Step 1** Select the reach specific measures' costs needed for price level updates.
- **Step 2** Using the CWCCIS Escalation Calculation Workbook:[17]
  - Enter each measure's recommended CWBS Code in cell A4
  - Select '**2020Q1**' as the Estimate Pricing Level Date in cell C7
  - Select the year and quarter corresponding to the preferred price level in cell C8
  - Note the updated 'Escalation Percentage' generated in cell E10
- **Step 3** Multiply this escalation percentage by all costs desired for the reach specific measure.

[15] The S&P Case-Shiller U.S. National Home Price Index values can be obtained from the Federal Reserve Economic Data (FRED) of St. Louis. The index reports monthly price changes for residential real estate by tracking repeat sales of single-family houses for the nine U.S. Census divisions using a 3-month moving average. https://fred.stlouisfed.org/series/CSUSHPISA

[16] If comparing with the ERA use similar price levels.

[17] Current CWCCIS Indices and escalation percentages can be obtained from the USACE Cost-Engineering: https://usace.army.mil/Cost-Engineering/cwccis/

Table 4-4: Price Level Adjustment Examples using Civil Work Cost Breakdown Structure (CWBS) Feature Codes

Measure Code	Index Recommendation	2020Q1 Index Value	2022Q3 Index Value	Escalation Percentage	Total First Unit Cost Low	Total Unit Cost Low in 2022Q3 Price Level
S-1 (NC_01)	CWBS: 16	965.11	1,048.58	108.65%	$1,976	$2,147
S-2 (NC_01)	CWBS: 10	905.00	971.42	107.34%	$8,171	$8,771
S-7 (NC_01)_	CWBS: 25 "ALL"	893.31	1022.10	114.42%	$2,070	$2,368
NNBF-1 (NC_01)	CWBS: 17	965.66	1031.72	106.84%	$231,105	$246,913

Method B:

- **Step 1** Select the reach specific measure costs needed for price level updates.
- **Step 2** Obtain the S&P/Case-Shiller Index Value corresponding to January 2020 by navigating to the St. Louis Federal Reserve web page.[18]
- **Step 3** Obtain the S&P Case-Shiller Index Value corresponding to the preferred price level year and month on the St. Louis Federal Reserve web page.
- **Step 4** Calculate the price level percentage change by dividing the index value obtained from Step 3 by the index value obtained in Step 2.
- **Step 5** Multiply the price level percentage change calculated from Step 4 by all NS-1 costs desired for the reach.

Table 4-5: Price Level Adjustment Examples using S&P Case-Shiller for NS-1

Measure Code	Index Recommendation	2020 January Index Value	2022 February Index Value	Price Level Percentage Change	Buyout Cost Per Asset Low	Buyout Cost Per Asset in 2022 Feb Price Level
NS-1 (NC_01)	S&P Case-Shiller	214.421	289.744	135.13%	$324,210	$438,100

4.3 Using the Measures and Cost Library to Select an Array of Measures

Below are the steps a user can follow when using the SACS MCL to develop risk management measures for a CSRM study.

- **Step 1** – Clearly identify problem in terms of hazard (inundation, wave attack, or erosion), subjects of risk management (public and private property, critical infrastructure, PAR, environmental resources, cultural resources), and location. Information on the physical setting is also useful.

[18] https://fred.stlouisfed.org/series/CSUSHPISA

- **Step 2** – Identify spatial extent of the problem. Using the Tier 2 Economic Risk Assessment Tool, select the census blocks that define the extent of the problem. Record the existing and future economic risk (expected annual damages [EADs]). These become the upper and lower bounds for a risk management measure cost estimate to justify Federal interest.
- **Step 3** – Select planning reach and range of measures that are effective at addressing the identified problem. Consider risk management function (inundation, wave attack, erosion) and measure applicability by wave characteristic relative to the stated problem when choosing measures. Then enter appropriate unit parameters for each selected measure to estimate ROM cost range.
- **Step 4** – Observe the annualized range of cost and compare to the range of risk. If the lower bound of the measure cost (EAC) exceeds the upper bound of the damages (EAD), there is a high likelihood that the measures cost will exceed its risk management benefits.
- **Step 5** – Describe the uncertainties associated with each of the preceding steps and the risk of making decisions without reducing those uncertainties.

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SECTION 5
Structural Measures

5.1 S-1: Groins

5.1.1 S-1 Measure Description

Structures that extend perpendicular to the shoreline to intercept sand moving parallel to the beach to retain sand, reduce beach erosion, and break waves. This measure is often implemented as a single groin known as a terminal groin or as a groin system (series of groins) extending across a section of ocean-facing shoreline. Groins are usually constructed with stone along ocean-facing shorelines but can also be constructed out of timber and metal sheet piles in more sheltered areas such as bays. Groins are occasionally constructed non-perpendicular to the shoreline, can be curved, have fishtails, or have a shore-parallel T-head at their seaward end. Shore-parallel spurs can shelter a stretch of beach or reduce the possibility of offshore sand transport by rip currents (USACE 2002). Groins can be long or short and high or low. Long and/or high groins will trap more sediment than comparatively shorter and/or lower ones. Some cross-groin transport is beneficial for obtaining a well-distributed retaining effect along the coast. For the same reason permeable groins, which allow sediment to be transported through the structure and may reduce rip currents, may be advantageous. Proper spacing of groins allows for sand to accumulate along the entire length of the area between the groins.

Figure 5-1: Fisher Island T-Head Groins

5.1.2 S-1 Measure Performance and Applicability

A groin or groin field moderates coastal erosion caused primarily by a net long shore loss of beach material. Primary and secondary risk management functions include reducing the effects of erosion and wave attack, respectively. Groins are typically applicable in mixed to high wave energy environments; however, site-specific shoreline types, adjacent water depths, erosion rates, soil conditions, currents, waves, as well as other physical, environmental and economic factors will typically dictate the overall applicability.

5.1.3 S-1 Coastal Storm Risk Management Effects and Adaptability

5.1.3.1 Physical and Temporal Effects

The physical effect of groins is accretion of beach material on the updrift side and erosion on the downdrift side; both effects extend some distance from the structure(s). Used in conjunction with beach nourishment, overtime a groin can reduce exposure updrift and in its lee. Risk management effects are deemed ‘intermediate’ because the measure must be used in conjunction with other measures and/or requires time for a protective beach to develop. If the measure is used in conjunction with beach nourishment (S-10), risk management effects happen immediately.

5.1.3.2 S-1 National Economic Development, Regional Economic Development, Other Social Effects, and Environmental Quality Effects

Groins provide reduction in beach erosion and when combined with fill can extend the maintenance needs and reduce potential for downdrift erosion. Possible other social benefits include recreational fishing opportunities. The following table shows the potential benefits and costs for each of the four national accounts.

Table 5-1: S-1 National Economic Development (NED), Regional Economic Development (RED), Other Social Effects (OSE), and Environmental Quality (EQ) Effects

Account	Potential Benefits	Potential Costs
NED	• Manage risk of property and critical infrastructure loss, vehicle damage, land loss, protective measure costs, emergency costs, transportation delay costs • Incidental recreation	• Measure total investment cost • O&M cost
RED	• Risk management to regional revenue and employment disruptions by preventing property damage • Direct, indirect, and induced multiplier effects from measure costs	• Potential revenue losses or employment disruptions as a result of the measure
OSE	• Manage risk to urban and community socioeconomic conditions • Emergency preparedness	• Potential cost to Non-Federal Sponsor (NFS)/ Opportunity costs
EQ	• Manage risks to any cultural resource buildings in its lee • Contribute to beach and dune habitat	• Possibility for adverse environmental impacts

5.1.3.3 S-1 Sea Level Change Adaptability

Groins can be adaptable to sea level change through adjustments to the length and elevation and in some cases the permeability of the structure to account for retreating shorelines, rising water, and changes in the wave and current climate. If the groin is a rubble-mound structure, the stone size can be adjusted as well to the changing conditions.

5.1.4 S-1 Design and Cost Components

5.1.4.1 S-1 Generic Design

Site-specific shoreline types, adjacent water depths, erosion rates, soil conditions, currents, waves, as well as other physical, environmental, and economic factors will typically dictate the applicability and groin type as well as the material type and structure profile. However, given the regional scale of the study, it is impossible to account for these local, site-specific conditions to determine the type of groin that may be most appropriate at each location. Therefore, for the purposes of regional framework development, a permeable limestone rubble-mound groin is assumed.

The design is based on a double layer graded quarry stone (protective armor and underlayer) with an assumed 400-foot length, average 5-foot crest width; 2 (Horizontal): 1 (Vertical) side slopes overlaid on marine mattresses, a container filled with rocks and constructed with a strong geogrid. Structural heights and stone weights range based on variations in regional hydrodynamics from one planning reach to another using standard empirical formulas contained within EM 1110-2-1100 Coastal Engineering Manual for armor weight. Hydrodynamic input accounts for the variability in the 2-percent annual exceedance probability (AEP) storm surge based on statistical analysis of verified historical extreme water levels at National Oceanic and Atmospheric Administration's (NOAA) tide stations and deepwater wave information from USACE Wave Information Study (WIS) extremal analysis.

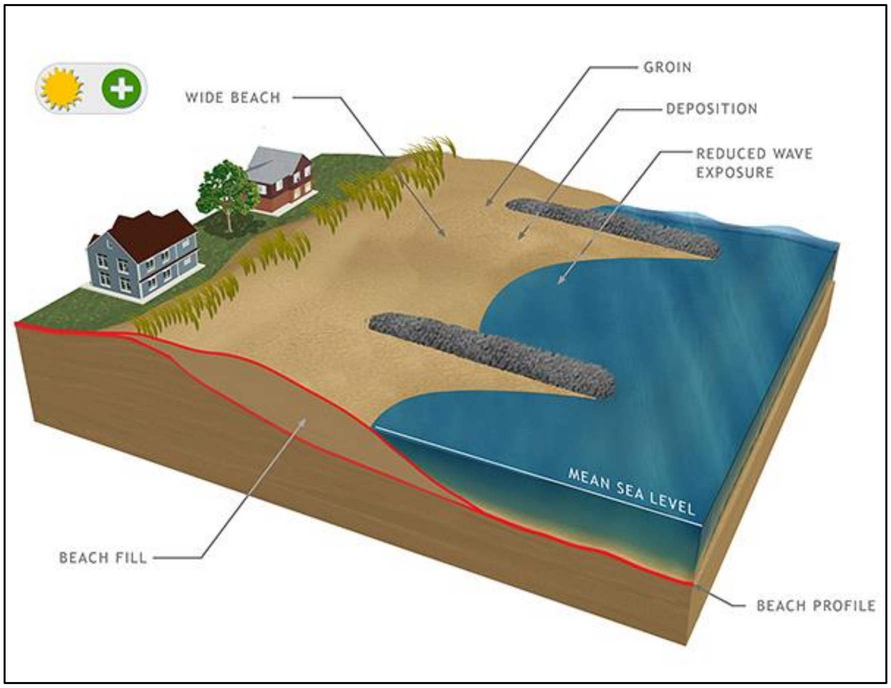

Figure 5-2: Example of Typical Groin Layout (USACE 2015a)

5.1.4.2 S-1 Cost Components

As previously discussed, site-specific shoreline characteristics will dictate the type of groin most applicable to a project. An example of a typical groin configuration is shown in **Figure 5-2**. Specifically, regarding cost, factors to consider include, but are not limited to, staging/access, regional stone availability, hauling/placement production, and placement area tidal influence.

The estimated costs for the groins are provided as a range of high and low. These costs are most impacted and sensitive to the quantity of stone per unit of measure and the size of the stone necessary. These costs are based upon calculated ranges of stone sizes which take into consideration variations in regional hydrodynamics from one planning reach to another. Such as typical water depths and crest heights.

Table 5-2 reflects what would be considered a contract cost prior to applying any additional markups, or owner markups. These additional costs include contingency at 20 percent for the low end and 40 percent for the high end, E&D and S&A are estimated at 15 percent and 12 percent, respectively, for both the high and low ends of the range presented. M&AM costs are estimated at 3 percent for the low end and 4 percent for the high end. The full or total owner costs are reflected as unit prices in **Table 5-3**. If the user prefers to analyze the cost components individually it is recommended that they consider applying each additional owner markup in the order discussed above in a compounded process. Section 4.2.6.1 contains details regarding cost computations.

Table 5-2: S-1 Cost Components

State / Planning Reach	Feature Category	Feature	Feature Unit	Quantity Low	Quantity High	Unit Cost Low	Unit Cost High
S1_1:[19] (NC, SC, FL_06, FL_07)	Unit	Groin Length	Linear foot (LF)	400	400	–	–
	Measure Cost	Mob/Demob	Lump sum (LS)	1	1	$150,000	$400,000
	Measure Cost	Armor Stone	$/Ton	804	2808	$180	$270
	Measure Cost	Underlayer/ Core Stone	$/Ton	283	804	$180	$270
	Measure Cost	Marine Mattress	$/Square foot (SF)	14800	27600	$19	$45
S1_2: (GA)	Unit	Groin Length	LF	400	400	–	–
	Measure Cost	Mob/Demob	LS	1	1	150,000	$400,000
	Measure Cost	Armor Stone	$/Ton	982	3127	$180	$270
	Measure Cost	Underlayer/ Core Stone	$/Ton	341	888	$180	$270
	Measure Cost	Marine Mattress	$/SF	14400	29200	$19	$45
S1_3: (FL_08, FL_09, FL_10, FL_11, FL_12, FL_13, AL_14, MS_15, PR, USVI)	Unit	Groin Length	LF	400	400	–	–
	Measure Cost	Mob/Demob	LS	1	1	$150,000	$400,000
	Measure Cost	Armor Stone	$/Ton	643	2505	$180	$270
	Measure Cost	Underlayer/ Core Stone	$/Ton	229	724	$180	$270
	Measure Cost	Marine Mattress	$/SF	13200	26000	$19	$45

5.1.5 S-1 Unit Cost Ranges by Planning Reach

Groins may be viable in all planning reaches within the SACS study area along open, eroding, exposed and sheltered sandy coastlines. **Table 5-3** provides details on the unit costs by planning reach for groins.

Table 5-3: S-1 Unit Costs by Planning Reach

Reach	Mob/Demob Low	Mob/Demob High	Total First Unit Cost Low	Total First Unit Cost High	Equivalent Annual Cost (EAC)-Mob-Low	EAC-Mob-High	EAC/ Linear Feet (LF)-Low	EAC/ LF-High
NC_01	$150,000	$400,000	$1,976	$10,450	$5,556	$14,816	$73	$387
NC_02	$150,000	$400,000	$1,976	$10,450	$5,556	$14,816	$73	$387
SC_03	$150,000	$400,000	$1,976	$10,450	$5,556	$14,816	$73	$387
SC_04	$150,000	$400,000	$1,976	$10,450	$5,556	$14,816	$73	$387
GA_05	$150,000	$400,000	$2,107	$11,241	$5,556	$14,816	$78	$416
FL_06	$150,000	$400,000	$1,976	$10,450	$5,556	$14,816	$73	$387
FL_07	$150,000	$400,000	$1,976	$10,450	$5,556	$14,816	$73	$387
FL_08	$150,000	$400,000	$1,717	$9,683	$5,556	$14,816	$64	$359
FL_09	$150,000	$400,000	$1,717	$9,683	$5,556	$14,816	$64	$359

[19] The notation 'S1_1' is a reference to the cost component array that contains the cost components, quantities and unit cost that make up the costs for a given range of planning reaches. The example given means the cost components apply for groins (S1) for all planning reaches in North Carolina, South Carolina, and FL_06 and FL_07 in Florida.

Reach	Mob/Demob Low	Mob/Demob High	Total First Unit Cost Low	Total First Unit Cost High	Equivalent Annual Cost (EAC)-Mob-Low	EAC-Mob-High	EAC/ Linear Feet (LF)-Low	EAC/ LF-High
FL_10	$150,000	$400,000	$1,717	$9,683	$5,556	$14,816	$64	$359
FL_11	$150,000	$400,000	$1,717	$9,683	$5,556	$14,816	$64	$359
FL_12	$150,000	$400,000	$1,717	$9,683	$5,556	$14,816	$64	$359
FL_13	$150,000	$400,000	$1,717	$9,683	$5,556	$14,816	$64	$359
AL_14	$150,000	$400,000	$1,717	$9,683	$5,556	$14,816	$64	$359
MS_15	$150,000	$400,000	$1,717	$9,683	$5,556	$14,816	$64	$359
PR_1	$150,000	$400,000	$1,717	$9,683	$5,556	$14,816	$64	$359
PR_2	$150,000	$400,000	$1,717	$9,683	$5,556	$14,816	$64	$359
PR_3	$150,000	$400,000	$1,717	$9,683	$5,556	$14,816	$64	$359
PR_4	$150,000	$400,000	$1,717	$9,683	$5,556	$14,816	$64	$359
VI_1	$150,000	$400,000	$1,717	$9,683	$5,556	$14,816	$64	$359
VI_2	$150,000	$400,000	$1,717	$9,683	$5,556	$14,816	$64	$359
VI_3	$150,000	$400,000	$1,717	$9,683	$5,556	$14,816	$64	$359

5.1.6 S-1 Assumptions, Sources, Limitations and Uncertainties

Costs are assumed based on a permeable rubble-mound fix length structure. Foundation conditions, exposure to wave action, availability of materials as well as structural and functional performance criteria will influence the type of groin, the structure profile and cost. Stand-alone groin(s) costs are provided on a cost per linear foot basis. Therefore, a user should estimate the number of groins necessary to construct the groin field to determine the cost range. Each groin unit is assumed to be approximately 400 feet in length and 5 feet in width at the crest and constructed with limestone armor, core and underlayer built upon marine mattresses.

The costs for this measure are parametric unit prices and calculated based upon recent bid date from a shore protection project known as Sarasota County Lido Key Segment. The project was awarded in FY20 and two groins are being constructed. Those two groins are approximately 175 linear feet and 300 linear. Prices received on that project were used to help develop the prices assumed for this measure. The 400 linear feet mentioned above is considered a good average length to be assumed when analyzing this measure and specifically when considering multiple groins for a segment of shoreline with limited site-specific information.

5.2 S-2: Seawalls

5.2.1 S-2 Measure Description

A seawall is a structure built parallel along a segment of coast with a principal function to reduce overtopping and consequent flooding of land and infrastructure behind it due to storm surges and large waves (typically greater than 5 feet). The structure often retains earth against its shoreward face. Seawalls range from vertical face structures such as massive gravity concrete walls, tied walls using steel or concrete piling and stone-filled cribwork to sloping structures with typical surfaces reinforced by concrete slabs or large stone.

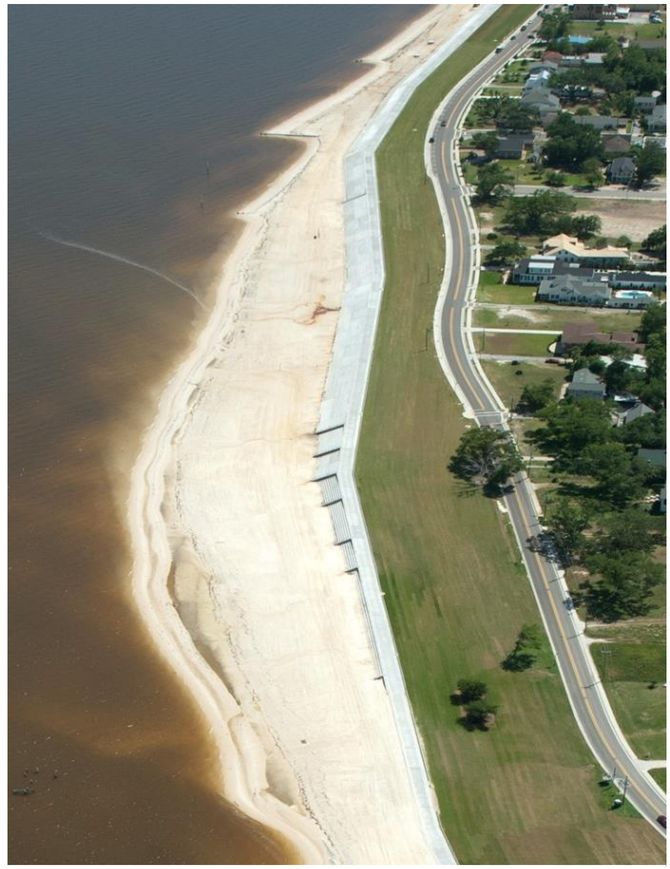

Figure 5-3: Bay St. Louis Concrete Stepped Seawall and Beach

5.2.2 S-2 Measure Performance, and Applicability

A seawall armors the shoreline to reduce damage to landward property and infrastructure from coastal storms. Its primary risk management function is to reduce wave attack, while its secondary functions reduce inundation and erosion impacts. Seawalls are typically applicable in high wave energy environments but are also used along mixed-energy coastlines. While wave energy is a factor, site-specific shoreline types, adjacent water depths, erosion rates, soil conditions, currents, as well as other physical, environmental and economic factors will typically dictate the overall applicability.

5.2.3 S-2 Coastal Storm Risk Management Effects and Adaptability

5.2.3.1 S-2 Physical and Temporal Effects

Seawalls manage the risk of damage that occurs from storm surge and wave run-up and tend to be placed close to the hazard. They can be used on shorelines that are exposed to wave and tidal energy. Upon construction, the measure reduces wave, inundation, and erosion harm to the property and critical infrastructure in its lee. Seawalls reduce damages to infrastructure and property in the lee by reducing overtopping, erosion, and consequent flooding of the land behind the structure. Erosion of the beach profile landward of a seawall might be reduced, but if the seawall is exposed to waves during a part or all of the tidal cycle, erosion of the seabed immediately in front of the structure may be enhanced due to increased wave reflection caused by the seawall and isolation of the beach from the inland sediment source. This can result in a steeper seabed profile, which can subsequently allow larger waves to reach the structure. To mitigate for this, seawalls are designed with toe protection and often are integrated with a seaward beach nourishment component.

5.2.3.2 S-2 National Economic Development, Regional Economic Development, Other Social Effects, and Environmental Quality Effects

Seawalls manage risks to critical infrastructure such as evacuation routes and provide recreation opportunities when open space walkways are included. By providing protection to public and private property, and critical infrastructure the measure reduces storm impacts to local economic activity, community income, and emergency preparedness. **Table 5-4** provides details on the seawall NED, RED, OSE, and EQ effects.

Table 5-4: S-2 National Economic Development (NED), Regional Economic Development (RED), Other Social Effects (OSE), and Environmental Quality Effects

Account	Potential Benefits	Potential Costs
NED	• Manage risk to property and critical infrastructure • Can provide incidental recreation	• Measure total investment cost • O&M Cost
RED	• Manage risk to regional revenue and employment in event of commercial property damage • Direct, indirect and induced effects of measure	• Revenue losses or employment disruptions as a result of the measure
OSE	• Manage risk to urban and community socioeconomic conditions • Emergency preparedness	• Potential cost to Non-Federal Sponsor (NFS)/ Opportunity costs • Erection of walls and barriers could impact community cohesion
EQ	• Manage risks to any cultural resource buildings in its lee	• Possibility for adverse environmental impacts

5.2.3.3 S-2 Sea Level Change Adaptability

Seawalls are typically employed in areas immediately adjacent to and seaward of at-risk real estate and infrastructure. Potential adaption strategies could include larger construction easements for future setbacks and/or land-building prior to shoreline armoring. This would allow room for increases in structure elevation that may be required to maintain design function. Other adaption strategies could include incorporation of hybrid or multiple lines of defense.

5.2.4 S-2 Design and Cost Components

5.2.4.1 S-2 Generic Design

Site-specific shoreline bank geometry, adjacent water depths, soil conditions, currents, waves, as well as other physical, environmental, and economic factors will typically dictate the applicability and type of seawall. However, given the regional scale of the study, it is impossible to account for these local, site-specific conditions to determine which seawall measure is most appropriate at each location. Therefore, for the purposes of regional framework development, a concaved-face concrete gravity seawall is assumed. An example is shown in **Figure 5-4.**

The design is based on a 1,000-foot-long section concaved-face concrete gravity seawall with an average 10-foot crest width, with batter and vertical piles placed every 8 linear feet of the wall's length and armor stone placed seaward for toe protection against scour. Structural heights range is based on variations in regional hydrodynamics from one planning reach to another and incorporates a range of 10 to 15 feet of freeboard. Hydrodynamic input accounts for the variability in the 2-percent AEP storm surge based on statistical analysis of verified historical extreme water levels at NOAA tide stations and deepwater wave information from USACE WIS extremal analysis.

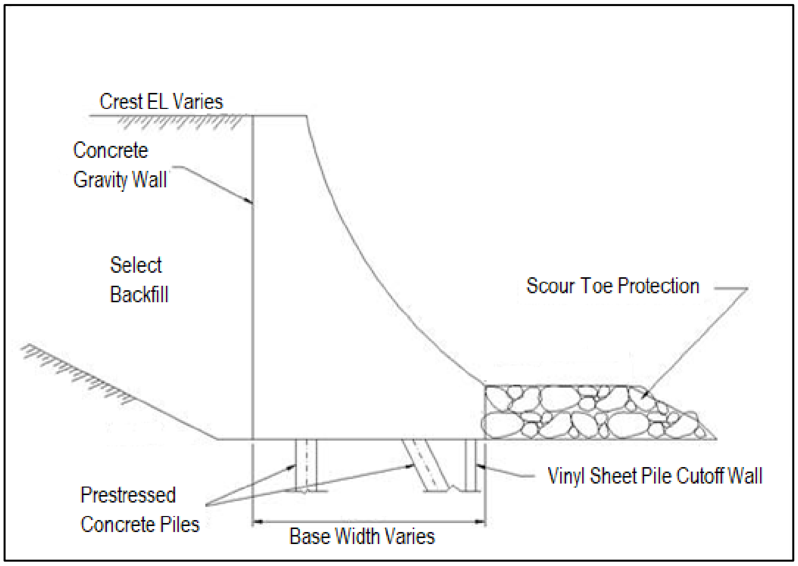

Figure 5-4: Typical Concrete Gravity Wall (USACE 2009)

5.2.4.2 S-2 Cost Components

The seawall cost components are based upon a concrete wall face with either 10 feet or 15 feet of freeboard height. It is assumed that batter and vertical piles are placed every 8 linear feet of the wall's length and armor stone is placed seaward. Cost drivers for this type of construction are the mobilization-demobilization of specialized equipment such as cranes, pile driving equipment, concrete placement equipment, armor stone cost per ton, and concrete cost per cubic yard. Work incidental to construction such as cofferdam construction and other possible costs, such as sheet piling, are not included.

Table 5-5 reflects what would be considered a contract cost prior to applying any additional markups, or owner markups. These additional costs include contingency at 20 percent for the low end and 40 percent for the high end. E&D and S&A are estimated at 15 percent and 12 percent, respectively, for both the high and low ends of the range presented. M&AM costs are estimated at 3 percent for the low end and 4 percent for the high end. The total owner costs are reflected as unit prices in **Table 5-7**. To analyze the cost components individually, the user may apply each additional owner markup in the order discussed above in a compounded process. Section 4.2.6.1 contains details regarding cost computations.

Table 5-5: S-2 Cost Components (Part-I)

State / Territory / Planning Reach	Feature Category	Feature	Feature Unit	Quantity Low	Quantity High	Unit Cost Low	Unit Cost High
S2_1: (NC_01)	Unit	Seawall Length	Linear foot (LF)	1,000	1,000	–	–
	Measure Cost	Mob/Demob	Lump sum (LS)	1	1	$500,000	$750,000
	Measure Cost	Seawall Concrete	$/Cubic yard (CY)	8,100	10,500	$460	$575
	Measure Cost	Vertical & Batter Piles	$/Vertical linear foot (VLF) of wall	6,000	7,500	$69	$84
	Measure Cost	Armor Stone	$/Ton	2,260	2,825	$265	$330
	Measure Cost	Under Armor Stone	$/Ton	600	750	$175	$220
	Measure Cost	Select Fill	$/CY	5,000	10,000	$96	$120

State / Territory / Planning Reach	Feature Category	Feature	Feature Unit	Quantity Low	Quantity High	Unit Cost Low	Unit Cost High
S2_2: (NC_02)	Unit	Seawall Length	LF	1,000	1,000	–	–
	Measure Cost	Mob/Demob	LS	1	1	$500,000	$750,000
	Measure Cost	Seawall Concrete	$/CY	9,450	12,000	$460	$575
	Measure Cost	Vertical & Batter Piles	$/VLF of wall	8,000	9,750	$67	$84
	Measure Cost	Armor Stone	$/Ton	2,540	3,175	$265	$330
	Measure Cost	Under Armor Stone	$/Ton	675	840	$175	$220
	Measure Cost	Select Fill	$/CY	5,000	10,000	$96	$120
S2_3: (SC_03)	Unit	Seawall Length	LF	1,000	1,000	–	–
	Measure Cost	Mob/Demob	LS	1	1	$500,000	$750,000
	Measure Cost	Seawall Concrete	$/CY	9,450	12,000	$460	$575
	Measure Cost	Vertical & Batter Piles	$/VLF of wall	8,000	9,750	$67	$84
	Measure Cost	Armor Stone	$/Ton	2,540	3,175	$265	$330
	Measure Cost	Under Armor Stone	$/Ton	675	840	$175	$220
	Measure Cost	Select Fill	$/CY	5,000	10,000	$96	$120
S2_4: (SC_04)	Unit	Seawall Length	LF	1,000	1,000	–	–
	Measure Cost	Mob/Demob	LS	1	1	$500,000	$750,000
	Measure Cost	Seawall Concrete	$/CY	9,450	12,000	$460	$575
	Measure Cost	Vertical & Batter Piles	$/VLF of wall	8,000	9,750	$67	$84
	Measure Cost	Armor Stone	$/Ton	2,540	3,175	$265	$330
	Measure Cost	Under Armor Stone	$/Ton	675	840	$175	$220
	Measure Cost	Select Fill	$/CY	5,000	10,000	$96	$120
S2_5: (GA_05)	Unit	Seawall Length	LF	1,000	1,000	–	–
	Measure Cost	Mob/Demob	LS	1	1	$500,000	$750,000
	Measure Cost	Seawall Concrete	$/CY	9,450	12,000	$460	$575
	Measure Cost	Vertical & Batter Piles	$/VLF of wall	8,000	9,750	$67	$84
	Measure Cost	Armor Stone	$/Ton	2,540	3,175	$265	$330
	Measure Cost	Under Armor Stone	$/Ton	675	840	$175	$220
	Measure Cost	Select Fill	$/CY	5,000	10,000	$96	$120

Table 5-6: S-2 Cost Components (Part-II)

State / Territory / Planning Reach	Feature Category	Feature	Feature Unit	Quantity Low	Quantity High	Unit Cost Low	Unit Cost High
S2_6: (FL_06, FL_07, FL_08)	Unit	Seawall Length	LF	1,000	1,000	–	–
	Measure Cost	Mob/Demob	Lump sum (LS)	1	1	$500,000	$750,000
	Measure Cost	Seawall Concrete	$/CY	9,450	12,000	$460	$575
	Measure Cost	Vertical & Batter Piles	$/VLF of wall	8,000	9,750	$69	$84
	Measure Cost	Armor Stone	$/Ton	2,540	3,175	$265	$330
	Measure Cost	Under Armor Stone	$/Ton	675	840	$175	$220
	Measure Cost	Select Fill	$/CY	5,000	10,000	$96	$120
S2_7: (FL_09, FL_10, FL_11, FL_12)	Unit	Seawall Length	LF	1,000	1,000	–	–
	Measure Cost	Mob/Demob	LS	1	1	$500,000	$750,000
	Measure Cost	Seawall Concrete	$/CY	8,400	10,500	$460	$575
	Measure Cost	Vertical & Batter Piles	$/VLF of wall	6,000	7,500	$69	$84
	Measure Cost	Armor Stone	$/Ton	2,260	2,825	$265	$330
	Measure Cost	Under Armor Stone	$/Ton	600	750	$175	$220
	Measure Cost	Select Fill	$/CY	5,000	10,000	$96	$120
S2_8: (FL_13, AL_14)	Unit	Seawall Length	LF	1,000	1,000	–	–
	Measure Cost	Mob/Demob	LS	1	1	$500,000	$750,000
	Measure Cost	Seawall Concrete	$/CY	8,100	10,500	$460	$575
	Measure Cost	Vertical & Batter Piles	$/VLF of wall	6,000	7,500	$69	$84
	Measure Cost	Armor Stone	$/Ton	2,260	2,825	$265	$330
	Measure Cost	Under Armor Stone	$/Ton	600	750	$175	$220
	Measure Cost	Select Fill	$/CY	5,000	10,000	$96	$120
S2_9: (MS_15)	Unit	Seawall Length	LF	1,000	1,000	–	–
	Measure Cost	Mob/Demob	LS	1	1	$500,000	$750,000
	Measure Cost	Seawall Concrete	$/CY	8,100	10,500	$460	$575
	Measure Cost	Vertical & Batter Piles	$/VLF of wall	6,000	7,500	$69	$84
	Measure Cost	Armor Stone	$/Ton	2,260	2,825	$265	$330
	Measure Cost	Under Armor Stone	$/Ton	600	750	$175	$220
	Measure Cost	Select Fill	$/CY	5,000	10,000	$96	$120
S2_10: (PR, VI)	Unit	Seawall Length	LF	1,000	1,000	–	–
	Measure Cost	Mob/Demob	LS	1	1	$700,000	$1,100,000
	Measure Cost	Seawall Concrete	$/CY	7,000	8750	$645	$800
	Measure Cost	Vertical & Batter Piles	$/VLF of wall	5,000	6,000	$94	$115
	Measure Cost	Armor Stone	$/Ton	4,768	10,850	$378	$470
	Measure Cost	Under Armor Stone	$/Ton	1,982	4,425	$245	$310
	Measure Cost	Select Fill	$/CY	5,000	10,000	$140	$175

5.2.5 S-2 Unit Cost Range by Planning Reach

Seawalls may be viable in all reaches within the SACS study area along eroding coastlines exposed to wave action. **Table 5-7** provides unit costs by planning reach for seawalls.

Table 5-7: S-2 Unit Cost by Planning Reach

Reach	Mob/Demob Low	Mob/Demob High	Total First Unit Cost Low	Total First Unit Cost High	Equivalent Annual Cost (EAC)-Mob-Low	EAC-Mob-High	EAC/Linear Foot (LF)-Low	EAC/LF-High
NC_01	$500,000	$750,000	$8,171	$16,097	$18,520	$27,781	$303	$596
NC_02	$500,000	$750,000	$7,668	$15,061	$18,520	$27,781	$284	$558
SC_03	$500,000	$750,000	$11,797	$23,540	$18,520	$27,781	$437	$872
SC_04	$500,000	$750,000	$9,481	$18,328	$18,520	$27,781	$351	$679
GA_05	$500,000	$750,000	$9,481	$18,328	$18,520	$27,781	$351	$679
FL_06	$500,000	$750,000	$8,601	$16,685	$18,520	$27,781	$319	$618
FL_07	$500,000	$750,000	$8,601	$16,685	$18,520	$27,781	$319	$618
FL_08	$500,000	$750,000	$8,601	$16,685	$18,520	$27,781	$319	$618
FL_09	$500,000	$750,000	$11,040	$24,842	$18,520	$27,781	$409	$920
FL_10	$500,000	$750,000	$11,040	$24,842	$18,520	$27,781	$409	$920
FL_11	$500,000	$750,000	$11,040	$24,842	$18,520	$27,781	$409	$920
FL_12	$500,000	$750,000	$11,040	$24,842	$18,520	$27,781	$409	$920
FL_13	$500,000	$750,000	$8,236	$16,251	$18,520	$27,781	$305	$602
AL_14	$500,000	$750,000	$8,236	$16,251	$18,520	$27,781	$305	$602
MS_15	$500,000	$750,000	$10,833	$23,637	$18,520	$27,781	$401	$876
PR_1	$700,000	$1,100,000	$12,309	$28,670	$25,929	$40,745	$456	$1,062
PR_2	$700,000	$1,100,000	$12,309	$28,670	$25,929	$40,745	$456	$1,062
PR_3	$700,000	$1,100,000	$12,309	$28,670	$25,929	$40,745	$456	$1,062
PR_4	$700,000	$1,100,000	$12,309	$28,670	$25,929	$40,745	$456	$1,062
VI_1	$700,000	$1,100,000	$12,309	$28,670	$25,929	$40,745	$456	$1,062
VI_2	$700,000	$1,100,000	$12,309	$28,670	$25,929	$40,745	$456	$1,062
VI_3	$700,000	$1,100,000	$12,309	$28,670	$25,929	$40,745	$456	$1,062

5.2.6 S-2 Assumptions, Sources, Limitations, and Uncertainties

No universal type of seawall can be prescribed to the study area because of the wide variation in conditions at each location. The foundation conditions, exposure to wave action, availability of materials, as well as structural and functional performance criteria will influence the seawall type and cost.

Factors affecting cost include construction location, whether it is performed onshore or from the water using marine equipment, climate and weather conditions, tidal influences, the season for which the work is planned, steel and concrete cost, and material and labor availability. Not considered in the price is the cost of constructing cofferdams along with dewatering. The prices given are based upon a Class 5 estimate using broad-based assumptions, historical data, and incomplete technical details (AACE-International 2020).

5.3 S-3: Revetments

5.3.1 S-3 Measure Description

A revetment typically refers to a layer or layers of stone that protect an embankment, or shore structure, against erosion by wave action or currents. Revetments are built at a slope and typically constructed with an assorted mass of quarry stone, concrete rubble or a well-ordered array of structural elements that interlock to form a geometric pattern.

Figure 5 5: San Juan, Puerto Rico Revetment

5.3.2 S-3 Measure Performance and Applicability

Revetments armor the shoreline to reduce the harm from coastal storms. Its primary risk management function is to reduce wave attack, while its secondary functions are to reduce erosion impacts and possibly reduce flooding if built to sufficient height. Revetments are typically applicable in mixed to high wave energy environments; however, site-specific shoreline types, adjacent water depths, erosion rates, soil conditions, currents, and waves as well as other physical, environmental and economic factors will typically dictate the overall applicability.

5.3.3 S-3 Coastal Storm Risk Management Effects and Adaptability

5.3.3.1 S-3 Physical and Temporal Effects

The primary function of a revetment is to stabilize embankments from erosion due to waves and currents. These structures when constructed as a rubble-mound feature can be efficient at absorbing wave energy and robust in design such that damage is often not catastrophic. Revetments stabilize the shoreline immediately behind it and dissipate waves. Once constructed the measure provides immediate reduction in wave attack, inundation, and erosion harm.

5.3.3.2 S-3 National Economic Development, Regional Economic Development, Other Social Effects, and Environmental Quality Effects

Table 5-8 provides details on revetment NED, RED, OSE, and EQ potential benefits and costs.

Table 5-8: S-3 National Economic Development (NED), Regional Economic Development (RED), Other Social Effects (OSE), and Environmental Quality (EQ) Effects

Account	Potential Benefits	Potential Costs
NED	• Manage risk of property and critical infrastructure loss, vehicle damage, land loss, protective measure costs, emergency costs, and transportation delay costs	• Measure total investment costs • O&M costs
RED	• Manage risk to regional revenue and employment in event of commercial property damage • Direct, indirect and induced effects of measure construction expenditure	• Possible revenue losses or employment disruptions as a result of the measure
OSE	• Manage risk to urban and community socioeconomic conditions • Emergency preparedness	• Potential cost to Non-Federal Sponsor (NFS)/ Opportunity costs
EQ	• Manage risks to any cultural resource buildings in its lee	• Possibility for adverse environmental impacts

5.3.3.3 S-3 Sea Level Change Adaptability

Revetments are typically employed in areas immediately adjacent to and seaward of at-risk real estate and infrastructure. Potential adaption strategies could include larger construction easements for future setbacks and/or land-building prior to shoreline armoring. This would allow room for increases in structure elevation and armor stone that may be required to maintain design function. Other adaption strategies could include incorporation of hybrid or multiple lines of defense.

5.3.4 S-3 Design and Cost Components

5.3.4.1 S-3 Generic Design

Site-specific shoreline bank geometry, adjacent water depths, soil conditions, currents, and waves, as well as other physical, environmental, and economic factors will typically dictate the applicability and type of revetment. However, given the regional scale of the study it is impossible to account for these local, site-specific conditions to determine which revetment measure is most appropriate at each location. Therefore, for the purposes of regional framework development, a rubble-mound revetment is assumed, as shown in **Figure 5-6**.

The design is based on two layers (protective armor and underlayer stone) with an average 10-foot crest width; a 2 (horizontal): 1 (vertical) slope integrated with toe protection and geotextile filter fabric. Structural heights and stone weights range is based on variations in regional hydrodynamics from one planning reach to another using standard empirical formulas contained within EM 1110-2-1100 Coastal Engineering Manual for armor weight, wave run-up and overtopping. Hydrodynamic input accounts for the variability in the 2-percent AEP storm surge based on statistical analysis of verified historical extreme water levels at NOAA tide stations and deepwater wave information from USACE WIS extremal analysis.

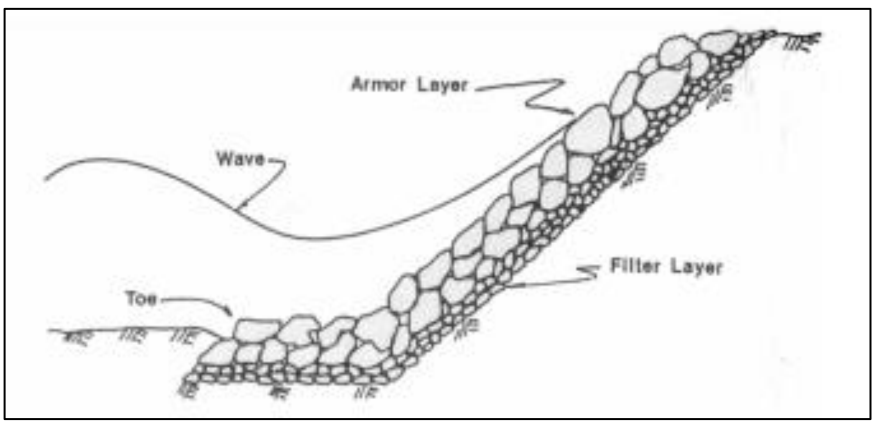

Figure 5-6: Typical Revetment (USACE 1995)

5.3.4.2 S-3 Cost Components

Revetment costs are provided as a cost per linear foot of coastal shoreline. Therefore, a user should estimate the amount of shoreline requiring protection. A revetment unit is assumed to be approximately 400 feet in length and 10 feet in width at the crest and constructed of limestone quarry stone armor over a filter layer that is overlaid on a geotextile fabric.

The estimated costs for revetments are provided as a range of high and low. These costs are most impacted and sensitive to the quantity of stone per unit of measure and the size of the stone necessary. These costs are based upon calculated ranges of stone sizes which take into consideration variations in regional hydrodynamics from one planning reach to another.

As previously discussed, site-specific shoreline characteristics will dictate the type of revetment most applicable to a project. Specifically, regarding cost, factors to consider include, but are not limited to, staging/access, water or land-based construction, regional stone availability, hauling/placement production, and placement area tidal influence.

Table 5-9 reflects what would be considered a contract cost prior to applying any additional markups, or owner markups. These additional costs include contingency at 20 percent for the low end and 40 percent for the high end. E&D and S&A are estimated at 15 percent and 12 percent, respectively, for both the high and low ends of the range presented. M&AM costs are estimated at 3 percent for the low end and 4 percent for the high end. The full or total owner costs are reflected as unit prices in **Table 5-10**. If the user prefers to analyze the cost components individually it is recommended that they considering apply each additional owner markup in the order discussed above in a compounded process. Section 4.2.6.1 contains details regarding cost computations.

Table 5-9: S-3 Cost Components

State / Territory / Planning Reach	Feature Category	Feature	Feature Unit	Quantity Low	Quantity High	Unit Cost Low	Unit Cost High
S3_1: (NC, SC, FL, AL, MS)	Unit	Revetment Length	Linear foot (LF)	400	400	–	–
	Measure Cost	Mob/Demob	Lump sum (LS)	1	1	$180,000	$430,000
	Measure Cost	Armor Stone	$/Ton	1796	3855	$180	$270
	Measure Cost	Underlayer/ Core Stone	$/Ton	575	1327	$180	$270
	Measure Cost	Marine Mattress	$/Square foot (SF)	30400	32800	$19	$45
	Measure Cost	Toe Protection	$/LF	400	400	$1,700	$3,000
S3_2: (GA)	Unit	Revetment Length	LF	400	400	–	–
	Measure Cost	Mob/Demob	LS	1	1	$180,000	$430,000
	Measure Cost	Armor Stone	$/Ton	2697	5024	$180	$270
	Measure Cost	Underlayer/ Core Stone	$/Ton	996	1703	$180	$270
	Measure Cost	Marine Mattress	$/SF	37600	37600	$19	$45
	Measure Cost	Toe Protection	$/LF	400	400	$1,700	$3,000
S3_3: (PR, VI)	Unit	Revetment Length	LF	400	400	–	–
	Measure Cost	Mob/Demob	LS	1	1	$180,000	$430,000
	Measure Cost	Armor Stone	$/Ton	686	2241	$180	$270
	Measure Cost	Underlayer/ Core Stone	$/Ton	271	799	$180	$270
	Measure Cost	Marine Mattress	$/SF	18400	24800	$19	$45
	Measure Cost	Toe Protection	$/LF	400	400	$1,700	$3,000

5.3.5 S-3 Unit Cost Range by Planning Reach

Revetments may be viable in all reaches within the CONUS, Puerto Rico, and U.S. Virgin Islands of SACS along exposed eroding coastlines. **Table 5-10** provides unit costs by planning reach for revetments.

Table 5-10: S-3 Unit Cost by Planning Reach

Reach	Measure	Mob/ Demob Low	Mob/ Demob High	Total First Unit Cost Low	Total First Unit Cost High	Equivalent Annual Cost (EAC)-Mob-Low	EAC-Mob-High	EAC/Linear Foot (LF)-Low	EAC/LF-High
NC_01	S-3	$180,000	$430,000	$3,885	$13,038	$6,667	$15,928	$144	$483
NC_02	S-3	$180,000	$430,000	$6,541	$18,635	$6,667	$15,928	$242	$690
SC_03	S-3	$180,000	$430,000	$7,947	$21,405	$6,667	$15,928	$294	$793
SC_04	S-3	$180,000	$430,000	$6,541	$18,635	$6,667	$15,928	$242	$690
GA_05	S-3	$180,000	$430,000	$6,541	$18,635	$6,667	$15,928	$242	$690
FL_06	S-3	$180,000	$430,000	$6,541	$18,635	$6,667	$15,928	$242	$690
FL_07	S-3	$180,000	$430,000	$6,541	$18,635	$6,667	$15,928	$242	$690
FL_08	S-3	$180,000	$430,000	$6,541	$18,635	$6,667	$15,928	$242	$690
FL_09	S-3	$180,000	$430,000	$6,541	$18,635	$6,667	$15,928	$242	$690
FL_10	S-3	$180,000	$430,000	$6,541	$18,635	$6,667	$15,928	$242	$690
FL_11	S-3	$180,000	$430,000	$6,541	$18,635	$6,667	$15,928	$242	$690
FL_12	S-3	$180,000	$430,000	$6,541	$18,635	$6,667	$15,928	$242	$690
FL_13	S-3	$180,000	$430,000	$6,541	$18,635	$6,667	$15,928	$242	$690
AL_14	S-3	$180,000	$430,000	$4,732	$14,530	$6,667	$15,928	$175	$538
MS_15	S-3	$180,000	$430,000	$4,732	$14,530	$6,667	$15,928	$175	$538
PR_1	S-3	$180,000	$430,000	$4,732	$14,530	$6,667	$15,928	$175	$538
PR_2	S-3	$180,000	$430,000	$4,732	$14,530	$6,667	$15,928	$175	$538
PR_3	S-3	$180,000	$430,000	$4,732	$14,530	$6,667	$15,928	$175	$538
PR_4	S-3	$180,000	$430,000	$4,732	$14,530	$6,667	$15,928	$175	$538
VI_1	S-3	$180,000	$430,000	$4,732	$14,530	$6,667	$15,928	$175	$538
VI_2	S-3	$180,000	$430,000	$6,541	$18,635	$6,667	$15,928	$242	$690
VI_3	S-3	$180,000	$430,000	$7,947	$21,405	$6,667	$15,928	$294	$793

5.3.6 S-3 Assumptions, Sources, Limitations, and Uncertainties

Foundation conditions, exposure to wave action, and availability of materials, as well as structural and functional performance criteria will influence the revetment type and cost.

The costs for this measure are parametric unit prices and were calculated considering information from multiple projects. Recent bid data from a shore protection project known as Sarasota County Lido Key Segment was considered for the majority of the itemized cost features. The project was awarded in FY20 and two groins are being constructed. This project is assumed to be of similar enough nature, level of effort, and risk to assume comparable construction costs.

Recent estimates developed on the Puerto Rico Coastal Storm Risk Management Study were also considered because of their focus on the toe protection features that are needed to prevent undermining of the structural measure.

Contingency is included at 20 percent for the low end and 40 percent for the high end. E&D and S&A are estimated at 15 percent and 12 percent, respectively, for both the high and low ends of the range presented. M&AM costs are estimated at 3 percent for the low end and 4 percent for the high end.

5.4 S-4: Bulkheads

5.4.1 S-4 Measure Description

Bulkheads are vertical shoreline stabilization structures that primarily retain or prevent sliding of the land. A secondary purpose is to protect the upland against erosion due to low to moderate waves. Types of bulkheads consist primarily of anchored and cantilevered walls commonly built of vinyl, concrete, steel, aluminum, or timber piles.

Figure 5-7: Clermont Harbor Bulkhead (Photo Source: USACE)

5.4.2 S-4 Measure Performance and Applicability

Bulkheads are coastal armor units constructed to establish and maintain elevated grades along shorelines in relatively sheltered areas not subject to appreciable wave attack. A bulkhead's primary risk management function is reducing erosion while secondary risk management functions include reducing wave attack and possibly reducing inundation, depending on the height of the structure and backfill. These structures reduce the risk of damages to infrastructure and property in the lee by reducing erosion and subsequent loss of land landward of the structure. Bulkheads are typically applicable to shorelines with low to mixed wave energy characteristics; however, site-specific shoreline types, adjacent water depths, erosion rates, soil conditions, currents, and waves, as well as other physical, environmental and economic factors will typically dictate the overall applicability.

5.4.3 S-4 Coastal Storm Risk Management Effects and Adaptability

5.4.3.1 S-4 Physical and Temporal Effects

The primary purpose of a bulkhead is to retain or prevent sliding of the land, with a secondary purpose of affording protection to the upland against low to moderate wave action. Upon construction, the measure provides reduced erosion and wave attack harm to the exposed areas in its lee.

5.4.3.2 S-4 National Economic Development, Regional Economic Development, Other Social Effects, and Environmental Quality Effects

Bulkheads provide shoreline stabilization for more sheltered coastal and waterfront properties while maximizing upland property area. Possible other social benefits of revetments include recreational fishing opportunities. The following table shows the potential benefits and costs for each of the four national accounts.

Table 5-11: S-4 National Economic Development (NED), Regional Economic Development (RED), Other Social Effects (OSE), and Environmental Quality (EQ) Effects

Account	Potential Benefits	Potential Costs
NED	• Manage risk of property and critical infrastructure loss, vehicle damage, land loss, protective measure costs, emergency costs, and transportation delay costs; incidental recreation	• Measure total investment cost, O&M cost
RED	• Manage risk to regional revenue and employment in event of commercial property damage / direct, indirect and induced effects of measure construction expenditure	• Revenue losses or employment disruptions as a result of the measure
OSE	• Manage risk to urban and community socioeconomic conditions; emergency preparedness	• Potential cost to Non-Federal Sponsor (NFS)/ Opportunity costs
EQ	• Manage risks to any cultural resource buildings in its lee	• Possibility for adverse environmental impacts

5.4.3.3 S-4 Sea Level Change Adaptability

Bulkheads are typically employed in areas immediately adjacent to and seaward of at-risk real estate and infrastructure. Potential adaption strategies could include larger construction easements for future setbacks and/or land-building prior to shoreline armoring. This would allow room for increases in structure elevation that may be required to maintain design function. Other adaption strategies could include incorporation of hybrid or multiple lines of defense.

5.4.4 S-4 Design and Cost Components

5.4.4.1 S-4 Generic Design

Site-specific shoreline bank geometry, soil conditions, foundation type, water depths, currents, and waves, as well as other physical, environmental and economic factors will typically dictate the applicability and type of bulkhead. However, given the regional scale of the study, it is impossible to account for these local, site-specific conditions to determine which bulkhead measure is most appropriate at each location. Therefore, for the purposes of regional framework development, a vinyl sheet-pile bulkhead is assumed.

The bulkhead design is based on a 1,000-foot-long concrete capped vinyl sheet-pile integrated with reinforced concrete between the sheet piling and shore. Structural heights range is based on variations in regional hydrodynamics from one planning reach to another, incorporating a range of 10 to 15 feet of freeboard. Hydrodynamic input accounts for the variability in 2-percent AEP storm surge based on statistical analysis of verified historical extreme water levels at NOAA tide stations. **Figure 5-8** provides a graphical representation of a bulkhead.

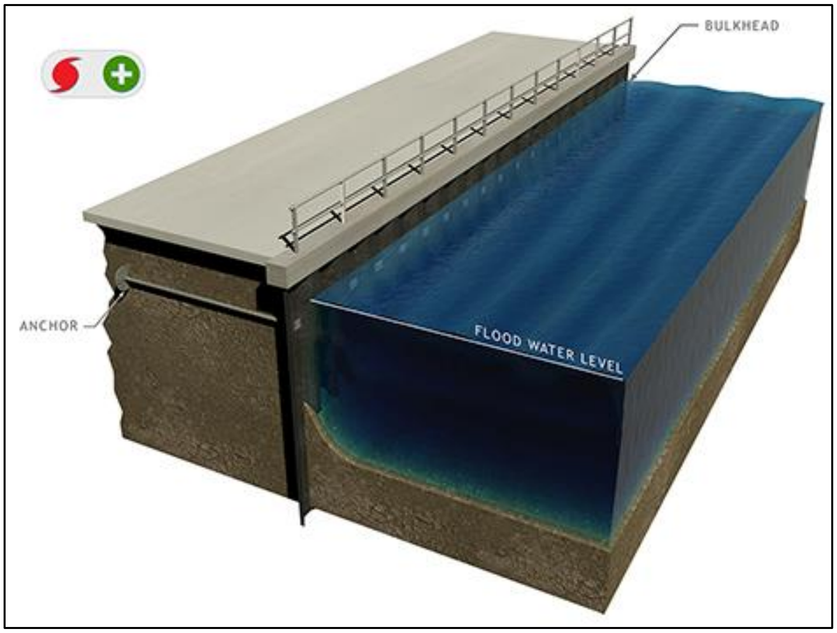

Figure 5-8: Example of Typical Bulkhead Layout (USACE 2015a)

5.4.4.2 S-4 Cost Components

Cost components are based on a vinyl sheet-pile bulkhead with concrete fill between the sheet piling and shore. The cost per linear foot represents a bulkhead constructed with vinyl sheet piling, batter and vertical piles, a concrete pile cap, wales, and anchors placed every 10 feet. Variation in height, including the driven portion, ranges from 20 feet to 30 feet for the purpose of this study, and it is assumed that the portion above the water body bed is equal to the portion driven below the bed. The price per square foot is based upon a vendor quote for the complete wall system (Maher 2020). It is assumed that the work is performed by a prime contractor and all work is performed from the shore.

Concrete price, rebar cost, and equipment mobilization are the main cost drivers. The construction schedule is also dictated by weather and climatic conditions. The cost of performing work from marine equipment and the cost of a cofferdam were not included.

Table 5-12 reflects what would be considered a contract cost prior to applying any additional markups, or owner markups. These additional costs include contingency at 20 percent for the low end and 40 percent for the high end. E&D and S&A are estimated at 15 percent and 12 percent, respectively, for both the high and low ends of the range presented. M&AM costs are estimated at 3 percent for the low end and 4 percent for the high end. The full or total owner cost are reflected as unit prices in **Table 5-14**. To analyze the cost components individually, the user can apply each additional owner markup in the order discussed above in a compounded process. Section 4.2.6.1 contains details regarding cost computations.

Table 5-12: S-4 Cost Components (Part-I)

State / Territory / Planning Reach	Feature Category	Feature	Feature Unit	Quantity Low	Quantity High	Unit Cost Low	Unit Cost High
S4_1: (NC_01)	Unit	Bulkhead Length	Linear foot (LF)	1000	1000	–	–
	Construction Unit	Bulkhead Freeboard Height	Feet (FT)	10	15	–	–
	Measure Cost	Mob/Demob	Lump sum (LS)	1	1	$160,000	$185,000
	Measure Cost	Bulkhead - Sheet Vinyl Sheath	$/Square foot (SF)	20000	30000	$50	$78
S4_2: (NC_02)	Unit	Bulkhead Length	LF	1000	1000	–	–
	Construction Unit	Bulkhead Freeboard Height	FT	10	15	–	–
	Measure Cost	Mob/Demob	LS	1	1	$160,000	$185,000
	Measure Cost	Bulkhead - Sheet Vinyl Sheath	$/SF	20000	30000	$50	$78
S4_3: (SC_03)	Unit	Bulkhead Length	LF	1000	1000	–	–
	Construction Unit	Bulkhead Freeboard Height	FT	10	15	–	–
	Measure Cost	Mob/Demob	LS	1	1	$160,000	$185,000
	Measure Cost	Bulkhead - Sheet Vinyl Sheath	$/SF	20000	30000	$50	$78
S4_4: (SC_04)	Unit	Bulkhead Length	LF	1000	1000	–	–
	Construction Unit	Bulkhead Freeboard Height	FT	10	15	–	–
	Measure Cost	Mob/Demob	LS	1	1	$160,000	$185,000
	Measure Cost	Bulkhead - Sheet Vinyl Sheath	$/SF	20000	30000	$50	$78
S4_5: (GA_05)	Unit	Bulkhead Length	LF	1000	1000	–	–
	Construction Unit	Bulkhead Freeboard Height	FT	10	15	–	–
	Measure Cost	Mob/Demob	LS	1	1	$160,000	$185,000
	Measure Cost	Bulkhead - Sheet Vinyl Sheath	$/SF	20000	30000	$50	$78

Table 5-13: S-4 Cost Components (Part-II)

State / Territory / Planning Reach	Feature Category	Feature	Feature Unit	Quantity Low	Quantity High	Unit Cost Low	Unit Cost High
S4_6: (FL_06, FL_07, FL_08)	Unit	Bulkhead Length	Linear feet (LF)	1000	1000	–	–
	Construction Unit	Bulkhead Freeboard Height	Feet (FT)	10	15	–	–
	Measure Cost	Mob/Demob	Lump sum (LS)	1	1	$160,000	$185,000
	Measure Cost	Bulkhead - Sheet Vinyl Sheath	$/Square feet (SF)	20000	30000	$50	$78
S4_7: (FL_09, FL_10, FL_11, FL_12)	Unit	Bulkhead Length	LF	1000	1000	–	–
	Construction Unit	Bulkhead Freeboard Height	FT	10	15	–	–
	Measure Cost	Mob/Demob	LS	1	1	$160,000	$185,000
	Measure Cost	Bulkhead - Sheet Vinyl Sheath	$/SF	20000	30000	$50	$78
S4_8: (FL_13, AL_14)	Unit	Bulkhead Length	LF	1000	1000	–	–
	Construction Unit	Bulkhead Freeboard Height	FT	10	15	–	–
	Measure Cost	Mob/Demob	LS	1	1	$160,000	$185,000
	Measure Cost	Bulkhead - Sheet Vinyl Sheath	$/SF	20000	30000	$50	$78
S4_9: (MS_15)	Unit	Bulkhead Length	LF	1000	1000	–	–
	Construction Unit	Bulkhead Freeboard Height	FT	10	15	–	–
	Measure Cost	Mob/Demob	LS	1	1	$160,000	$185,000
	Measure Cost	Bulkhead - Sheet Vinyl Sheath	$/SF	20000	30000	$50	$78
S4_10: (PR, VI)	Unit	Bulkhead Length	LF	1000	1000	–	–
	Construction Unit	Bulkhead Freeboard Height	FT	10	15	–	–
	Measure Cost	Mob/Demob	LS	1	1	$180,000	$210,000
	Measure Cost	Bulkhead - Sheet Vinyl Sheath	$/SF	20000	30000	$56	$86

5.4.5 S-4 Unit Cost Ranges by Planning Reach

Bulkheads may be viable in all reaches within the CONUS, Puerto Rico, and U.S. Virgin Islands of SACS along more sheltered eroding coastlines. **Table 5-14** provides unit costs by planning reach for bulkheads.

Table 5-14: S-4 Unit Costs by Planning Reach

Reach	Mob/Demob Low	Mob/Demob High	Total First Unit Cost Low	Total First Unit Cost High	Equivalent Annual Cost (EAC)-Mob-Low	EAC-Mob-High	EAC/Linear Foot (LF)-Low	EAC/LF-High
NC_01	$160,000	$185,000	$1,580	$4,234	$5,927	$6,853	$59	$157
NC_02	$160,000	$185,000	$1,580	$4,234	$5,927	$6,853	$59	$157
SC_03	$160,000	$185,000	$1,580	$4,234	$5,927	$6,853	$59	$157
SC_04	$160,000	$185,000	$1,580	$4,234	$5,927	$6,853	$59	$157
GA_05	$160,000	$185,000	$1,580	$4,234	$5,927	$6,853	$59	$157
FL_06	$160,000	$185,000	$1,580	$4,234	$5,927	$6,853	$59	$157
FL_07	$160,000	$185,000	$1,580	$4,234	$5,927	$6,853	$59	$157
FL_08	$160,000	$185,000	$1,580	$4,234	$5,927	$6,853	$59	$157
FL_09	$160,000	$185,000	$1,580	$4,234	$5,927	$6,853	$59	$157
FL_10	$160,000	$185,000	$1,580	$4,234	$5,927	$6,853	$59	$157
FL_10	$160,000	$185,000	$1,770	$4,673	$6,667	$7,779	$66	$173
FL_10	$160,000	$185,000	$1,770	$4,673	$6,667	$7,779	$66	$173
FL_10	$160,000	$185,000	$1,770	$4,673	$6,667	$7,779	$66	$173
FL_10	$160,000	$185,000	$1,770	$4,673	$6,667	$7,779	$66	$173
FL_10	$160,000	$185,000	$1,770	$4,673	$6,667	$7,779	$66	$173
FL_10	$180,000	$210,000	$1,770	$4,673	$6,667	$7,779	$66	$173
FL_10	$180,000	$210,000	$1,770	$4,673	$6,667	$7,779	$66	$173
FL_10	$180,000	$210,000	$1,580	$4,234	$5,927	$6,853	$59	$157
FL_10	$180,000	$210,000	$1,580	$4,234	$5,927	$6,853	$59	$157
FL_10	$180,000	$210,000	$1,580	$4,234	$5,927	$6,853	$59	$157
FL_10	$180,000	$210,000	$1,580	$4,234	$5,927	$6,853	$59	$157
FL_10	$180,000	$210,000	$1,580	$4,234	$5,927	$6,853	$59	$157

5.4.6 S-4 Assumptions, Sources, Limitations, and Uncertainties

No universal type of bulkhead can be prescribed because of the wide variation in conditions at each location. Foundation conditions, exposure to wave action, type and amount of real estate, availability of materials, and water depth, as well as structural and functional performance criteria will influence the bulkhead type and cost.

The prices given are based on a Class 5 estimate using broad-based assumptions, historical data, and incomplete technical details (AACE-International 2020). Shore versus marine work location, the need for a cofferdam with dewatering, climatic events, and material availability and cost, particularly that of steel and concrete, can affect project cost.

Several vendor sites and historical data from past contracts were referenced. It is assumed that the work will be performed by a prime contractor with minimal subcontractor effort and subcontractor distributed costs. It is also assumed that there is a 10-foot water depth and that the length of driven bulkhead is equal to the height of the bulkhead wall.

5.5 S-5: Breakwaters

5.5.1 S-5 Measure Description

Breakwaters are relatively short, nearshore structures built parallel to the shore just seaward of the shoreline in shallow water depths, with the principal function of reducing beach erosion through reducing wave height and thus, longshore and cross-shore sediment transport. Like groins, a series of detached breakwaters can be used to control the distribution of beach material along a coastline. When used as harbor risk management, breakwater structures are typically attached to the shore and enclose the harbor basin to reduce the impacts from waves. Breakwaters are usually built as rubble-mound quarry stone structures but can be constructed from a variety of materials such as geotextile and concrete.

Figure 5-9: East End Dauphin Island Breakwaters (Photo Source: Flythecoast.com)

5.5.2 S-5 Measure Performance, and Applicability

Breakwaters moderate shoreline erosion rates to reduce the damage to leeward property from coastal storms. Its primary risk management function is to attenuate wave energy, while its secondary function is to reduce erosion impacts. Breakwaters are typically applicable in mixed to high wave energy environments; however, site-specific shoreline types, adjacent water depths, erosion rates, soil conditions, currents, and waves, as well as other physical, environmental and economic factors will typically dictate the overall applicability.

5.5.3 S-5 Coastal Storm Risk Management Effects and Adaptability

5.5.3.1 S-5 Physical and Temporal Effects

Breakwaters dissipate waves and stabilize the shoreline immediately behind it. Once constructed the measure reduces wave energy and erosion to the exposed areas in its lee, resulting in immediate risk management effects. Properly designed and sited structures can reduce erosion of an existing beach, promote natural sedimentation to form a new beach, increase the longevity of a beachfill, and maintain a wide beach for storm risk management and recreation.

5.5.3.2 S-5 National Economic Development, Regional Economic Development, Other Social Effects, and Environmental Quality Effects

Breakwaters provide wave sheltering in its lee, reduce erosion, and promote natural sedimentation. These functions can increase the longevity of a beachfill and help maintain a wide beach for storm risk management and recreation. In addition, the combination of low-crested breakwaters and planted wetland vegetation is increasingly being used to establish wetlands and control erosion along estuarine shorelines. Given the low crest elevation and typical location offshore, these structures are less visible than other coastal structures. In some cases, submerged, detached breakwaters are used for aesthetic and/or ecological reasons. While these features can enhance ecological and other social benefits, including recreational fishing opportunities, they can also represent a serious non-visible hazard to boats and swimmers. The following table shows the potential benefits and costs for each of the four national accounts.

Table 5-15: S-5 National Economic Development (NED), Regional Economic Development (RED), Other Social Effects (OSE), and Environmental Quality (EQ) Effects

Account	Potential Benefits	Potential Costs
NED	• Manage risk of property and critical infrastructure loss, vehicle damage; land loss, protective measure costs, emergency costs, and transportation delay costs • Incidental recreation	• Measure total investment cost • O&M cost
RED	• Manage risk to regional revenue and employment in event of commercial property damage • Direct, indirect and induced effects of measure construction expenditure	• Possible revenue losses or employment disruptions as a result of the measure
OSE	• Manage risk to urban and community impacts • Emergency preparedness • Educational, cultural, and recreational opportunities	• Potential risks to health, life, and safety
EQ	• Manage risks to any cultural resource buildings in its lee • Habitat provision	• Possibility for adverse environmental impacts

5.5.3.3 S-5 Sea Level Change Adaptability

Breakwaters can potentially be adapted to sea level change by increasing the crest height and changing the stone size as appropriate. Sufficient width of the base; however, is necessary for changes to crest elevation.

5.5.4 S-5 Design and Cost Components

5.5.4.1 S-5 Generic Design

Offshore water depths, erosion rates, soil conditions, currents, and waves, as well as other physical, environmental and economic factors will typically dictate the applicability of a breakwater as well as the material type and structure profile. However, given the regional scale of the study, it is impossible to account for these local, site-specific conditions to determine the type or size of breakwater that may be most appropriate at each location. Therefore, for the purposes of regional framework development, a permeable limestone rubble-mound breakwater unit is assumed.

The design of the breakwater consists of a 400-liner-foot rubble-mound two-layer structure (protective armor and underlayer stone) with a smaller stone core center structure overlaid on a geotextile filter fabric. The crest width is 25 feet with 2 (horizontal): 1 (vertical) side slopes. Structural heights and stone weights range is based on variations in regional hydrodynamics from one planning reach to another using standard empirical formulas contained within EM 1110-2-1100 Coastal Engineering Manual for armor weight, wave run-up and overtopping. Hydrodynamic input accounts for the variability in the 2-percent AEP storm surge based on statistical analysis of verified historical extreme water levels at NOAA tide stations and deepwater wave information from USACE WIS extremal analysis.

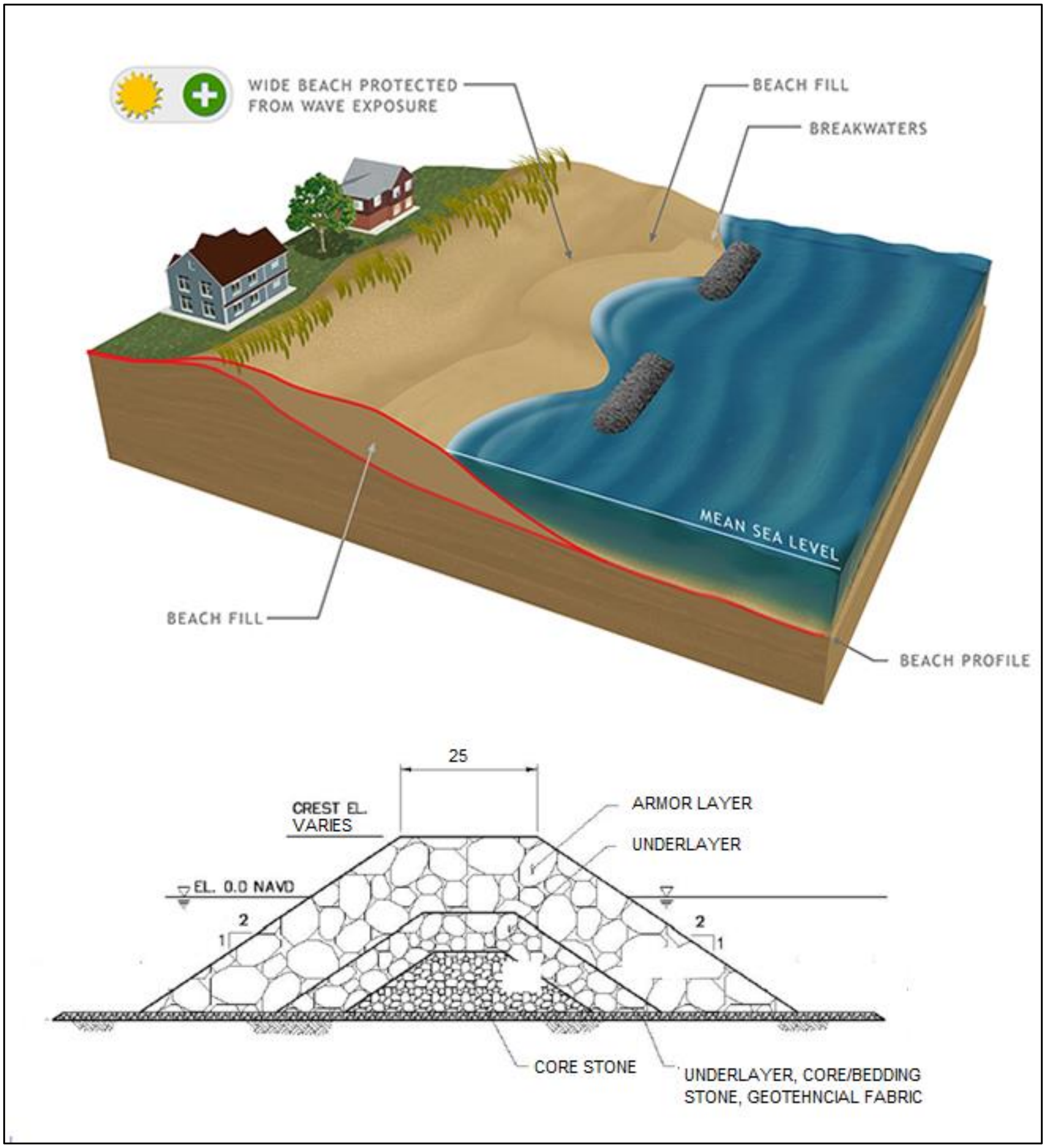

Figure 5-10: Example of Typical Breakwater Layout and Section (USACE 2015a)

5.5.4.2 S-5 Cost Components

Breakwater costs are provided as a cost per linear foot of coastal shoreline. Therefore, a user should estimate the amount of shoreline requiring protection. A breakwater unit is assumed to be approximately 400 feet in length and 25 feet in width at the crest and constructed of limestone quarry stone armor, over an underlayer of core and bedding stone that is covered with a geotextile fabric.

The estimated costs for breakwaters are provided as a range of high and low. These costs are most impacted and sensitive to the quantity of stone per unit of measure and the size of the stone necessary. These costs are based upon calculated ranges of stone sizes which take into consideration variations in regional hydrodynamics from one planning reach to another.

The estimated costs for the breakwaters include placement of armor stone, underlayer, and marine mattress, as well as the cost for mobilization and demobilization. The costs for this measure are parametric unit prices and calculated based upon bid data from multiple bidders received on a recent project solicitation for Jacksonville District. The measures in that project were of similar scope. As previously discussed, site-specific shoreline characteristics will dictate the type of breakwater most applicable to a project. Specifically, regarding cost, factors to consider include, but are not limited to, staging/access, water- or land-based construction, regional stone availability, hauling/placement production, and placement area tidal influence.

Table 5-16 reflects what would be considered a contract cost prior to applying any additional markups, or owner markups. These additional costs include contingency at 20 percent for the low end and 40 percent for the high end. E&D and S&A are estimated at 15 percent and 12 percent, respectively, for both the high and low ends of the range presented. M&AM costs are estimated at 3 percent for the low end and 4 percent for the high end. The full or total owner cost are reflected as unit prices in **Table 5-17**. To analyze the cost components individually, the user can apply each additional owner markup in the order discussed above in a compounded process. Section 4.2.6.1 contains details regarding cost computations.

Table 5-16: S-5 Cost Components

State / Territory / Planning Reach	Feature Category	Feature	Feature Unit	Quantity Low	Quantity High	Unit Cost Low	Unit Cost High
S5_1: (NC_01, FL, AL, MS, PR, VI)	Unit	Breakwater Length	Linear foot (LF)	400	400	–	–
	Measure Cost	Mob/Demob	Lump sum (LS)	1	1	$400,000	$1,200,000
	Measure Cost	Armor Stone	$/Ton	3077	7654	$180	$270
	Measure Cost	Underlayer/Core Stone	$/Ton	1240	2869	$180	$270
	Measure Cost	Marine Mattress	$/Square foot (SF)	29200	45200	$19	$45
S5_2: (NC_02, SC_03, SC_04, FL_06)	Unit	Breakwater Length	LF	400	400	–	–
	Measure Cost	Mob/Demob	LS	1	1	$400,000	$1,200,000
	Measure Cost	Armor Stone	$/Ton	3461	8200	$180	$270
	Measure Cost	Underlayer/Core Stone	$/Ton	1385	3058	$180	$270
	Measure Cost	Marine Mattress	$/SF	30800	46800	$19	$45
S5_3: (GA_05)	Unit	Breakwater Length	LF	400	400	–	–
	Measure Cost	Mob/Demob	LS	1	1	$400,000	$1,200,000
	Measure Cost	Armor Stone	$/Ton	3461	8200	$180	$270
	Measure Cost	Underlayer/Core Stone	$/Ton	1385	3058	$180	$270
	Measure Cost	Marine Mattress	$/SF	30800	46800	$19	$45

5.5.5 S-5 Unit Cost Range by Planning Reach

Breakwaters may be viable in all reaches within the SACS study area along exposed and sheltered eroding coastlines. **Table 5-17** provides unit costs by planning reach for breakwaters.

Table 5-17: S-5 Unit Costs by Planning Reach

Reach	Mob/Demob Low	Mob/Demob High	Total First Unit Cost Low	Total First Unit Cost High	Equivalent Annual Cost (EAC)-Mob-Low	EAC-Mob-High	EAC/ Linear Foot (LF)-Low	EAC/ LF-High
NC_01	$400,000	$1,200,000	$5,494	$23,579	$14,816	$44,449	$204	$873
NC_02	$400,000	$1,200,000	$5,966	$24,762	$14,816	$44,449	$221	$917
SC_03	$400,000	$1,200,000	$5,966	$24,762	$14,816	$44,449	$221	$917
SC_04	$400,000	$1,200,000	$5,966	$24,762	$14,816	$44,449	$221	$917
GA_05	$400,000	$1,200,000	$5,966	$24,762	$14,816	$44,449	$221	$917
FL_06	$400,000	$1,200,000	$5,966	$24,762	$14,816	$44,449	$221	$917
FL_07	$400,000	$1,200,000	$5,494	$23,579	$14,816	$44,449	$204	$873
FL_08	$400,000	$1,200,000	$5,494	$23,579	$14,816	$44,449	$204	$873
FL_09	$400,000	$1,200,000	$5,494	$23,579	$14,816	$44,449	$204	$873
FL_10	$400,000	$1,200,000	$5,494	$23,579	$14,816	$44,449	$204	$873
FL_11	$400,000	$1,200,000	$5,494	$23,579	$14,816	$44,449	$204	$873
FL_12	$400,000	$1,200,000	$5,494	$23,579	$14,816	$44,449	$204	$873
FL_13	$400,000	$1,200,000	$5,494	$23,579	$14,816	$44,449	$204	$873
AL_14	$400,000	$1,200,000	$5,494	$23,579	$14,816	$44,449	$204	$873
MS_15	$400,000	$1,200,000	$5,494	$23,579	$14,816	$44,449	$204	$873
PR_1	$400,000	$1,200,000	$5,494	$23,579	$14,816	$44,449	$204	$873
PR_2	$400,000	$1,200,000	$5,494	$23,579	$14,816	$44,449	$204	$873
PR_3	$400,000	$1,200,000	$5,494	$23,579	$14,816	$44,449	$204	$873
PR_4	$400,000	$1,200,000	$5,494	$23,579	$14,816	$44,449	$204	$873
VI_1	$400,000	$1,200,000	$5,494	$23,579	$14,816	$44,449	$204	$873
VI_2	$400,000	$1,200,000	$5,494	$23,579	$14,816	$44,449	$204	$873
VI_3	$400,000	$1,200,000	$5,494	$23,579	$14,816	$44,449	$204	$873

5.5.6 S-5 Assumptions, Sources, Limitations, and Uncertainties

No universal type of breakwater can be prescribed because of the wide variation in conditions at each location. Foundation conditions, exposure to wave action, and availability of materials, as well as structural and functional performance criteria will influence the type of breakwater, its profile, and cost.

The costs for this measure are parametric unit prices and calculated based on information from multiple projects. Recent bid data from a shore protection project known as Sarasota County Lido Key Segment was considered for the majority of the itemized cost features. That project was awarded in FY20 and two groins are being constructed. These prices are assumed to be of similar enough nature, level of effort, and risk to assume comparable construction costs.

The breakwaters would most likely be constructed using marine equipment and barges. As a result, a different project was reviewed and utilized to estimate the mobilization and demobilization costs. This project was Brevard Mid-Reach Mitigation which included building offshore reef structures parallel to the shoreline, similar to a breakwater configuration.

Contingency is included at 20 percent for the low end and 40 percent for the high end. E&D and S&A are estimated at 15 percent and 12 percent, respectively, for both the high and low ends of the range presented. M&AM costs are estimated at 3 percent for the low end and 4 percent for the high end.

5.6 S-6: Floodwalls

5.6.1 S-6 Measure Description

Figure 5 11: Sunbury Floodwall (Photo Source: The Daily Items)

Coastal floodwalls are structures built to manage the risk of damage associated with surge tide and waves in relatively small areas with limited space for flood risk management. Typical types of flood walls include cantilever T-type, I-type, and braced sheet-pile structures. These structures are generally located landward of the normal high water line so that they are inundated only by hurricane or other surge tide events. Unlike wider, more stable levees, narrow floodwalls require significant reinforcement and anchoring construction to prevent collapse from hydrostatic pressure. The significant amounts of steel sheeting and/or reinforced concrete used in constructing a typical wall make the feature extremely heavy. Because construction in a flood-prone area, such as near a river or estuary, may occur on soft organic soil, pile reinforcement may be required under the base of the wall. The combination of steel sheeting, reinforcement, concrete, and pile support make a floodwall a much more costly structural risk management measure than a similar length and height levee.

5.6.2 S-6 Measure Performance and Applicability

Floodwalls are another form coastal armoring designed to reduce the damage from storm surge inundation. Its primary risk management function is to reduce flooding, while its secondary function is reducing wave attack. Floodwalls are typically applicable in low to mixed wave energy environments; however, site-specific shoreline types, adjacent water depths, erosion rates, soil conditions, currents, waves, as well as other physical, environmental and economic factors will typically dictate the overall applicability. Differences in the design methodology between floodwalls and bulkheads are discussed in **Figure 5-12**.

2-13. Design Philosophy. Retaining walls are normally built as an appurtenance to other structures: dams, hydroelectric power houses, pump stations, etc. The consequences of failure of a retaining wall are often lower than for flood walls. Also, retaining walls are seldom more than a few hundred feet long; if they are designed conservatively, the added costs are of limited significance. Flood walls, on the other hand, are usually the primary feature of a local protection project. They must be designed for the most economical cross section per unit length of wall, because they often extend for great distances. Added to this need for an economical cross section is the requirement for safety. The consequences of failure for a flood wall are normally very great since it protects valuable property and human life. Thus, the design of retaining and flood walls is a complex process involving safety and economy factors, and design must be executed in a logical, conservative manner based on the function of the wall and the consequences of failure. Design documents should describe the decisions leading to the final degree of conservatism.

Figure 5-12: Floodwall versus Bulkhead Design Method (EM 1110-2-2502)

5.6.3 S-6 Coastal Storm Risk Management Effects and Adaptability

5.6.3.1 S-6 Physical and Temporal Effects

The principal function of a floodwall is to reduce the risk of flooding to adjacent lands. Properly designed and constructed floodwalls can reduce inundation associated with short-term loadings from waves along with wind/tide high water surges. Wave overtopping can occur resulting in severe scour at or near the protected side of the stem, which requires setbacks and integration of adequate scour protection. In addition, floodwalls tend to trap rainfall runoff associated with storms on the landward side, creating a residual flooding risk. To reduce this residual risk, gravity outlets are installed along the length of the structure. The measure provides immediate inundation and wave risk management to the exposed areas in its lee. These structures provide barriers against inundation, protect buildings from equalized hydrostatic and hydrodynamic loading situations, and in some cases may deflect flood borne debris from infrastructure (FEMA 2012).

5.6.3.2 S-6 National Economic Development, Regional Economic Development, Other Social Effects, and Environmental Quality Effects

Table 5-18 provides details on floodwall effects by national account.

Table 5-18: S-6 National Economic Development (NED), Regional Economic Development (RED), Other Social Effects (OSE), and Environmental Quality (EQ) Effects

Account	Potential Benefits	Potential Costs
NED	• Manage risk of property and critical infrastructure loss, vehicle damage, protective measure costs, emergency costs, and transportation delay costs	• Measure total investment cost, O&M cost
RED	• Manage risk to regional revenue and employment in event of commercial property damage • Direct, indirect and induced effects of measure construction expenditure	• Revenue losses or employment disruptions as a result of the measure
OSE	• Manage risk to urban and community socioeconomic conditions • Emergency preparedness, security of life, health, and safety	–
EQ	• Manage risks to any cultural resource buildings in its lee	• Possibility for adverse environmental impacts

5.6.4 S-6 Sea Level Change Adaptability

5.6.4.1 S-6 Design and Cost Components

5.6.4.1.1 S-6 Generic Design

Site-specific soil conditions, foundation type, water depths, currents, waves, as well as other physical, environmental and economic factors will typically dictate the applicability and type of floodwall. However, given the regional scale of the study, it is impossible to account for these local, site-specific, conditions to determine which floodwall measure is most appropriate at each location. Therefore, for the purposes of regional framework development, a concrete T-wall is assumed.

The floodwall design for cost purposes included 1-mile-long, 12-foot-high segment of concrete T-wall protection system with a base supported by H-piles driven under the base and extending within the base, and sheet-pile driven under the wall and extending into the wall. A floodwall system could be accompanied by various gates such as vehicle, pedestrian, sluice, miter, and railroads, as well as pump stations. Costs are based on a 1-mile-long system with a variety of gates assumed within the cost estimate.

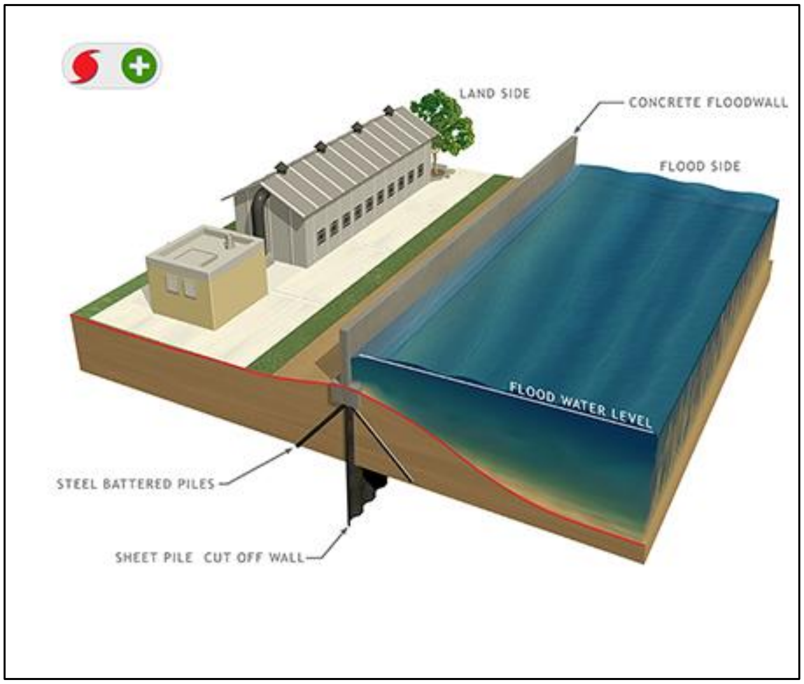

Figure 5-13: Example of a Floodwall (USACE 2015a)

5.6.4.2 S-6 Cost Components

Cost drivers include concrete quantity as determined by wall length and height, depth of driven piling, various gate quantities and size, quantities and size of pumps and pump houses, and the extent of clearing, grubbing and other earthwork required. Prices and availability of steel and concrete will also impact price.

Table 5-19 reflects what would be considered a contract cost prior to applying any additional markups, or owner markups. These additional costs include contingency at 20 percent for the low end and 40 percent for the high end. E&D and S&A are estimated at 15 percent and 12 percent, respectively, for both the high and low ends of the range presented. M&AM costs are estimated at 3 percent for the low end and 4 percent for the high end. The full or total owner cost are reflected as unit prices in **Table 5-20**. To analyze the cost components individually, the user may apply each additional owner markup in the order discussed above in a compounded process. Section 4.2.6.1 contains details regarding cost computations.

Table 5-19: S-6 Cost Components

State / Territory / Planning Reach	Feature Category	Feature	Feature Unit	Quantity Low	Quantity High	Unit Cost Low	Unit Cost High
S6_1: (NC, SC, GA, FL, AL, MS)	Unit	Floodwall Length	Linear foot (LF)	5,280	13,000	–	–
	Measure Cost Consideration	Floodwall Height	Feet (FT)	12	12	–	–
	Measure Cost	Mob/Demob	Lump sum (LS)	1	1	$500,000	$500,000
	Measure Cost	Concrete T-Floodwall	$/Cubic yard (CY)	7,392	23400	$651	$651
	Measure Cost	Concrete Cap	$/CY	1,214	2990	$525	$525

State / Territory / Planning Reach	Feature Category	Feature	Feature Unit	Quantity Low	Quantity High	Unit Cost Low	Unit Cost High
S6_1: (NC, SC, GA, FL, AL, MS) - continued	Measure Cost	Vehicle Gate	$/Each	2	12	$207,328	$207,420
	Measure Cost	Pedestrian Gate	$/Each	2	4	$57,515	$57,515
	Measure Cost	Sluice Gate	$/Each	4	9	$1,278,195	$1,278,195
	Measure Cost	Miter Gate	$/Each	1	1	$913,273	$913,273
	Measure Cost	Railroad Gate	$/Each	1	1	$210,000	$210,000
	Measure Cost	Pump Station	$/Each	1	1	$6,500,000	$32,000,000
	Measure Cost	Dewatering	$/Day	20	220	$1,716	$1,716
	Measure Cost	Incidental Work	Lump sum (LS)	1	1	$350,000	$840,000
S6_2: (PR, VI)	Unit	Floodwall Length	LF	5,280	13,000	–	–
	Measure Cost Consideration	Floodwall Height	FT	12	12	–	–
	Measure Cost	Mob/Demob	LS	1	1	$560,000	$560,000
	Measure Cost	Concrete T-Floodwall	$/CY	7,392	23400	$729	$729
	Measure Cost	Concrete Cap	$/CY	1,214	2990	$588	$588
	Measure Cost	Vehicle Gate	$/Each	2	12	$232,207	$232,310
	Measure Cost	Pedestrian Gate	$/Each	2	4	$64,417	$64,417
	Measure Cost	Sluice Gate	$/Each	4	9	$1,431,578	$1,431,578
	Measure Cost	Miter Gate	$/Each	1	1	$1,022,866	$1,022,866
	Measure Cost	Railroad Gate	$/Each	1	1	$235,200	$235,200
	Measure Cost	Pump Station	$/Each	1	1	$7,280,000	$35,840,000
	Measure Cost	Dewatering	$/Day	20	220	$1,922	$1,922
	Measure Cost	Incidental Work	$/Job	1	1	$392,000	$940,800

5.6.5 S-6 Unit Cost Range by Planning Reach

Floodwalls may be viable in all reaches within the SACS study area typically along more sheltered developed estuary and river shorelines. **Table 5-20** provides unit costs by planning reach for floodwalls.

Table 5-20: S-6 Unit Cost by Planning Reach

Reach	Measure	Mob/Demob Low	Mob/Demob High	Total First Unit Cost Low	Total First Unit Cost High	Equivalent Annual Cost (EAC)-Mob-Low	EAC-Mob-High	EAC/ LF-Low	EAC/ LF-High
NC_01	S-6	$500,000	$500,000	$5,473	$8,828	$18,520	$18,520	$203	$327
NC_02	S-6	$500,000	$500,000	$5,473	$8,828	$18,520	$18,520	$203	$327
SC_03	S-6	$500,000	$500,000	$5,473	$8,828	$18,520	$18,520	$203	$327
SC_04	S-6	$500,000	$500,000	$5,473	$8,828	$18,520	$18,520	$203	$327
GA_05	S-6	$500,000	$500,000	$5,473	$8,828	$18,520	$18,520	$203	$327
FL_06	S-6	$500,000	$500,000	$5,473	$8,828	$18,520	$18,520	$203	$327
FL_07	S-6	$500,000	$500,000	$5,473	$8,828	$18,520	$18,520	$203	$327
FL_08	S-6	$500,000	$500,000	$5,473	$8,828	$18,520	$18,520	$203	$327

Reach	Measure	Mob/Demob Low	Mob/Demob High	Total First Unit Cost Low	Total First Unit Cost High	Equivalent Annual Cost (EAC)-Mob-Low	EAC-Mob-High	EAC/ LF-Low	EAC/ LF-High
FL_09	S-6	$500,000	$500,000	$5,473	$8,828	$18,520	$18,520	$203	$327
FL_10	S-6	$500,000	$500,000	$5,473	$8,828	$18,520	$18,520	$203	$327
FL_11	S-6	$500,000	$500,000	$5,473	$8,828	$18,520	$18,520	$203	$327
FL_12	S-6	$500,000	$500,000	$5,473	$8,828	$18,520	$18,520	$203	$327
FL_13	S-6	$500,000	$500,000	$5,473	$8,828	$18,520	$18,520	$203	$327
AL_14	S-6	$500,000	$500,000	$5,473	$8,828	$18,520	$18,520	$203	$327
MS_15	S-6	$500,000	$500,000	$5,473	$8,828	$18,520	$18,520	$203	$327
PR_1	S-6	$560,000	$560,000	$6,130	$9,887	$20,743	$20,743	$227	$366
PR_2	S-6	$560,000	$560,000	$6,130	$9,887	$20,743	$20,743	$227	$366
PR_3	S-6	$560,000	$560,000	$6,130	$9,887	$20,743	$20,743	$227	$366
PR_4	S-6	$560,000	$560,000	$6,130	$9,887	$20,743	$20,743	$227	$366
VI_1	S-6	$560,000	$560,000	$6,130	$9,887	$20,743	$20,743	$227	$366
VI_2	S-6	$560,000	$560,000	$6,130	$9,887	$20,743	$20,743	$227	$366
VI_3	S-6	$560,000	$560,000	$6,130	$9,887	$20,743	$20,743	$227	$366

5.6.6 S-6 Assumptions, Sources, Limitations, and Uncertainties

No universal type of floodwall can be prescribed because of the wide variation in conditions at each location. Foundation conditions, exposure to wave action, availability of materials, and real estate availability, as well as structural and functional performance criteria will influence the applicability and type of floodwall, its height and cost.

The Charleston, South Carolina floodwall study was referenced for design and costs. It is assumed that floodwalls will consist of a combination of structures including concrete T-walls of variable height, driven sheet piling, vertical and batter piles, operable and sealable floodgates, pumps, pump houses, and drainage structures (USACE 2020a).

Prices can vary with the volatility of market conditions affected by many factors, including material and labor shortages as a result of recent coastal storms and the political climate. Prices given are based upon a Class 5 estimate using broad-based assumptions, historical data, and incomplete technical details (AACE-International 2020).

5.7 S-7: Deployable Floodwalls

5.7.1 S-7 Measure Description

Figure 5-14: Boston Deployable Floodwall (Photo Source: City of Boston)

Rapid deployment floodwalls (RDFWs) are structures that are temporarily erected along the banks of a river or estuary, or in the path of floodwaters to prevent water from reaching the area behind the structure. After the storm or flood, the structures are removed. This category also includes permanently installed, deployable flood barriers that rise into position during flooding due to the buoyancy of the barrier material and hydrostatic pressure. Some systems, such as stop logs, require a permanent base or footing, while others may be deployed without a base. Structural base components contribute to the overall effectiveness and level of risk management that an RDFW can provide. Often, traditional floodwalls or levees are used to manage risk to some portions of the waterfront, with intermittent closure structures like a RDFW.

5.7.2 S-7 Measure Performance and Applicability

Similar to floodwalls (S-6), RDFWs manage risk by placing a barrier between the hazard and the exposed assets. Primarily, the risk management function of RDFWs is to reduce inundation damage to leeward property. This measure is appropriate for more sheltered, low-energy wave environments where maintaining access is crucial under non-flood conditions.

5.7.3 S-7 Coastal Storm Risk Management Effects and Adaptability

5.7.3.1 S-7 Physical and Temporal Effects

Upon deployment, RDFWs immediately reduce inundation to the exposed area in its lee. RDFWs tend to be deployed in areas of less significant flooding as the height and strength of the structure is somewhat limited. A deployable floodwall is a passive CSRM measure, meaning that it must be deployed prior to the flood event to be effective.

5.7.3.2 S-7 National Economic Development, Regional Economic Development, Other Social Effects, and Environmental Quality Effects

Temporary measures like these are particularly useful for risk management in smaller areas and are usually considered for locations where access to the waterfront is essential to the economy or character of a community. RDFWs provide the same benefits as similarly sized static floodwalls or levees, but at lower flood levels and more sheltered areas. RDFWs are often considered for areas of limited available real estate for permanent structural coastal storm risk management measures and/or with valuable view sheds. **Table 5-21** provides more detail on the deployable floodwall impacts on the national accounts.

Table 5-21: S-7 National Economic Development (NED), Regional Economic Development (RED), Other Social Effects (OSE), and Environmental Quality (EQ) Effects

Account	Potential Benefits	Potential Costs
NED	• Manage risk of property and critical infrastructure loss, vehicle damage, and emergency costs	• Measure total investment cost • O&M cost • Measure deployment cost
RED	• Manage risk to regional revenue and employment in event of commercial property damage / direct, indirect and induced effects of measure construction expenditure	–
OSE	• Manage risk to urban and community impacts / emergency preparedness	–
EQ	• Manage risks to any cultural resource buildings in its lee	• Possibility for adverse environmental impacts

5.7.3.3 S-7 Sea Level Change Adaptability

Deployable floodwalls come in standard structural heights. If the system is not at the maximum height for this type of CSRM measure, then future replacements of larger systems could be considered, however, these adaptions strategies are limited.

5.7.4 S-7 Design and Cost Components

5.7.4.1 S-7 Generic Design

A representative typical cross section of a RDFW includes base or anchor plates, stanchions, gasketed stop logs, and bracing, if needed. For the MCL, the deployable floodwall design incorporates two 8 inch wide floodwall systems at 6 and 9 foot heights spanning distances ranging between 30 feet for overpass closures to 330 feet for larger areas. The RDFW 6-foot-high deployable floodwall is freestanding without bracing; however, the 9-foot-high deployable floodwall is braced along its length with Hesco-type baskets filled with sand.

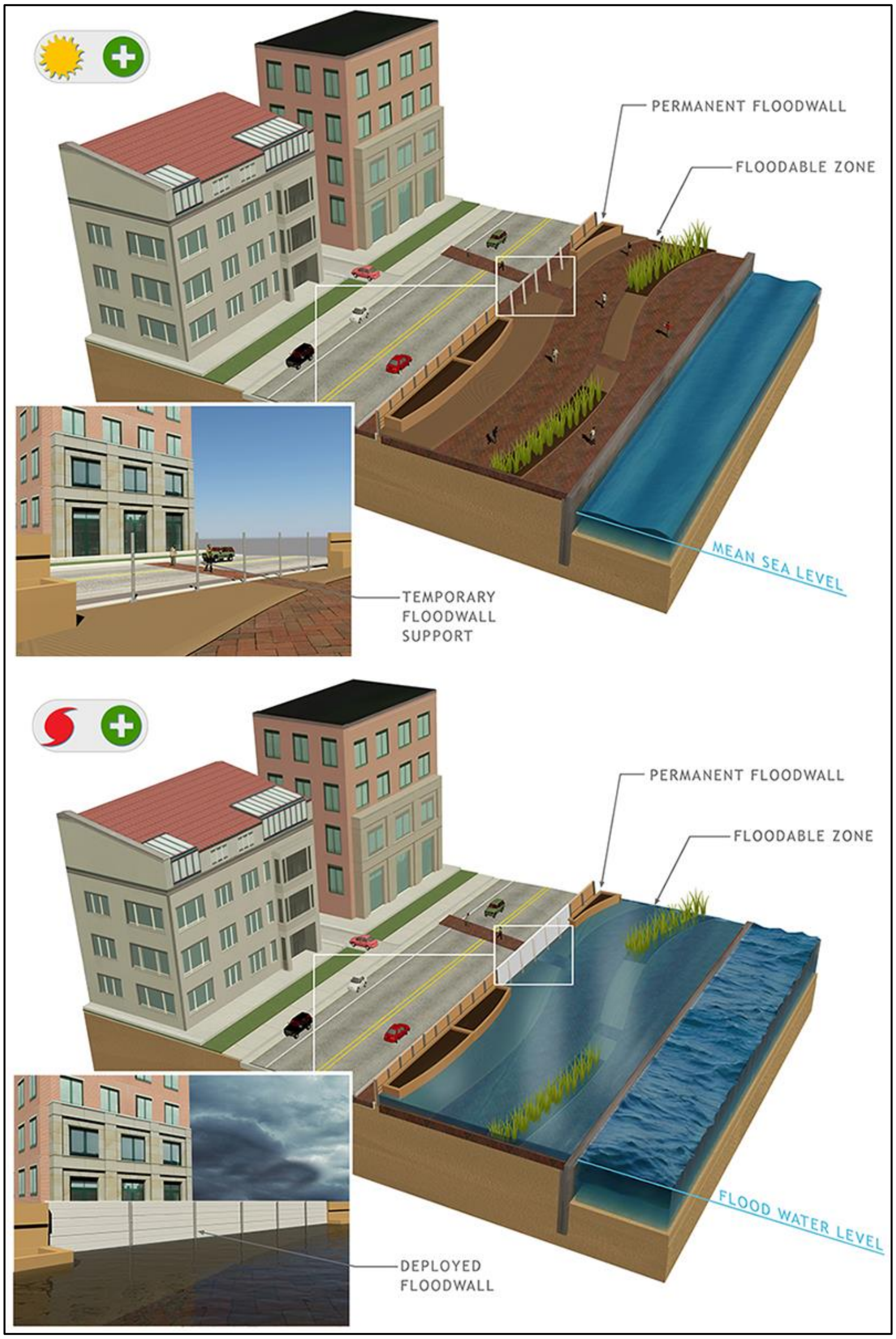

Figure 5-15: Example of a Typical Deployable Floodwall Layout (USACE 2015a)

5.7.4.2 S-7 Cost Components

Bracing for deployable walls greater than 9 feet is assumed to be Hesco-type sand baskets. Baskets are assumed to be continuous along the length of the floodwall with no spaces. Other means of bracing, such as armoring with stone, will impact cost. The cost of storing the deployable floodwalls when not needed is not considered in this study. Pricing for RDFW deployable floodwall assumes a 6-foot-high floodwall for the low unit price and a 9-foot-high wall for the high unit price spanning distances of 30 to 330 feet. The 6-foot-high wall does not require bracing; the 9-foot-high wall is braced along its length with Hesco-type baskets filled with sand.

Table 5-22 reflects what would be considered a contract cost prior to applying any additional markups, or owner markups. These additional costs include contingency at 20 percent for the low end and 40 percent for the high end. E&D and S&A are estimated at 15 percent and 12 percent, respectively, for both the high and low ends of the range presented. M&AM costs are estimated at 3 percent for the low end and 4 percent for the high end. The full or total owner costs are reflected as unit prices in **Table 5-23**. To analyze the cost components individually, the user may apply each additional owner markup in the order discussed above in a compounded process. Section 4.2.6.1 contains details regarding cost computations.

Table 5-22: S-7 Cost Components

State / Territory / Planning Reach	Feature Category	Feature	Feature Unit	Quantity Low	Quantity High	Unit Cost Low	Unit Cost High
S7_1: (NC, FL_08, FL_09, FL_10, FL_11, FL_12, FL_13, AL, MS)	Unit	Floodwall Length	Linear feet (LF)	30	330	–	–
	Measure Cost	Mob/Demob	Lump sum	1	1	$13,768	$17,000
	Measure Cost	Floodwall Construction	$/LF	30	330	$1,225	$1,570
	Measure Cost	Dismantle	$/LF	30	330	$2.00	$5.51
S7_2: (SC, GA, FL_06, FL_07)	Unit	Floodwall Length	LF	30	330	–	–
	Measure Cost	Mob/Demob	Lump sum	1	1	$13,768	$17,000
	Measure Cost	Floodwall Construction	$/LF	30	330	$1,082	$1,570
	Measure Cost	Dismantle	$/LF	1	1	$1.90	$5.50
S7_3: (PR, VI)	Unit	Floodwall Length	LF	30	330	–	–
	Measure Cost	Mob/Demob	Lump sum	1	1	$19,000	$24,000
	Measure Cost	Floodwall Construction	$/LF	30	330	$1,700	$1,962
	Measure Cost	Dismantle	$/LF	30	330	$2	$6

5.7.5 S-7 Unit Cost Range by Planning Reach

RDFWs may be viable in all reaches within the SACS study area typically along more sheltered urban estuary and river shorelines. **Table 5-23** provides unit costs by planning reach for deployable floodwalls.

Table 5-23: S-7 Unit Cost by Planning Reach

Reach	Mob/Demob Low	Mob/Demob High	Total First Unit Cost Low	Total First Unit Cost High	Equivalent Annual Cost (EAC)-Mob-Low	EAC-Mob-High	EAC/LF-Low	EAC/LF-High
NC_01	$13,768	$17,000	$2,070	$2,796	$510	$630	$77	$104
NC_02	$13,768	$17,000	$2,070	$2,796	$510	$630	$77	$104
SC_03	$13,768	$17,000	$1,855	$2,796	$510	$630	$69	$104
SC_04	$13,768	$17,000	$1,855	$2,796	$510	$630	$69	$104
GA_05	$13,768	$17,000	$1,855	$2,796	$510	$630	$69	$104
FL_06	$13,768	$17,000	$1,855	$2,796	$510	$630	$69	$104
FL_07	$13,768	$17,000	$1,855	$2,796	$510	$630	$69	$104
FL_08	$13,768	$17,000	$2,070	$2,796	$510	$630	$77	$104
FL_09	$13,768	$17,000	$2,070	$2,796	$510	$630	$77	$104
FL_10	$13,768	$17,000	$2,070	$2,796	$510	$630	$77	$104
FL_11	$13,768	$17,000	$2,070	$2,796	$510	$630	$77	$104
FL_12	$13,768	$17,000	$2,070	$2,796	$510	$630	$77	$104
FL_13	$13,768	$17,000	$2,070	$2,796	$510	$630	$77	$104
AL_14	$13,768	$17,000	$2,070	$2,796	$510	$630	$77	$104
MS_15	$13,768	$17,000	$2,070	$2,796	$510	$630	$77	$104
PR_1	$19,000	$24,000	$2,870	$3,499	$704	$889	$106	$130
PR_2	$19,000	$24,000	$2,870	$3,499	$704	$889	$106	$130
PR_3	$19,000	$24,000	$2,870	$3,499	$704	$889	$106	$130
PR_4	$19,000	$24,000	$2,870	$3,499	$704	$889	$106	$130
VI_1	$19,000	$24,000	$2,870	$3,499	$704	$889	$106	$130
VI_2	$19,000	$24,000	$2,870	$3,499	$704	$889	$106	$130
VI_3	$19,000	$24,000	$2,870	$3,499	$704	$889	$106	$130

5.7.6 S-7 Assumptions, Sources, Limitations, and Uncertainties

The successful performance of RDFWs hinges on advance flood warning. Advance warning is needed prior to deployment to facilitate transportation and assembly. Therefore, use of RDFWs is not appropriate in areas subject to flooding shortly after a rain or storm event. Stop logs must be stored close nearby, typically in a separate, dedicated facility, and must be transported to the deployment site. Because of the relatively high cost to assemble, disassemble and store the RDFW, they are not desirable in areas of frequent flooding.

The wall width, distance between stationary anchors, and the use of bracing limit the height to which a wall may be constructed. In some areas, RDFWs may be subject to minor wave action with proper construction. For cost purposes, however, it is assumed typical application is not subject to wave action.

Cost factors include mobilization and demobilization, material cost, deploying, and dismantling. Vendor pricing was used to price the RDFW (Aquafence 2020). It is assumed that the work will be performed by a prime contractor. The prices given are based upon a Class 5 estimate using broad-based assumptions, historical data, and incomplete technical details.

5.8 S-8: Levees and Dikes

5.8.1 S-8 Measure Description


Figure 5-16: Algiers Point (Photo Source: Rebecca Todd)

Levees and dikes are embankments constructed along a waterfront to prevent flooding in relatively large areas. They are typically constructed by compacting soil into a large berm that is wide at the base and tapers toward the top. Grass or some other type of non-woody vegetation is usually planted on the levee/dike to add stability to the structure. If a levee or dike is located in an erosive shoreline environment, revetments may be needed on the waterfront side to reduce impacts from erosion, or in cases of extreme conditions, the dike face may be constructed entirely of rock. Levees may be constructed in urban areas or coastal areas; however, large tracts of real estate are usually required owing to the levee width and required setbacks. Depending on the density of development of a vulnerable area, levees and floodwalls are often constructed as a system whereby floodwalls are interspersed between levee segments as available property space dictates.

5.8.2 S-8 Measure Performance and Applicability

Levees manage risk by providing a barrier between the hazard and the exposed area. Their primary and secondary risk management functions are to reduce inundation and wave attack, respectively. Levees are appropriate for low to mixed wave energy environments.

5.8.3 S-8 Coastal Storm Risk Management Effects and Adaptability

5.8.3.1 S-8 Physical and Temporal Effects

The principal function of levees and dikes is reducing flood frequency in large low-lying areas. Upon construction the measure reduces inundation and wave harm to the exposed area in its lee. Levees can manage risks to critical infrastructure, such as evacuation routes, and can provide community connectivity with recreational paths. If properly maintained levees and dikes are highly effective methods of flood risk management. However, if the design level of risk management is exceeded, water will overtop the structure, trapping floodwater behind it and risking erosion and failure of the feature. Levees and dikes tend to trap rainfall runoff associated with storms on the landward side, creating a residual flooding risk. To reduce this residual risk, gravity outlets are installed along the length of the structure. In cases where significant runoff may be trapped behind the structure, ponding areas and pump stations are required.

5.8.3.2 S-8 National Economic Development, Regional Economic Development, Other Social Effects, and Environmental Quality Effects

Similar to floodwalls, levees and dikes manage risk to a specific area from high water during storm events, but are costly, can require significant land/real estate, may impact scenic views, and may impact habitat. The height and width usually limit access to the water for recreation and commercial activities, and like floodwalls, impact the view shed of coastal properties. In some cases, levees have been incorporated into trail systems and frequently include amenities such as benches, street lighting, and jogging paths. **Table 5-27** provides detail on potential levee impacts by national account.

Table 5-24: S-8 National Economic Development, Regional Economic Development, Other Social Effects, and Environmental Quality Effects

Account	Potential Benefits	Potential Costs
NED	• Manage risk of property and critical infrastructure loss, vehicle damage, protective measure costs, emergency costs, and transportation delay costs • Potential incidental recreation	• Measure total investment cost • O&M cost
RED	• Manage risk to regional revenue and employment in event of commercial property damage • Direct, indirect and induced effects of measure construction expenditure	• Potential revenue losses or employment disruptions as a result of the measure
OSE	• Manage risk to urban and community socioeconomic conditions • Emergency preparedness • Security of life, health, and safety	• Potential to disrupt community cohesion • Non-Federal Sponsor (NFS) share of cost/ opportunity cost of risk management measure
EQ	• Manage risks to any cultural resource buildings in its lee	• Possibility for adverse environmental impacts

5.8.3.3 S-8 Sea Level Change Adaptability

Levees and dikes can be adapted to sea level change by adjusting the crest elevation. This type of action requires sufficient available land to ensure stable design.

5.8.4 S-8 Design and Cost Components

5.8.4.1 S-8 Generic Design

Site-specific soil conditions, foundation type, water depths, currents, waves, as well as other physical, environmental and economic factors will typically dictate the applicability and features of a levee and dike system. However, given the regional scale of the study, it is impossible to account for these local, site-specific conditions to determine whether a levee and dike measure is most appropriate at each location. Therefore, for the purposes of regional framework development, a levee earthen embankment, with grass erosion control, and gravity outlets are assumed.

The levee design is based an assumed 1,000-foot-long earthen levee fill with an average 20-foot crest width and 3 (Horizontal): 1 (Vertical) side slopes. Structural heights range between 10 and 15 feet based on variations in regional hydrodynamics from one planning.

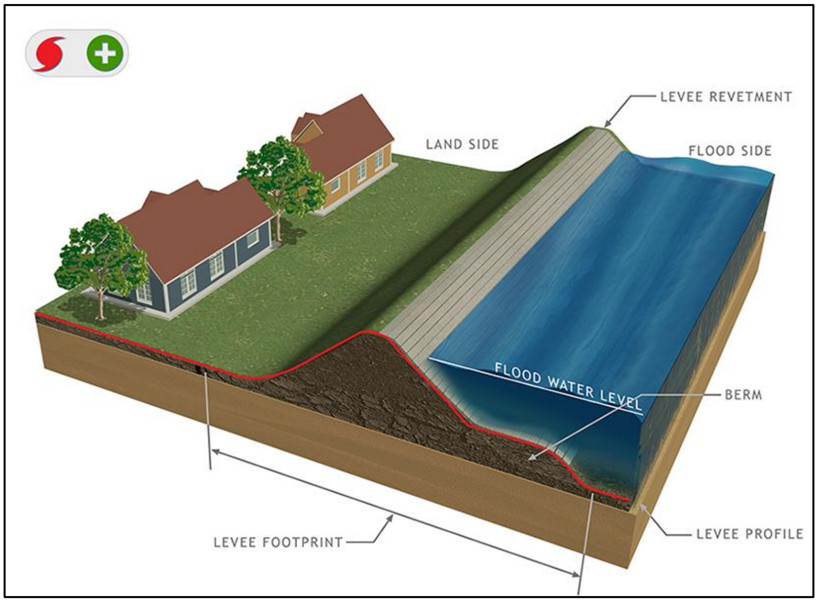

Figure 5-17: Typical Levee and Dike Layout (USACE 2015a)

5.8.4.2 S-8 Cost Components

Table 5-25 reflects what would be considered a contract cost prior to applying any additional markups, or owner markups. These additional costs include contingency at 20 percent for the low end and 40 percent for the high end, E&D and S&A are estimated at 15 percent and 12 percent, respectively, for both the high and low ends of the range presented. M&AM costs are estimated at 3 percent for the low end and 4 percent for the high end. The full or total owner cost are reflected as unit prices in **Table 5-28**. To analyze the cost components individually, the user may apply each additional owner markup in the order discussed above in a compounded process. Section 4.2.6.1 contains details regarding cost computations.

Table 5-25: S-8 Cost Components (Part-I)

State / Territory / Planning Reach	Feature Category	Feature	Feature Unit	Quantity Low	Quantity High	Unit Cost Low	Unit Cost High
S8_1: (NC_01)	Unit	Levee Length	Linear feet (LF)	1,000	1,000	–	–
	Measure Cost Consideration	Levee Height	Feet (FT)	15	20	–	–
	Measure Cost	Mob/Demob	Lump sum (LS)	1	1	$181,000	$226,150
	Measure Cost	Truck Wash Rack	LS	1	1	$55,000	$68,750
	Measure Cost	Silt Fencing	$/LF	1,100	1,100	$5.25	$6.60
	Measure Cost	Clearing-Grubbing	$/Acre (AC)	3	4	$8,900	$11,125
	Measure Cost	Geotextile	$/Square yard (SY)	12,000	16,000	$8.00	$10.00
	Measure Cost	Embankment	$/Cubic yard (CY)	45,000	70,000	$32.00	$48.00
	Measure Cost	Seeding	$/AC	3	4	$4,100	$5,125
	% Measure Cost	Contingency	%	20%	40%	–	–

State / Territory / Planning Reach	Feature Category	Feature	Feature Unit	Quantity Low	Quantity High	Unit Cost Low	Unit Cost High
S8_2: NC_02)	Unit	Levee Length	LF	1,000	1,000	–	–
	Measure Cost Consideration	Levee Height	FT	15	20	–	–
	Measure Cost	Mob/Demob	LS	1	1	$181,000	$226,150
	Measure Cost	Truck Wash Rack	LS	1	1	$55,000	$68,750
	Measure Cost	Silt Fencing	$/LF	1,100	1,100	$5.25	$6.60
	Measure Cost	Clearing-Grubbing	$/AC	3	4	$8,900	$11,125
	Measure Cost	Geotextile	$/SY	12,000	16,000	$8.00	$10.00
	Measure Cost	Embankment	$/CY	45,000	70,000	$32.00	$48.00
	Measure Cost	Seeding	$/AC	3	4	$4,100	$5,125
	% Measure Cost	Contingency	%	20%	40%	–	–
S8_3: (SC)	Unit	Levee Length	LF	1,000	1,000	–	–
	Measure Cost Consideration	Levee Height	FT	15	20	–	–
	Measure Cost	Mob/Demob	LS	1	1	$181,000	$226,150
	Measure Cost	Truck Wash Rack	LS	1	1	$55,000	$68,750
	Measure Cost	Silt Fencing	$/LF	1100	1100	$5.25	$6.60
	Measure Cost	Clearing-Grubbing	$/AC	3	4	$8,900	$11,125
	Measure Cost	Geotextile	$/SY	12,000	16,000	$8.00	$10.00
	Measure Cost	Embankment	$/CY	45,000	70,000	$32.00	$48.00
	Measure Cost	Seeding	$/AC	3.5	4.5	$4,100.00	$5,125.00
	% Measure Cost	Contingency	%	20%	40%	–	–

Table 5-26: S-8 Cost Components (Part-II)

State / Territory / Planning Reach	Feature Category	Feature	Feature Unit	Quantity Low	Quantity High	Unit Cost Low	Unit Cost High
S8_4: (GA)	Unit	Levee Length	Linear Feet (LF)	1000	1000	–	–
	Measure Cost Consideration	Levee Height	Feet (FT)	8	10	–	–
	Measure Cost	Mob/Demob	Lump sum (LS)	1	1	$181,000.00	$226,150.00
	Measure Cost	Truck Wash Rack	LS	1	1	$55,000.00	$68,750.00
	Measure Cost	Silt Fencing	$/LF	1,100	1,100	$5.25	$6.60
	Measure Cost	Clearing-Grubbing	$/AC	2	2.5	$8,900.00	$11,125.00
	Measure Cost	Geotextile	$/SY	7,600	9,000	$8.00	$10.00
	Measure Cost	Embankment	$/CY	23,000	28,000	$32.00	$48.00
	Measure Cost	Seeding	$/AC	2	2.5	$4,100.00	$5,125.00

State / Territory / Planning Reach	Feature Category	Feature	Feature Unit	Quantity Low	Quantity High	Unit Cost Low	Unit Cost High
S8_5: (FL_06, FL_07, FL_08)	Unit	Levee Length	LF	1,000	1,000	–	–
	Measure Cost Consideration	Levee Height	FT	15	20	–	–
	Measure Cost	Mob/Demob	LS	1	1	$181,000.00	$226,150.00
	Measure Cost	Truck Wash Rack	LS	1	1	$55,000.00	$68,750.00
	Measure Cost	Silt Fencing	$/LF	1,100	1,100	$5.25	$6.60
	Measure Cost	Clearing-Grubbing	$/AC	3	4	$8,900.00	$11,125.00
	Measure Cost	Geotextile	$/SY	12,000	16,000	$8.00	$10.00
	Measure Cost	Embankment	$/CY	45,000	70,000	$32.00	$48.00
	Measure Cost	Seeding	$/AC	3	4	$4,100.00	$5,125.00
S8_6: (FL_09, FL_10, FL_11)	Unit	Levee Length	LF	1,000	1,000	–	–
	Measure Cost Consideration	Levee Height	FT	15	20	–	–
	Measure Cost	Mob/Demob	LS	1	1	$181,000.00	$226,150.00
	Measure Cost	Truck Wash Rack	LS	1	1	$55,000.00	$68,750.00
	Measure Cost	Silt Fencing	$/LF	1100	1100	$5.25	$6.60
	Measure Cost	Clearing-Grubbing	$/AC	2.5	3.0	$8,900.00	$11,125.00
	Measure Cost	Geotextile	$/SY	9,000	12,300	$8.00	$10.00
	Measure Cost	Embankment	$/CY	45,000	70,000	$32.00	$48.00
	Measure Cost	Seeding	$/AC	3.0	4.0	$4,100.00	$5,125.00

Table 5-27: S-8 Cost Components (Part-III)

State / Territory / Planning Reach	Feature Category	Feature	Feature Unit	Quantity Low	Quantity High	Unit Cost Low	Unit Cost High
S8_7: (FL_12, FL_13, AL_14)	Unit	Levee Length	Linear Feet (LF)	1000	1000	–	–
	Measure Cost Consideration	Levee Height	Feet (FT)	15	20	–	–
	Measure Cost	Mob/Demob	Lump sum (LS)	1	1	$181,000.00	$226,150.00
	Measure Cost	Truck Wash Rack	LS	1	1	$55,000.00	$68,750.00
	Measure Cost	Silt Fencing	$/LF	1100	1100	$5.25	$6.60
	Measure Cost	Clearing-Grubbing	$/AC	3	4	$8,900.00	$11,125.00
	Measure Cost	Geotextile	$/SY	12,000	16,000	$8.00	$10.00
	Measure Cost	Embankment	$/CY	45,000	70,000	$32.00	$48.00
	Measure Cost	Seeding	$/AC	3	4	$4,100.00	$5,125.00

State / Territory / Planning Reach	Feature Category	Feature	Feature Unit	Quantity Low	Quantity High	Unit Cost Low	Unit Cost High
S8_8: (MS_15)	Unit	Levee Length	LF	1000	1000	–	–
	Measure Cost Consideration	Levee Height	FT	8	10	–	–
	Measure Cost	Mob/Demob	LS	1	1	$181,000.00	$226,150.00
	Measure Cost	Truck Wash Rack	LS	1	1	$55,000.00	$68,750.00
	Measure Cost	Silt Fencing	$/LF	1100	1100	$5.25	$6.60
	Measure Cost	Clearing-Grubbing	$/AC	2	2.5	$8,900.00	$11,125.00
	Measure Cost	Geotextile	$/SY	7,600	9,000	$8.00	$10.00
	Measure Cost	Embankment	$/CY	23,000	28,000	$32.00	$48.00
	Measure Cost	Seeding	$/AC	2	2.5	$4,100.00	$5,125.00
S8_9: (PR, VI)	Unit	Levee Length	LF	1000	1000	–	–
	Measure Cost Consideration	Levee Height	FT	8	10	–	–
	Measure Cost	Mob/Demob	LS	1	1	$260,000.00	$330,000.00
	Measure Cost	Truck Wash Rack	LS	1	1	$80,000.00	$100,000.00
	Measure Cost	Silt Fencing	$/LF	1100	1100	$7.70	$9.60
	Measure Cost	Clearing-Grubbing	$/AC	3	4	$13,000.00	$16,000.00
	Measure Cost	Geotextile	$/SY	12,000	16,000	$11.70	$14.60
	Measure Cost	Embankment	$/CY	45,000	70,000	$47.00	$58.00
	Measure Cost	Seeding	$/AC	1.5	2	$6,000.00	$7,500.00

5.8.5 S-8 Unit Cost Range by Planning Reach

Levees and dikes may be viable in all reaches within the SACS study area, typically along more sheltered urban estuary and river shorelines. **Table 5-28** provides unit costs by planning reach for levees and dikes.

Table 5-28: S-8 Unit Cost by Planning Reach

Reach	Mob/Demob Low	Mob/Demob High	Total First Unit Cost Low	Total First Unit Cost High	EAC-Mob-Low	EAC-Mob-High	EAC/LF-Low	EAC/LF-High
NC_01	$181,000	$226,150	$1,260	$3,989	$6,704	$8,377	$47	$148
NC_02	$181,000	$226,150	$1,260	$3,989	$6,704	$8,377	$47	$148
SC_03	$181,000	$226,150	$1,394	$4,462	$6,704	$8,377	$52	$165
SC_04	$181,000	$226,150	$1,394	$4,462	$6,704	$8,377	$52	$165
GA_05	$181,000	$226,150	$735	$2,175	$6,704	$8,377	$27	$81
FL_06	$181,000	$226,150	$1,394	$4,462	$6,704	$8,377	$52	$165
FL_07	$181,000	$226,150	$1,394	$4,462	$6,704	$8,377	$52	$165
FL_08	$181,000	$226,150	$1,394	$4,462	$6,704	$8,377	$52	$165
FL_09	$181,000	$226,150	$1,260	$3,989	$6,704	$8,377	$47	$148
FL_10	$181,000	$226,150	$1,260	$3,989	$6,704	$8,377	$47	$148
FL_11	$181,000	$226,150	$1,260	$3,989	$6,704	$8,377	$47	$148
FL_12	$181,000	$226,150	$1,260	$3,989	$6,704	$8,377	$47	$148
FL_13	$181,000	$226,150	$1,260	$3,989	$6,704	$8,377	$47	$148
AL_14	$181,000	$226,150	$1,260	$3,989	$6,704	$8,377	$47	$148

Reach	Mob/Demob Low	Mob/Demob High	Total First Unit Cost Low	Total First Unit Cost High	EAC-Mob-Low	EAC-Mob-High	EAC/LF-Low	EAC/LF-High
MS_15	$181,000	$226,150	$735	$2,175	$6,704	$8,377	$27	$81
PR_1	$260,000	$330,000	$2,043	$5,545	$9,631	$12,224	$76	$205
PR_2	$260,000	$330,000	$2,043	$5,545	$9,631	$12,224	$76	$205
PR_3	$260,000	$330,000	$2,043	$5,545	$9,631	$12,224	$76	$205
PR_4	$260,000	$330,000	$2,043	$5,545	$9,631	$12,224	$76	$205
VI_1	$260,000	$330,000	$2,043	$5,545	$9,631	$12,224	$76	$205
VI_2	$260,000	$330,000	$2,043	$5,545	$9,631	$12,224	$76	$205
VI_3	$260,000	$330,000	$2,043	$5,545	$9,631	$12,224	$76	$205

5.8.6 S-8 Assumptions, Sources, Limitations, and Uncertainties

No universal levee and dike system can be prescribed because of the wide variation in conditions at each location. Foundation conditions, exposure to wave action, availability of materials, real estate availability as well as structural and functional performance criteria will influence the applicability of a levee and dike system, its height, level of armor, drainage, and borrow availability.

Levees may require pump stations in areas that receive significant runoff. Costs for pump station maintenance would be significant but are site-specific and were not considered in the parametric cost development. Costs provided were developed using New Orleans historical costs for levees built in the past 2 years.

Prices were adjusted using indices found in the publication “EM 1110-2-1304 31 Mar 18, (CWCCIS)” (USACE 2019). The prices given are considered a Class 5 estimate based on broad-based assumptions and detailed cost items are not fully captured.

The cost of paving the levee crown with crushed stone or asphalt, regular mowing, inspection, and maintenance for levee slides, animal burrows, and washouts are not considered in the cost calculation. Seepage could occur and would require mitigation possibly with driven sheet piling. The prices given are based on a Class 5 estimate using broad-based assumptions, historical data, and incomplete technical details (AACE-International 2020).

5.9 S-9: Storm Surge Barriers

5.9.1 S-9 Measure Description

Storm surge barriers are barrier 'systems' that manage risk to an estuary or bay and consist of a series of coastal dikes, gates, and in some cases, navigation locks. In most cases, the barrier consists of a series of movable gates that stay open under normal conditions to maintain flow and are closed when storm surges are expected. The gates are sliding or rotating steel structures supported in most cases by concrete structures on pile foundations (USACE 2002). In addition, storm surge barriers are usually combined with other flood risk management measures such as levees and floodwalls.

Figure 5-18: New Orleans Storm Surge Barrier (Photo Source: Julie Dermansky)

5.9.2 S-9 Measure Performance and Applicability

Storm surge barriers manage risk by providing a barrier between the hazard and the exposed area. Their primary and secondary risk management functions are to reduce inundation and wave attack, respectively. The measure is appropriate for mixed to high wave energy environments; however, site-specific shoreline types, adjacent water depths, erosion rates, soil conditions, currents, waves, as well as other physical, environmental and economic factors will typically dictate the overall applicability.

5.9.3 S-9 Coastal Storm Risk Management Effects and Adaptability

5.9.3.1 S-9 Physical and Temporal Effects

Upon construction, the measure reduces wave and inundation harm to the exposed area in its lee. Storm surge barriers reduce storm damage risk to cities and estuaries from storm surge flooding and waves. They are typically designed to achieve storm risk management up to 1-percent and 0.5-percent AEP storm surge events. Given the high cost to operate, these structures are typically not designed to reduce flooding for less energetic and frequent tidal events but rather to protect against the threat of storm surges. Storm surge barriers can manage risks to critical infrastructure, such as evacuation routes.

5.9.3.2 S-9 National Economic Development, Regional Economic Development, Other Social Effects, and Environmental Quality Effects

Storm surge barriers manage risk to estuaries against significant storm surge flooding and waves. Storm surge barriers are often chosen as a preferred alternative to close off estuaries and reduce the required length of flood risk management measures behind the barriers. Another important characteristic is that they are often (partly) opened during normal conditions to allow for navigation and saltwater exchange with the estuarine areas landward of the barrier. Nonetheless, storm surge barriers could have negative effects on the ecological system and on navigation. Potential impacts of large storm barrier systems include environmental disruptions, impacts to fish migration, and also to shipping and water traffic which would need to be channeled through gates, sluices, or passageways. Some installations have adversely affected historical properties. Any storm surge barrier design must also consider any adverse effects of the system on property that is not protected behind the system. The following table shows the potential benefits and costs for each of the four national accounts.

Table 5-29: National Economic Development, Regional Economic Development, Other Social Effects, and Environmental Quality Effects

Account	Potential Benefits	Potential Costs
NED	• Manage risk of property and critical infrastructure loss, vehicle damage, protective measure costs, emergency costs, and transportation delay costs	• Measure total investment cost • O&M cost • Measure deployment cost
RED	• Manage risk to regional revenue and employment in event of commercial property damage • Direct, indirect and induced effects of measure construction expenditure	• Revenue losses or employment disruptions as a result of the measure
OSE	• Manage risk to urban and community socioeconomic conditions • Emergency preparedness	–
EQ	• Manage risks to any cultural resource buildings in its lee	• Possibility for adverse environmental impacts

Large regional storm surge barrier systems are very expensive and require long-term construction efforts coordinated in multiple locations. Systems may require strengthening or upgrade projects on existing dikes, and floodwalls. A key consideration in these projects is determining what level of risk management is desired.

5.9.3.3 S-9 Sea Level Change Adaptability

Storm surge barriers could potentially be adaptable to sea level change by increasing the elevation of portions of the structure overtime. This type of action requires sufficient available land to ensure stable design.

5.9.4 S-9 Design and Cost Components

5.9.4.1 S-9 Generic Design

Site-specific soil conditions, foundation type, water depths, currents, waves, as well as other physical, environmental and economic factors will typically dictate the applicability and necessary features of a storm surge barrier system. However, given the regional scale of the study, it is impossible to account for these local, site-specific conditions at each location. Given the regional scale of this study, a construction cost estimate based on the actual design of a site-specific storm surge barrier is well beyond the scope. This would require knowing the general characteristics and dimensions of each component, including dikes, closure structures, gates, and gate monoliths, which would require a significant amount of additional study and design work.

The basis of the design was taken from the Lake Borgne Storm Surge Barrier in Louisiana which offered historical data for developing an estimate (USACE 2013b; Flood Protection Authority 2018) with gates for smaller barriers taken from the ongoing Collier County, Florida CSRM Study.

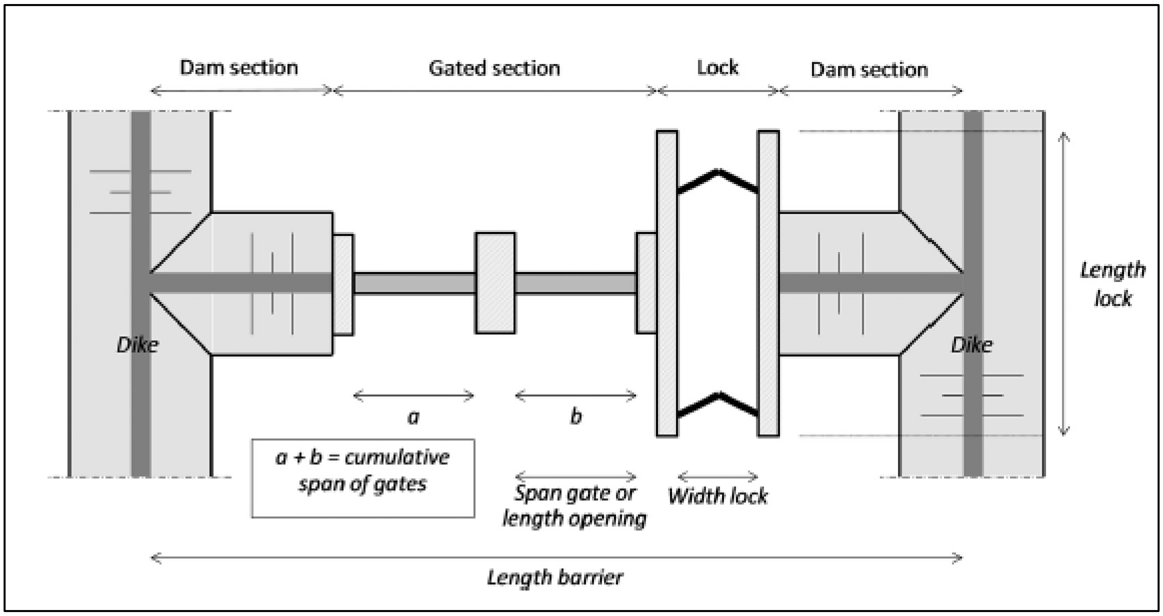

Figure 5-19: Typical Storm Surge Barrier Components (Mooyaart and Jonkman 2017)

5.9.4.2 S-9 Cost Components

Storm surge barriers are complex structures with costs driven by many factors. Standard components of a storm surge barrier consist of a dam section, an auxiliary flow gate section, and a navigable gate section (USACE 2020c; Daniel and Paulus 2019). Barges filled with concrete to make a barge gate have also been utilized.

Table 5-30 reflects what would be considered a contract cost prior to applying any additional markups, or owner markups. These additional costs include contingency at 20 percent for the low end and 40 percent for the high end, E&D and S&A are estimated at 15 percent and 12 percent, respectively, for both the high and low ends of the range presented. M&AM costs are estimated at 3 percent for the low end and 4 percent for the high end. The full or total owner cost are reflected as unit prices in **Table 5-31**. To analyze the cost components individually, the user may apply each additional owner markup in the order discussed above in a compounded process. Section 4.2.6.1 contains details regarding cost computations.

Table 5-30: S-9 Cost Components (Part-I)

State / Territory / Planning Reach	Feature Category	Feature	Feature Unit	Quantity Low	Quantity High	Unit Cost Low	Unit Cost High
S9_1: (ALL)	Unit	Storm Surge Barrier Length	Linear feet (LF)	200	5280	–	–
	Measure Cost Consideration	Storm Surge Barrier Freeboard Height	Feet (FT)	15	20	–	–
	Measure Cost	Mob/Demob	$/LF	1	1	$2,000,000	$187,500,000
	Measure Cost	Barrier Wall - Concrete Piles-Batter Piles-Cap	$/LF	100	5280	$105,000	$136,000
	Measure Cost	Gated Structures	Lump sum	1	1	$13,000,000	$62,000,000

5.9.5 S-9 Unit Cost Range by Planning Reach

Storm surge barriers may be viable in all reaches within the SACS study area in regions with a large estuary or bay with significant population and infrastructure at risk from coastal storm surge. **Table 5-31** provides unit costs by planning reach for storm surge barriers.

Table 5-31: S-9 Unit Costs by Planning Reach

Reach	Mob/Demob Low	Mob/Demob High	Total First Unit Cost Low	Total First Unit Cost High	Equivalent Annual Cost (EAC)-Mob-Low	EAC-Mob-High	EAC/LF-Low	EAC/LF-High
NC_01	$2,000,000	$187,500,000	$181,250	$285,183	$74,082	$6,945,172	$6,714	$10,563
NC_02	$2,000,000	$187,500,000	$181,250	$285,183	$74,082	$6,945,172	$6,714	$10,563
SC_03	$2,000,000	$187,500,000	$181,250	$285,183	$74,082	$6,945,172	$6,714	$10,563
SC_04	$2,000,000	$187,500,000	$181,250	$285,183	$74,082	$6,945,172	$6,714	$10,563
GA_05	$2,000,000	$187,500,000	$181,250	$285,183	$74,082	$6,945,172	$6,714	$10,563
FL_06	$2,000,000	$187,500,000	$181,250	$285,183	$74,082	$6,945,172	$6,714	$10,563
FL_07	$2,000,000	$187,500,000	$181,250	$285,183	$74,082	$6,945,172	$6,714	$10,563
FL_08	$2,000,000	$187,500,000	$181,250	$285,183	$74,082	$6,945,172	$6,714	$10,563
FL_09	$2,000,000	$187,500,000	$181,250	$285,183	$74,082	$6,945,172	$6,714	$10,563
FL_10	$2,000,000	$187,500,000	$181,250	$285,183	$74,082	$6,945,172	$6,714	$10,563
FL_11	$2,000,000	$187,500,000	$181,250	$285,183	$74,082	$6,945,172	$6,714	$10,563
FL_12	$2,000,000	$187,500,000	$181,250	$285,183	$74,082	$6,945,172	$6,714	$10,563
FL_13	$2,000,000	$187,500,000	$181,250	$285,183	$74,082	$6,945,172	$6,714	$10,563
AL_14	$2,000,000	$187,500,000	$181,250	$285,183	$74,082	$6,945,172	$6,714	$10,563
MS_15	$2,000,000	$187,500,000	$181,250	$285,183	$74,082	$6,945,172	$6,714	$10,563
PR_1	$2,000,000	$187,500,000	$181,250	$285,183	$74,082	$6,945,172	$6,714	$10,563
PR_2	$2,000,000	$187,500,000	$181,250	$285,183	$74,082	$6,945,172	$6,714	$10,563
PR_3	$2,000,000	$187,500,000	$181,250	$285,183	$74,082	$6,945,172	$6,714	$10,563
PR_4	$2,000,000	$187,500,000	$181,250	$285,183	$74,082	$6,945,172	$6,714	$10,563
VI_1	$2,000,000	$187,500,000	$181,250	$285,183	$74,082	$6,945,172	$6,714	$10,563
VI_2	$2,000,000	$187,500,000	$181,250	$285,183	$74,082	$6,945,172	$6,714	$10,563
VI_3	$2,000,000	$187,500,000	$181,250	$285,183	$74,082	$6,945,172	$6,714	$10,563

5.9.6 S-9 Assumptions, Sources, Limitations, and Uncertainties

No storm surge barrier system can be prescribed because of the wide variation in conditions at each location. Foundation conditions, exposure to wave action, availability of materials, real estate availability as well as structural and functional performance criteria will influence the applicability of a system, its height and necessary components to meet design criteria.

The majority of the pricing information has been taken from the Lake Borgne Storm Surge Barrier in Louisiana which offered historical data for developing an estimate (USACE 2013b; Flood Protection Authority 2018). The cost was adjusted for time and location using cost indices from EM 1110-2-1304 31 Mar 19, (CWCCIS). However, as part of the low estimate, the unit of length and unit price for the gates was taken from the ongoing Collier County, Florida CSRM Study. The referenced storm surge barrier offers insight into the cost of a concept per linear feet. Components costed are the dam section noted as 'barrier wall,' and gated structures which include one or more gates that could be vertical gates for flow control or navigation gates such as 'sector gates' or a 'miter gate.' The high price takes into consideration historical data (USACE 2011).

The prices given are based on a Class 5 estimate using broad-based assumptions, historical data, and incomplete technical details (AACE-International 2020). Prices can vary from -20 percent to +50 percent of the construction cost.

5.10 S-10: Beach Nourishment

5.10.1 S-10 Measure Description

Beach nourishment, also commonly referred to as beach restoration or beachfill, typically includes the placement of large quantities of sand to either replace eroded beaches or increase the size (width and/or height) of an existing beach and dune system. Material similar to the natural sand is mechanically placed (i.e., hydraulic cutterhead, hopper and/or truck haul with land-based construction equipment) on the eroded part of the beach. Beach and dune nourishment can manage risk not only to the beach where it is placed and infrastructure landward of the beach, but also downdrift stretches by providing an updrift point source of sand (USACE 2002). Most coastal engineering practitioners consider beach nourishment as a technically sound coastal storm risk management engineering alterative when properly designed and placed in the appropriate location (National Research Council 1995). A comprehensive database of beach projects in the United States can be found at http://beachnourishment.wcu.edu. Beach nourishment can also be considered a nature-based feature.

Figure 5-20: Martin County Beach Restoration (Nourishment)

5.10.2 S-10 Measure Performance and Applicability

Beach and dune nourishment manage risk by maintaining a minimum distance between the hazard and the exposed area. The primary risk management functions of beach and dune nourishment are to reduce inundation, wave attack, and erosion. Beach nourishment is applicable to mixed and high wave energy environments. Although very effective in managing storm damage to the areas they are designed to manage risk to, beach and dune nourishment projects are typically applicable only where there is an existing, gently sloping, sandy shoreline having a natural source of sand to help sustain the beach.

5.10.3 S-10 Coastal Storm Risk Management Effects and Adaptability

5.10.3.1 S-10 Physical and Temporal Effects

Upon construction, a beach and dune nourishment project immediately reduces inundation, erosion, and wave attack damage to the property, infrastructure, and habitats in its lee. It provides a buffer against the increased wave energy and storm surge generated during a coastal storm event. Beach nourishment can also be used in combination with other structural coastal storm risk management measures such as seawalls, breakwaters, and groins; it can also function well as a stand-alone measure. For this reason, beach and dune nourishment can be used in locations where the use of hard structures is not acceptable. Artificially placed sand for beach and dune nourishment also provides a sand source for downdrift beaches. The direction and rate of movement of the newly deposited sand along the shoreline should be carefully considered to avoid shoaling and filling of any adjacent navigable waterways.

5.10.3.2 S-10 National Economic Development, Regional Economic Development, Other Social Effects, and Environmental Quality Effects

As indicated by the numerous Federal, state, and local beach and dune nourishment projects located throughout the study area, beach and dune nourishment is a very effective and commonly used method of coastal storm risk management in the southeast. Beaches serve as frontlines of defense dissipating wave energy for landward infrastructure and habitats. In addition to the coastal storm risk management benefits, constructed beaches can provide ecosystem services like improved water quality, storage, and filtration of water through the sand and wildlife habitat and biodiversity. Other social benefits include ecotourism, educational sites, and recreation. **Table 5-32** provides details on the effects of beach and dune nourishment on the national accounts.

Table 5-32: S-10 National Economic Development, Regional Economic Development, Other Social Effects, and Environmental Quality Effects

Account	Potential Benefits	Potential Costs
NED	• Manage risk of property and critical infrastructure loss, vehicle damage, land loss, protective measure costs, emergency costs, and transportation delay costs • Incidental recreation	• Measure total investment costs • M&AM cost
RED	• Manage risk to regional revenue and employment in event of commercial property damage • Direct, indirect and induced effects of measure construction expenditure	• Revenue losses or employment disruptions as a result of the measure
OSE	• Manage risk to urban and community socioeconomic conditions • Emergency preparedness • Potential educational, cultural, and recreational opportunities	–
EQ	• Manage risks to any cultural resource buildings in its lee • Can provide positive EQ effects by contributing to beach and dune habitat	• Possibility for adverse environmental impacts

5.10.3.3 S-10 Sea Level Change Adaptability

Beach and dune nourishment can be adaptable to sea level change by changing the dune and/or berm elevation, the placement volume, and/or the renourishment interval provided an adequate sand source is present.

5.10.4 S-10 Design and Cost Components

5.10.4.1 S-10 Generic Design

For the MCL, the beach and dune nourishment design is based on standard beach and dune fill densities. Variation in beach nourishment densities were made based on regional differences in current beach nourishment practice.

Beach nourishment fill densities range from 100 cubic yard per linear foot to 120 cubic yard per linear foot for the Atlantic Coast beaches, 60 cubic yard per linear foot to 75 cubic yard per linear foot for Island and Southern Florida areas, and 80 cubic yard per linear foot to 100 cubic yard per linear foot for Gulf Coast reaches.

Renourishment is estimated to occur every ten years, with renourishment quantities estimated at 40 cubic yard per linear foot to 50 cubic yard per linear foot for Atlantic Coast beaches, 20 cubic yard per linear foot to 27 cubic yard per linear foot for Island and Southern Florida areas, and 30 cubic yard per linear foot to 40 cubic yard per linear foot for Gulf Coast reaches.

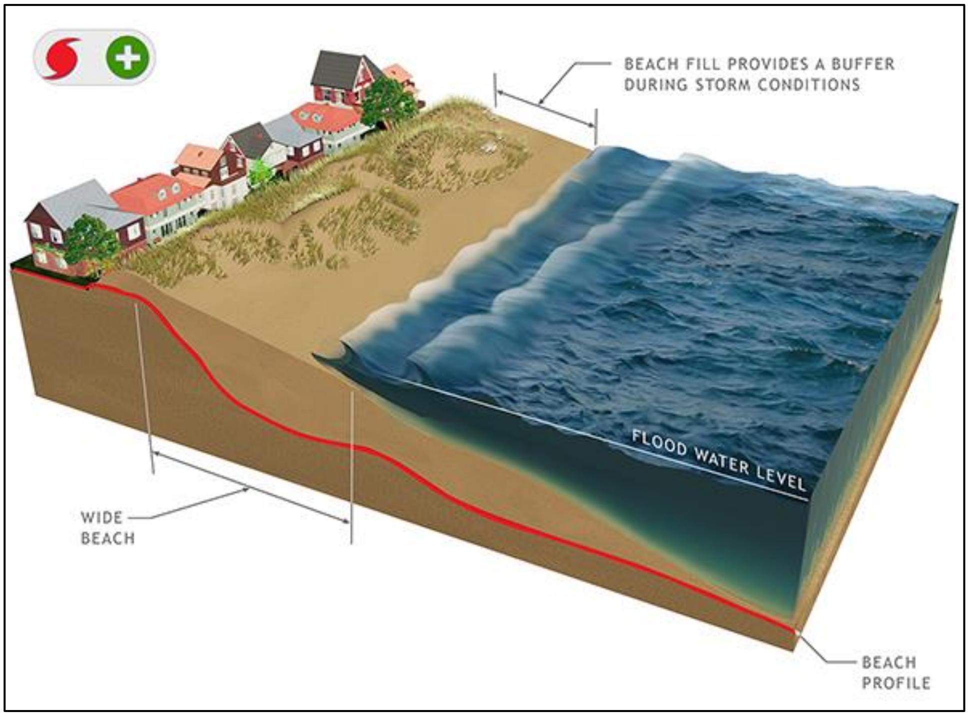

Figure 5-21: Typical Beach Nourishment Layout (USACE 2015a)

5.10.4.2 S-10 Cost Components

This estimate assumes use of dredged material with shaping of the placed material by shore-based equipment. Actual placement amounts will depend upon the desired beach template and the existing conditions. For the purposes of the MCL, beach and dune nourishment fill densities described in the generic design section were used in the cost development. The low-end cost range includes a cutterhead dredge piping the fill a short distance to the fill template. The high-end cost range would be realized using a large hopper dredge hauling the material a significant distance.

For cost purposes assumptions have been made that beach compatible sand would be available at reasonable haul distances to sustain a beach and dune nourishment project. Several beach projects throughout the Southeast, however, are facing sand shortages, which could impact the long-term economic viability of this measure at certain sites.

Table 5-33 reflects what would be considered a contract cost prior to applying any additional markups, or owner markups. These additional costs include contingency at 20 percent for the low end and 40 percent for the high end, E&D and S&A are estimated at 15 percent and 12 percent, respectively, for both the high and low ends of the range presented. M&AM costs are estimated at 3 percent for the low end and 4 percent for the high end. The full or total owner cost are reflected as unit prices in **Table 5-34**. To analyze the cost components individually, the user may apply each additional owner markup in the order discussed above in a compounded process. Section 4.2.6.2 contains details regarding cost computations.

Table 5-33: S-10 Cost Components

State / Territory / Planning Reach	Feature Category	Feature	Feature Unit	Quantity Low	Quantity High	Unit Cost Low	Unit Cost High
S10_1: (NC, SC, GA, FL_06, FL_07, FL_08)	Unit	Beach Nourishment Length	Linear foot (LF)	6000	6000	–	–
	Measure Cost	Mob/Demob	Lump sum (LS)	1	1	$2,500,000	$6,000,000
	Construction Unit	Beach Nourishment Fill Density	Cubic yard (CY)/LF	100	120	–	–
	Measure Cost	Beach Nourishment	$/CY	600,000	720,000	$7	$30
	Unit	Renourishment Length*	LF	6000	6000	–	–
	Measure Cost	Mob/Demob*	LS	1	1	$2,500,000	$6,000,000
	Construction Unit	Renourishment Fill Density*	CY/LF	40	50	–	–
	Measure Cost	Renourishment*	$/CY	240,000	300,000	$7	$30
S10_2: (FL_09, PR, VI)	Unit	Beachfill Length	LF	6000	6000	–	–
	Measure Cost	Mob/Demob	LS	1	1	$2,500,000	$6,000,000
	Construction Unit	Beach Nourishment Fill Density	CY/LF	60	75	–	–
	Measure Cost	Beach Nourishment	$/CY	360,000	450,000	$7	$30
	Unit	Renourishment Length*	LF	6000	6000	–	–
	Measure Cost	Mob/Demob*	Lump sum	1	1	$2,500,000	$6,000,000
	Construction Unit	Renourishment Fill Density*	CY/LF	20	27	–	–
	Measure Cost	Renourishment*	$/CY	120,000	162,000	$7	$30
S10_3: (FL_10, FL_11, FL_12, FL_13, AL_14, MS_15)	Unit	Beach Nourishment Fill Length	LF	6000	6000	–	–
	Measure Cost	Mob/Demob	LS	1	1	$2,500,000	$6,000,000
	Construction Unit	Beachfill Density	CY/LF	80	100	–	–
	Measure Cost	Beach Nourishment	$/CY	480,000	600,000	$7	$30
	Unit	Renourishment Length*	LF	6000	6000	–	–
	Measure Cost	Mob/Demob*	LS	1	1	$2,500,000	$6,000,000
	Construction Unit	Renourishment Fill Density*	CY/LF	30	40	–	–
	Measure Cost	Renourishment*	$/CY	180,000	240,000	$7	$30

5.10.5 S-10 Unit Cost Range by Planning Reach

Beach nourishment may be viable in all reaches within the SACS study area along eroding exposed and sheltered sandy coastlines. **Table 5-34** provides unit costs by planning reach for beach nourishment.

Table 5-34: S-10 Unit Costs by Planning Reach (Initial Construction Event)

Reach	Mob/Demob Low	Mob/Demob High	Total First Unit Cost Low	Total First Unit Cost High	Equivalent Annual Cost (EAC)-Mob-Low	EAC-Mob-High	EAC/Linear Foot (LF)-Low	EAC/LF-High
NC_01	$2,500,000	$6,000,000	$1,258	$7,050	$92,602	$222,246	$47	$261
NC_02	$2,500,000	$6,000,000	$1,258	$7,050	$92,602	$222,246	$47	$261
SC_03	$2,500,000	$6,000,000	$1,258	$7,050	$92,602	$222,246	$47	$261
SC_04	$2,500,000	$6,000,000	$1,258	$7,050	$92,602	$222,246	$47	$261
GA_05	$2,500,000	$6,000,000	$1,258	$7,050	$92,602	$222,246	$47	$261
FL_06	$2,500,000	$6,000,000	$1,258	$7,050	$92,602	$222,246	$47	$261
FL_07	$2,500,000	$6,000,000	$1,258	$7,050	$92,602	$222,246	$47	$261
FL_08	$2,500,000	$6,000,000	$1,258	$7,050	$92,602	$222,246	$47	$261
FL_09	$2,500,000	$6,000,000	$838	$4,688	$92,602	$222,246	$31	$174
FL_10	$2,500,000	$6,000,000	$1,048	$6,000	$92,602	$222,246	$39	$222
FL_11	$2,500,000	$6,000,000	$1,048	$6,000	$92,602	$222,246	$39	$222
FL_12	$2,500,000	$6,000,000	$1,048	$6,000	$92,602	$222,246	$39	$222
FL_13	$2,500,000	$6,000,000	$1,048	$6,000	$92,602	$222,246	$39	$222
AL_14	$2,500,000	$6,000,000	$1,048	$6,000	$92,602	$222,246	$39	$222
MS_15	$2,500,000	$6,000,000	$1,048	$6,000	$92,602	$222,246	$39	$222
PR_1	$2,500,000	$6,000,000	$838	$4,688	$92,602	$222,246	$31	$174
PR_2	$2,500,000	$6,000,000	$838	$4,688	$92,602	$222,246	$31	$174
PR_3	$2,500,000	$6,000,000	$838	$4,688	$92,602	$222,246	$31	$174
PR_4	$2,500,000	$6,000,000	$838	$4,688	$92,602	$222,246	$31	$174
VI_1	$2,500,000	$6,000,000	$838	$4,688	$92,602	$222,246	$31	$174
VI_2	$2,500,000	$6,000,000	$838	$4,688	$92,602	$222,246	$31	$174
VI_3	$2,500,000	$6,000,000	$838	$4,688	$92,602	$222,246	$31	$174

Table 5-35: S-10 Unit Cost Ranges by Planning Reach (Renourishment Event)

Reach	Mob/Demob Low	Mob/Demob High	Total First Unit Cost Low	Total First Unit Cost High	Equivalent Annual Cost (EAC)-Mob-Low	EAC-Mob-High	EAC/LF-Low	EAC/LF-High
NC_01	$2,500,000	$6,000,000	$628	$3,375	$92,602	$222,246	$23	$125
NC_02	$2,500,000	$6,000,000	$628	$3,375	$92,602	$222,246	$23	$125
SC_03	$2,500,000	$6,000,000	$628	$3,375	$92,602	$222,246	$23	$125
SC_04	$2,500,000	$6,000,000	$628	$3,375	$92,602	$222,246	$23	$125
GA_05	$2,500,000	$6,000,000	$628	$3,375	$92,602	$222,246	$23	$125
FL_06	$2,500,000	$6,000,000	$628	$3,375	$92,602	$222,246	$23	$125
FL_07	$2,500,000	$6,000,000	$628	$3,375	$92,602	$222,246	$23	$125
FL_08	$2,500,000	$6,000,000	$628	$3,375	$92,602	$222,246	$23	$125
FL_09	$2,500,000	$6,000,000	$418	$2,168	$92,602	$222,246	$15	$80
FL_10	$2,500,000	$6,000,000	$523	$2,850	$92,602	$222,246	$19	$106

Reach	Mob/Demob Low	Mob/Demob High	Total First Unit Cost Low	Total First Unit Cost High	Equivalent Annual Cost (EAC)-Mob-Low	EAC-Mob-High	EAC/LF-Low	EAC/LF-High
FL_11	$2,500,000	$6,000,000	$523	$2,850	$92,602	$222,246	$19	$106
FL_12	$2,500,000	$6,000,000	$523	$2,850	$92,602	$222,246	$19	$106
FL_13	$2,500,000	$6,000,000	$523	$2,850	$92,602	$222,246	$19	$106
AL_14	$2,500,000	$6,000,000	$523	$2,850	$92,602	$222,246	$19	$106
MS_15	$2,500,000	$6,000,000	$523	$2,850	$92,602	$222,246	$19	$106
PR_1	$2,500,000	$6,000,000	$418	$2,168	$92,602	$222,246	$15	$80
PR_2	$2,500,000	$6,000,000	$418	$2,168	$92,602	$222,246	$15	$80
PR_3	$2,500,000	$6,000,000	$418	$2,168	$92,602	$222,246	$15	$80
PR_4	$2,500,000	$6,000,000	$418	$2,168	$92,602	$222,246	$15	$80
VI_1	$2,500,000	$6,000,000	$418	$2,168	$92,602	$222,246	$15	$80
VI_2	$2,500,000	$6,000,000	$418	$2,168	$92,602	$222,246	$15	$80
VI_3	$2,500,000	$6,000,000	$418	$2,168	$92,602	$222,246	$15	$80

5.10.6 S-10 Assumptions, Sources, Limitations, and Uncertainties

The costs for this measure are parametric unit prices and calculated based upon historical bid date from a variety of projects from Jacksonville and Mobile Districts, with all costs escalated to FY20 levels. The wide variation between high and low costs presented in **Table 5-33** is intentional and reflects that relatively small differences in haul distance can cause significant changes to the cost of construction. Projects used in developing these costs include, but are not limited to:

SAM – Cat Island Beach and Dune Fill
SAM – Ship Island Restoration Phase 1
SAM – Ship Island Restoration Phase 2
SAM – Ship Island Restoration Phases 3 and 4
SAM – Various Coastal Dredging IDIQ MATOCs

As with all estimates including dredged material, the key cost drivers are distance to mobilize and distance to move the sediment. Small changes in haul distance can have great impact on the unit and total cost of a placement project. Vegetation and sand fence are not included in the estimate for beach nourishment provided but may be incorporated into projects. Also, all real estate considerations are excluded from the MCL estimates.

5.11 S-11: Nearshore Nourishment

5.11.1 S-11 Measure Description

Nearshore nourishments include sediment bypassing at inlets and open-water applications, including thin layer placement on bay bottoms. This is the artificial placement of sediment with the intent to maintain sediment supplies to benefit downdrift shoals, tidal flats and/or shorelines. Sediment is most often obtained from navigation channels but could be mined from borrow sources 'outside' the sediment budget system, such as offshore borrow sites similar to those used for beach nourishment projects. Nearshore nourishment can also be considered a nature-based feature.

Figure 5-22: Thin Layer Placement (Photo Source: USACE ERDC)

5.11.2 S-11 Measure Performance and Applicability

Nearshore placement manages risk by moderating shoreline change and erosion rate. It also has the potential to help establish a minimum distance between the hazard and the exposed area. The primary and secondary risk management and performance functions include reducing coastal erosion and wave attack, respectively. Nearshore placement is appropriate for use in mixed to high wave energy environments. This measure has been growing in popularity and application within regional sediment management practice.

5.11.3 S-11 Coastal Storm Risk Management Effects and Adaptability

5.11.3.1 S-11 Physical and Temporal Effects

Over time, nearshore nourishment reduces erosion and wave attack harm to the property, infrastructure, and habitats in its lee. It reduces incoming wave energy generated during a coastal storm event. When properly designed and constructed nearshore placement can provide a sediment source which can reduce erosion and perhaps migrate onshore to increase the dry beach width. Nearshore placement can also be used in combination with other structural coastal storm risk management measures such as seawalls, breakwaters, and groins but can also function well as a stand-alone measure. For this reason, nearshore nourishment can be used in locations where the use of hard structures is not acceptable. Artificially placed sand for nearshore nourishment also provides a sand source for downdrift beaches similarly to beach and dune nourishment. Like beach restoration, the direction and rate of movement of the newly deposited sand along the shoreline should be carefully considered to avoid shoaling and filling of any adjacent navigable waterways.

5.11.3.2 S-11 National Economic Development, Regional Economic Development, Other Social Effects, and Environmental Quality Effects

The primary benefit of nearshore nourishment is to increase net sediment availability and offset coastal erosion. The following table shows the potential benefits and costs for each of the four national accounts.

Table 5-36: National Economic Development, Regional Economic Development, Other Social Effects, and Environmental Quality Effects

Account	Potential Benefits	Potential Costs
NED	• Manage risk of property and critical infrastructure loss, vehicle damage, land loss, protective measure costs, emergency costs, and transportation delay costs • Incidental recreation	• Measure total investment cost • M&AM cost
RED	• Manage risk to regional revenue and employment in event of commercial property damage • Direct, indirect and induced effects of measure construction expenditure	• Revenue losses or employment disruptions as a result of the measure
OSE	• Manage risk to urban and community socioeconomic conditions • Emergency preparedness • Potential educational, cultural, and recreational opportunities	–
EQ	• Manage risks to any cultural resource buildings in its lee • Can provide positive EQ effects by contributing to beach and dune habitat	• Possibility for adverse environmental impacts

5.11.3.3 S-11 Sea Level Change Adaptability

Nearshore nourishment is potentially adaptable by increasing the nourishment volume and increasing the placement elevation off the bottom.

5.11.4 S-11 Design and Cost Components

5.11.4.1 S-11 Generic Design

For the MCL, the nearshore nourishment design assumed a variation in placement volumes of 100,000 to 500,000 cubic yards over a 3,000-foot nearshore placement area with existing water depths generally less than 20 feet. An example of a typical nearshore nourishment is shown in Figure 5-23.

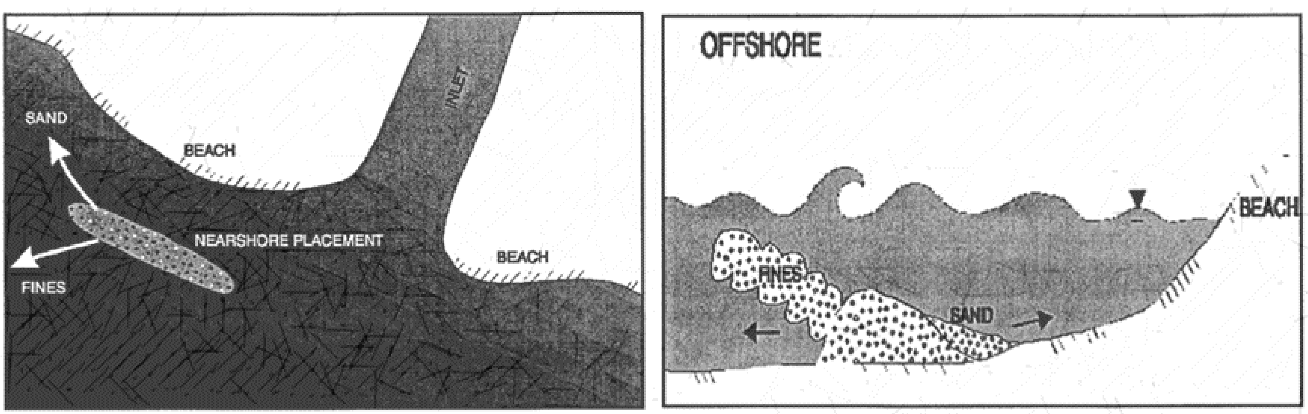

Figure 5-23: Schematic of Nearshore Nourishment (USACE 1998)

The components of the unit cost for nearshore nourishment include mobilization of the dredge equipment and a unit cost for moving material.

As with all estimates including dredged material, the key cost drivers will be distance to mobilize and distance to move the sediment. Actual placement amounts will depend upon the desired fill template and the existing conditions. The low-end cost range is based on a relatively small nourishment amount per length. The high-end cost range would be realized using a larger fill volume. Note that the unit cost for placement and mobilization was kept constant for both estimates.

Table 5-37 reflects what would be considered a contract cost prior to applying any additional markups, or owner markups. These additional costs include contingency at 20 percent for the low end and 40 percent for the high end, E&D and S&A are estimated at 15 percent and 12 percent, respectively, for both the high and low ends of the range presented. M&AM costs are estimated at 3 percent for the low end and 4 percent for the high end. The full or total owner cost are reflected as unit prices in **Table 5-38**.

To analyze the cost components individually, the user may apply each additional owner markup in the order discussed above in a compounded process. Section 4.2.6.2 contains details regarding cost computations.

Table 5-37: S-11 Cost Components

State / Territory / Planning Reach	Feature Category	Feature	Feature Unit	Quantity Low	Quantity High	Unit Cost Low	Unit Cost High
S11_1: (NC, SC, GA, FL_06, FL_10, FL_11, FL_12, FL_13, AL_14, MS_15)	Unit	Nearshore Reach Length	Linear foot (LF)	3000	3000	–	–
	Measure Cost	Mob/Demob	Lump sum (LS)	1	1	$450,000.00	$450,000.00
	Measure Cost	Nearshore Nourishment	$/Cubic yard (CY)	100,000	500,000	$7.60	$7.60
S11_2: (FL_07, FL_08, FL_09)	Unit	Nearshore Reach Length	LF	3000	3000	–	–
	Measure Cost	Mob/Demob	LS	1	1	$450,000.00	$450,000.00
	Measure Cost	Nearshore Nourishment	$/CY	10000	50000	$7.60	$7.60
S11_3: (PR, VI)	Unit	Nearshore Reach Length	LF	3000	3000	–	–
	Measure Cost	Mob/Demob	LS	1	1	$450,000.00	$450,000.00
	Measure Cost	Nearshore Nourishment	$/CY	10000	50000	$7.60	$7.60

5.11.5 S-11 Unit Cost Range by Planning Reach

Nearshore placement may be viable in all reaches within the SACS study area along eroding exposed and sheltered coastlines. **Table 5-38** provides unit costs by planning reach for nearshore nourishment.

Table 5-38: S-11 Unit Costs by Planning Reach

Reach	Mob/Demob Low	Mob/Demob High	Total First Unit Cost Low	Total First Unit Cost High	Equivalent Annual Cost (EAC)-Mob-Low	EAC-Mob-High	EAC/Linear foot (LF)-Low	EAC/LF-High
NC_01	$450,000	$450,000	$455	$2,329	$16,668	$16,668	$17	$86
NC_02	$450,000	$450,000	$455	$2,329	$16,668	$16,668	$17	$86
SC_03	$450,000	$450,000	$455	$2,329	$16,668	$16,668	$17	$86
SC_04	$450,000	$450,000	$455	$2,329	$16,668	$16,668	$17	$86
GA_05	$450,000	$450,000	$455	$2,329	$16,668	$16,668	$17	$86
FL_06	$450,000	$450,000	$455	$2,329	$16,668	$16,668	$17	$86
FL_07	$450,000	$450,000	$113	$334	$16,668	$16,668	$4	$12
FL_08	$450,000	$450,000	$113	$334	$16,668	$16,668	$4	$12
FL_09	$450,000	$450,000	$113	$334	$16,668	$16,668	$4	$12
FL_10	$450,000	$450,000	$455	$2,329	$16,668	$16,668	$17	$86
FL_11	$450,000	$450,000	$455	$2,329	$16,668	$16,668	$17	$86
FL_12	$450,000	$450,000	$455	$2,329	$16,668	$16,668	$17	$86
FL_13	$450,000	$450,000	$455	$2,329	$16,668	$16,668	$17	$86
AL_14	$450,000	$450,000	$455	$2,329	$16,668	$16,668	$17	$86
MS_15	$450,000	$450,000	$455	$2,329	$16,668	$16,668	$17	$86
PR_1	$450,000	$450,000	$113	$334	$16,668	$16,668	$4	$12
PR_2	$450,000	$450,000	$113	$334	$16,668	$16,668	$4	$12
PR_3	$450,000	$450,000	$113	$334	$16,668	$16,668	$4	$12
PR_4	$450,000	$450,000	$113	$334	$16,668	$16,668	$4	$12
VI_1	$450,000	$450,000	$113	$334	$16,668	$16,668	$4	$12
VI_2	$450,000	$450,000	$113	$334	$16,668	$16,668	$4	$12
VI_3	$450,000	$450,000	$113	$334	$16,668	$16,668	$4	$12

5.11.6 S-11 Assumptions, Sources, Limitations, and Uncertainties

This measure has not traditionally been designed or used as a coastal storm risk management measure. The engineering behavior and physical characteristics of dredge material vary with grain distribution, organic matter content, mineralogy, and bulk density. This along with the deposition thickness, which is a function of hydraulic sorting processes, including the distance from the discharge location, duration of discharge, quantity of sediment placement and bathymetry will influence the measure’s applicability, design, and cost.

This estimate assumes that the placement would be similar to onshore placement, but completely subaqueous. Nearshore placement could be in shallow water, so bottom dumping is not included in the estimate, only pump off. Therefore, no onshore equipment would be included. A reach length of 3000 linear feet was used and dredge equipment assumed a small (24-inch or less) cutterhead pipeline dredge.

The costs for this measure are parametric unit prices and calculated based upon historical bid date from a variety of coastal dredging projects from Mobile District, with all cost data normalized and escalated to FY20 levels. The projects selected were a variety of IDIQ MATOCS that were averaged and weighted to give more recent examples more emphasis.

As with all estimates including dredged material, the key cost drivers are distance to mobilize and distance to move the sediment. Small changes in haul distance can have great impact on the unit and total cost of a placement project. All real estate considerations are excluded from the MCL estimates.

5.12 S-12: Road Elevation

Road elevation involves raising roads in place so that the road sees a reduction in frequency and/or depth of flooding during high water events. Selection of proper elevation method depends on flood characteristics, such as flood depth or velocity.

5.12.1 S-12 Measure Description

Roads that are prone to flooding may need to be floodproofed to reduce the vulnerability. Available options to manage the negative impacts of flooding are maintenance and the potential for elevating roads.

5.12.2 S-12 Measure Performance and Applicability

Road elevation manages risk by retrofitting exposed infrastructure to be more resilient to coastal storm impacts. The measure can also impede the movement of floodwater within the flood plain and is therefore considered structural. Its primary risk management function is to manage inundation impacts, and is suitable for low, mixed, and high wave energy environments. Elevated roads can include bridges but for the purposes of this measure discussion, they are assumed to be elevated by additional earthen fill. If elevated roads similar to a bridge is considered a possible measure, it would need to be analyzed separately and costed separately since these costs would not apply. An example of a road elevation plan for Miami Beach is shown in **Figure 5-24**.

5.12.3 S-12 Coastal Storm Risk Management Effects and Adaptability

5.12.3.1 S-12 Physical and Temporal Effects

Upon construction, the road elevation reduces wave and inundation harm to critical infrastructure and evacuation routes in the exposed area. In addition to reducing harm to the road, the elevated road can also act as an impedance to floodwater movement in the exposed area. Measure risk management effects occur as soon as the measure is implemented.

5.12.3.2 S-12 National Economic Development, Regional Economic Development, Other Social Effect, and Environmental Quality Effects

Table 5-39 shows the potential benefits and costs for each of the four national accounts.

Table 5-39: S-12 National Economic Development, Regional Economic Development, Other Social Effects, and Environmental Quality Effects

Account	Potential Benefits	Potential Costs
NED	• Manage risk to property and critical infrastructure	• Measure total investment cost • O&M cost
RED	• Manage risk to regional revenue and employment in event of commercial property damage • Direct, indirect and induced effects of measure construction expenditure	• Revenue losses or employment disruptions as a result of the measure
OSE	• Manage risk to urban and community socioeconomic conditions • Emergency preparedness	–
EQ	• Manage risks to any cultural resource buildings in its lee	• Possibility for adverse environmental impacts

5.12.3.3 Sea Level Change Adaptability

Road elevations are potentially adaptable through additional increases in elevation. If sea levels reach a critical threshold in the future, bridge structures may at some point become the preferred measure if the height of elevating the road becomes unreasonable because of location or cost.

5.12.4 S-12 Design and Cost Components

5.12.4.1 S-12 Generic Design

The design was based elevating a 100- to 5,280-foot section of standard two-lane single-direction highway with a 1-foot lift along an existing earthen embankment.

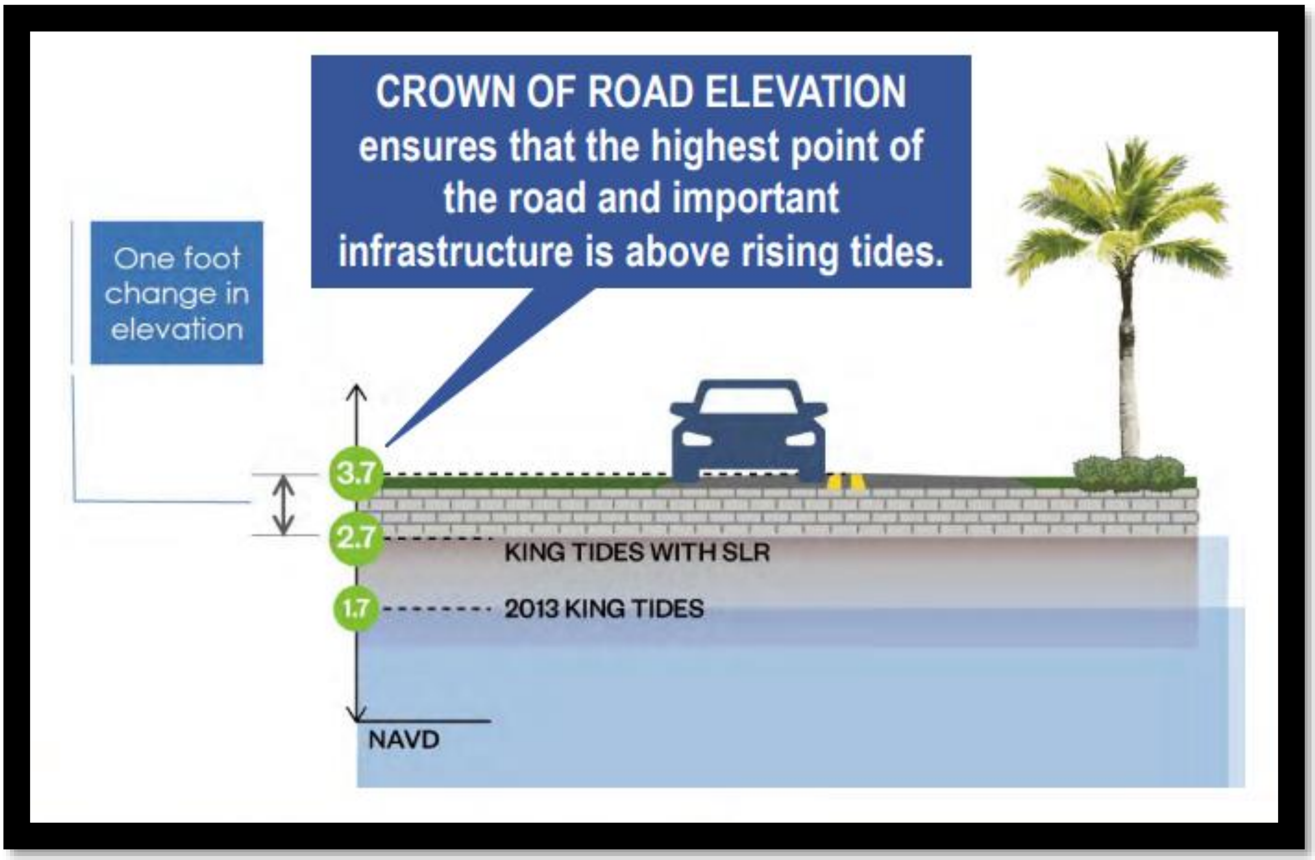

Figure 5-24: Example of Road Elevation Strategy for Miami Beach, Florida (Jacobs 2020)

5.12.4.2 S-12 Cost Components

Cost drivers associated with this measure can relate to the existing condition of the roadway, the amount of traffic, possibility of being a hurricane evacuation route, adjacent or underground utilities, and the type of structures nearby that are subject to flooding. When analyzing the options for implementing roadway elevation, risk management could be achieved by impeding the flow of floodwater and/or the provision of continuous transit during flood events. If maintaining road access is the main goal, other options such as bridge structures may eventually become the preferred measure.

Table 5-40 reflects what would be considered a contract cost prior to applying any additional markups, or owner markups. These additional costs include contingency at 20 percent for the low end and 40 percent for the high end, E&D and S&A are estimated at 15 percent and 12 percent, respectively, for both the high and low ends of the range presented. M&AM costs are estimated at 3 percent for the low end and 4 percent for the high end. The full or total owner cost are reflected as unit prices in **Table 5-41**. To analyze the cost components individually, the user may apply each additional owner markup in the order discussed above in a compounded process. Section 4.2.6.1 contains details regarding cost computations.

Table 5-40: S-12 Cost Components

State / Territory / Planning Reach	Feature Category	Feature	Feature Unit	Quantity Low	Quantity High	Unit Cost Low	Unit Cost High
S12_1 (All)	Unit	Length of Roadway	Linear foot (LF)	100	5280	–	–
	Measure Cost	Mob/Demob	Lump sum	1	1	$10,000	$150,000
	Measure Cost	Structural Fill	$/Cubic yard CY)	200	10560	$5.00	$18.00
	Measure Cost	Resurfacing	$/LF	100	5280	$3,200	$4,900
	Measure Cost	Cast in Place Jersey Barrier	$/LF	100	5280	$1,800	$3,000

5.12.5 S-12 Unit Cost Ranges by Planning Reach

Table 5-41 provides unit costs by planning reach for road elevations.

Table 5-41: S-12 Unit Cost Ranges by Planning Reach

Reach	Mob/Demob Low	Mob/Demob High	Total First Unit Cost Low	Total First Unit Cost High	Equivalent Annual Cost (EAC)-Mob-Low	EAC-Mob-High	EAC/Linear Foot (LF)-Low	EAC/LF-High
NC_01	$10,000	$150,000	$7,565	$13,909	$370	$5,556	$280	$515
NC_02	$10,000	$150,000	$7,565	$13,909	$370	$5,556	$280	$515
SC_03	$10,000	$150,000	$7,565	$13,909	$370	$5,556	$280	$515
SC_04	$10,000	$150,000	$7,565	$13,909	$370	$5,556	$280	$515
GA_05	$10,000	$150,000	$7,565	$13,909	$370	$5,556	$280	$515
FL_06	$10,000	$150,000	$7,565	$13,909	$370	$5,556	$280	$515
FL_07	$10,000	$150,000	$7,565	$13,909	$370	$5,556	$280	$515
FL_08	$10,000	$150,000	$7,565	$13,909	$370	$5,556	$280	$515
FL_09	$10,000	$150,000	$7,565	$13,909	$370	$5,556	$280	$515
FL_10	$10,000	$150,000	$7,565	$13,909	$370	$5,556	$280	$515
FL_11	$10,000	$150,000	$7,565	$13,909	$370	$5,556	$280	$515
FL_12	$10,000	$150,000	$7,565	$13,909	$370	$5,556	$280	$515
FL_13	$10,000	$150,000	$7,565	$13,909	$370	$5,556	$280	$515
AL_14	$10,000	$150,000	$7,565	$13,909	$370	$5,556	$280	$515
MS_15	$10,000	$150,000	$7,565	$13,909	$370	$5,556	$280	$515
PR_1	$10,000	$150,000	$7,565	$13,909	$370	$5,556	$280	$515
PR_2	$10,000	$150,000	$7,565	$13,909	$370	$5,556	$280	$515
PR_3	$10,000	$150,000	$7,565	$13,909	$370	$5,556	$280	$515
PR_4	$10,000	$150,000	$7,565	$13,909	$370	$5,556	$280	$515
VI_1	$10,000	$150,000	$7,565	$13,909	$370	$5,556	$280	$515
VI_2	$10,000	$150,000	$7,565	$13,909	$370	$5,556	$280	$515
VI_3	$10,000	$150,000	$7,565	$13,909	$370	$5,556	$280	$515

5.12.6 S-12 Assumptions, Sources, Limitations, and Uncertainties

The costs for this measure are based on the Port Monmouth Project for New York District. A portion of this project included road elevation and resurfacing, earth fill, tree removal jersey barriers, and a range of utility work. For this measure, road resurfacing and elevating were considered along with cast in place jersey barriers. The prices referenced were at FY20 price levels. The cost assumes 1 foot of elevating on a two-way traffic road or 1 foot of elevating on a double-lane single-direction roadway. The costs are presented in cost per linear foot of roadway.

5.13 S-13: Ringwalls

5.13.1 S-13 Measure Description

Ringwalls, small floodwalls, berms, or ring levees are located away from the structure to be protected and prevent the encroachment of floodwaters. They may surround the structure or protect only the low side of the property. A ringwall is considered nonstructural because it is intended to be used to protect a single structure from flooding, and not intended to influence the occurrence or magnitude of flooding in the floodplain, which is what structural measures do. These relatively small structures are distinguished from large public investments by their scale and location on privately owned land. Unlike some other floodproofing measures, a well-designed and constructed freestanding floodwall or berm results in no floodwater forces on the structure itself. Consequently, if the floodwall or berm is not overtopped or otherwise failed, the structure is not exposed to damaging hydrostatic or hydrodynamic forces. With these kinds of measures, there is no need to make structural alterations to the building or structure to be protected. These measures require installation of a sump pump or other feature to drain seepage water flowing through or under the berm or floodwall, and rainwater falling inside the berm or floodwall.

5.13.2 S-13: Measure Performance and Applicability

Ringwalls are a form of armoring designed to reduce the damage from storm surge inundation. The primary risk management function is to reduce flooding. Ringwalls are typically applicable in low wave energy environments. They are usually considered in much smaller scale than other similar measures previously discussed and their placement is usually around individual facilities, including critical infrastructure.

5.13.3 S-13 Measure Effects and Adaptability

5.13.3.1 S-13 Physical and Temporal Effects

The principal function of a ringwall is to reduce the risk of flooding to the structure in its lee. Properly designed and constructed ringwalls can reduce inundation associated with short-term loadings from small waves along with wind/tide high water stages. Wave overtopping can occur resulting in severe scour at or near the protected side of the stem. Ringwalls provide immediate inundation risk management to the exposed area in its lee. These structures provide barriers against inundation to individual facilities such as apartments, commercial, industrial, and public structures. In some cases, ringwalls may deflect floodborne debris.

5.13.3.2 S-13 National Economic Development, Regional Economic Development, Other Social Effects, and Environmental Quality Effects

Table 5-42 shows the potential benefits and costs for each of the four national accounts.

Table 5-42: S-13 National Economic Development, Regional Economic Development, Other Social Effects, and Environmental Quality Effects

Account	Potential Benefits	Potential Costs
NED	• Manages risk to property and infrastructure	• Ringwall construction cost • Measure deployment costs
RED	• Manages risk to regional output and employment by reducing damage to commercial assets • Direct, indirect, and induced effects from the measure.	–
OSE	• Risk management of urban and community effects	–
EQ	• Manage risks to cultural resources buildings by making them more resilient to inundation harm	–

5.13.3.3 S-13 Sea Level Change Adaptability

Ringwalls are potentially adaptable to sea level change by adjusting the height of the wall.

5.13.4 S-13 Generic Design and Information Sources

Costs for this measure were based upon information developed in the North Atlantic Comprehensive Coastal Study. The prices were updated to bring them to the FY20 price levels.

5.13.4.1 S-13 Design and Cost Components

Cost drivers for this measure can vary depending on the location, climate, and anticipated water levels expected from flooding. The cost can also vary depending on the types of protected structures (commercial or residential) and any architectural features included to allow the measure to match the surrounding buildings or to better blend into the topography.

Table 5-43 reflects what would be considered a contract cost prior to applying any additional markups, or owner markups. These additional costs include contingency at 20 percent for the low end and 40 percent for the high end. M&AM costs are estimated at 3 percent for the low end and 4 percent for the high end. The full or total owner cost are reflected as unit prices in the Unit Cost by Planning Reach table. If the user prefers to analyze the cost components individually, it is recommended that they considering apply each additional owner markup in the order discussed above in a compounded process. Section 3.0 contains details regarding cost computations.

Table 5-43: S-13 Cost Components

State / Territory / Planning Reach	Feature Category	Feature	Feature Unit	Quantity Low	Quantity High	Unit Cost Low	Unit Cost High
S-13_1: All	Unit	Ringwall Length/ Perimeter of Protection	Linear foot (LF)	2000	2000	–	–
	Measure Cost	Mob/Demob	Lump sum	1	1	$10,000	$150,000
	Measure Cost	Floodproof	$/LF	2000	2000	$1,550	$1,550
	Measure Cost	Roller gates	$/Each	3	3	$113,000	$113,000

5.13.5 S-13 Unit Cost Ranges by Planning Reach

Table 5-44 provides unit costs by planning reach for ringwalls.

Table 5-44: S-13 Unit Cost Ranges by Planning Reach

Reach	Mob/Demob Low	Mob/Demob High	Total First Unit Cost Low	Total First Unit Cost High	Equivalent Annual Cost (EAC)-Mob-Low	EAC-Mob-High	EAC/Linear Foot (LF)-Low	EAC/LF-High
NC_01	$10,000	$150,000	$2,064	$2,437	$370	$5,556	$76	$90
NC_02	$10,000	$150,000	$2,064	$2,437	$370	$5,556	$76	$90
SC_03	$10,000	$150,000	$2,064	$2,437	$370	$5,556	$76	$90
SC_04	$10,000	$150,000	$2,064	$2,437	$370	$5,556	$76	$90
GA_05	$10,000	$150,000	$2,064	$2,437	$370	$5,556	$76	$90
FL_06	$10,000	$150,000	$2,064	$2,437	$370	$5,556	$76	$90
FL_07	$10,000	$150,000	$2,064	$2,437	$370	$5,556	$76	$90
FL_08	$10,000	$150,000	$2,064	$2,437	$370	$5,556	$76	$90
FL_09	$10,000	$150,000	$2,064	$2,437	$370	$5,556	$76	$90
FL_10	$10,000	$150,000	$2,064	$2,437	$370	$5,556	$76	$90
FL_11	$10,000	$150,000	$2,064	$2,437	$370	$5,556	$76	$90
FL_12	$10,000	$150,000	$2,064	$2,437	$370	$5,556	$76	$90
FL_13	$10,000	$150,000	$2,064	$2,437	$370	$5,556	$76	$90
AL_14	$10,000	$150,000	$2,064	$2,437	$370	$5,556	$76	$90
MS_15	$10,000	$150,000	$2,064	$2,437	$370	$5,556	$76	$90
PR_1	$10,000	$150,000	$2,064	$2,437	$370	$5,556	$76	$90
PR_2	$10,000	$150,000	$2,064	$2,437	$370	$5,556	$76	$90
PR_3	$10,000	$150,000	$2,064	$2,437	$370	$5,556	$76	$90
PR_4	$10,000	$150,000	$2,064	$2,437	$370	$5,556	$76	$90
VI_1	$10,000	$150,000	$2,064	$2,437	$370	$5,556	$76	$90
VI_2	$10,000	$150,000	$2,064	$2,437	$370	$5,556	$76	$90
VI_3	$10,000	$150,000	$2,064	$2,437	$370	$5,556	$76	$90

5.13.6 S-13 Assumptions, Limitations and Uncertainties

No universal type of ringwall can be prescribed because of the wide variations in locations and structures which they will surround. Foundation conditions, wave exposure, availability of materials, real estate availability, as well as structural and functional performance criteria will influence the applicability and type of ringwall, its height, and cost.

SECTION 6

Natural and Nature-Based Features

6.1 NNBF-1: Barrier Island Restoration

6.1.1 NNBF-1 Measure Description

Barrier islands are detached offshore islands that are located between two inlets. Restoration of these landscape features typically includes the placement of large quantities of beach quality sandy material to either replace eroded island shorelines, replace breach areas, or increase the size (width and/or height) of an existing island. Typical restoration includes the entire barrier island such as the beach, dune system, and back bay platforms, but can also include incorporation of smaller dunes, herbaceous woody areas, beaches, tidal flats, and wetlands.

Figure 6-1: Ship Island Restoration

6.1.2 NNBF-1 Measure Performance and Applicability

Barrier Islands manage risk by maintaining a minimum distance between the hazard and the exposed area. Primary and secondary risk management functions include reducing erosion and wave impacts respectively. It is well documented that barrier islands are a first line of defense in reducing damage to wetlands and communities located in their lee during coastal storms (Knotts et al. 2006; USACE 2009). Offshore barrier islands act as a natural breakwater providing shelter in their lee from coastal storms. Their effectiveness, however, has been documented to depend not only on the specific characteristics of the storm (Grzegorzewski A. S. et al. 2009), but also on the island elevation, length, width, land cover, breach susceptibility, as well as proximity to the mainland shore.

Barrier islands are appropriate for use in mixed to high wave energy environments. Although very effective in reducing storm damage to the areas they are designed to manage risk to, barrier island restoration projects are typically applicable only where there is an existing barrier island with a natural source of sand to help sustain the island.

6.1.3 NNBF-1 Coastal Storm Risk Management Effects and Adaptability

6.1.3.1 NNBF-1 Physical and Temporal Effects

Upon construction, immediate risk management effects should be realized to the property and infrastructure in its lee. Barrier island restoration can have a lengthy construction timeline but benefits will be received throughout the construction process as the island elevation, length, width, and land cover increase leading to a reduction in storm surge inundation and wave energy in their lee and resulting in decreasing erosion.

6.1.3.2 NNBF-1 National Economic Development, Regional Economic Development, Other Social Effects, and Environmental Quality Effects

Barrier islands are known to support complex dunes and dune ridges, freshwater lakes, maritime forest, wetlands, seagrasses as well as help regulate salinity levels in the back bay and sound areas. Coastal storm risk management benefits include wave attenuation and/or dissipation and sediment stabilization. Other socioeconomic and environmental benefits include improved water quality, providing storage and filtration of water through the sand, supporting diverse flora and fauna, ecosystem diversification, aesthetic landscapes, tourism, recreation and educational sites. **Table 6-1** shows the potential benefits and costs for each of the four national accounts.

Table 6-1: NNBF-1 National Economic Development, Regional Economic Development, Other Social Effects, and Environmental Quality Effects

Account	Potential Benefits	Potential Costs
NED	• Manage risk of property and critical infrastructure loss, vehicle damage, land loss, protective measure costs, emergency costs, and transportation delay costs • Incidental recreation	• Measure total investment cost • M&AM cost
RED	• Manage risk to regional revenue and employment in event of commercial property damage • Direct, indirect, and induced effects of measure construction expenditure	• Potential revenue losses or employment disruptions as a result of the measure
OSE	• Manage risk to urban and community socioeconomic conditions • Emergency preparedness • Potential educational, cultural, and recreational opportunities	–
EQ	• Manages risk to habitat and species as well as any cultural resource assets in its lee	• Possibility for adverse environmental impacts

6.1.3.3 Sea Level Change Adaptability

Barrier islands are potentially adaptable to sea level change by changing elevation and width. After a storm impact, a restored barrier island should experience some natural recovery aiding in the adaptability of the measure.

6.1.4 NNBF-1 Design and Cost Components

6.1.4.1 NNBF-1 Generic Design

For the purposed of the MCL, the barrier island design assumed a 250-acre island platform restoration consisting of beach, dune, and back barrier shoreline restoration with a fill density of 20,800 cubic yards per acre based on an averages obtained from recent barrier island restoration efforts within SAD, namely Ship Island and Cat Island.

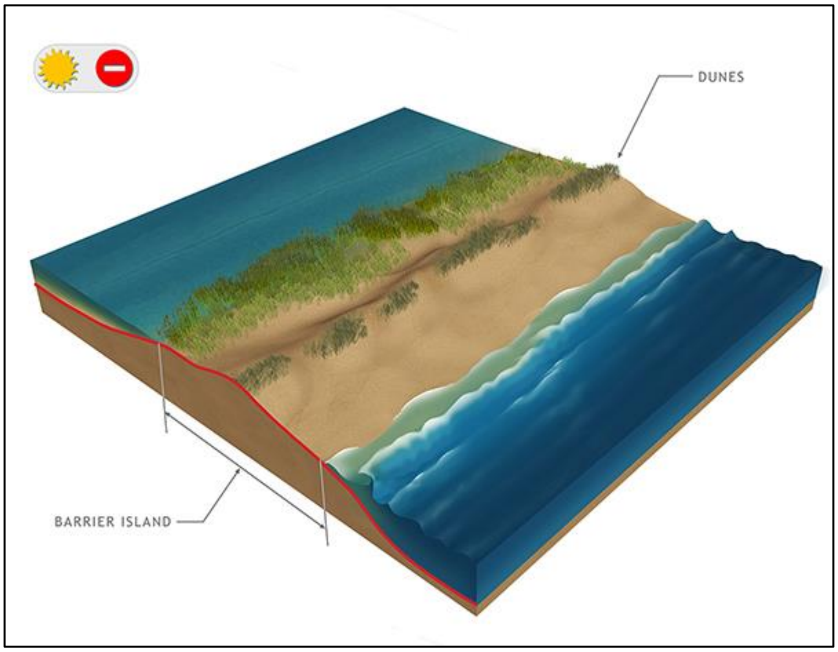

Figure 6-2: Conceptual Barrier Island Restoration Layout (USACE 2015a)

6.1.4.2 NNBF-1 Cost Components

The costs for this measure are parametric unit prices and calculated based upon historical bid data from a variety of projects from Mobile District performed for the Mississippi Coastal Improvements Program and from a variety of Jacksonville District dredging projects. All costs were escalated to FY20 levels. The wide variation between high and low costs presented in

Table 6-2 is intentional and it reflects that a relatively small difference in haul distance can cause significant changes to the cost of construction. Projects used in developing these costs include, but are not limited to:

SAM – Cat Island Beach and Dune Fill
SAM – Ship Island Restoration Phase 1
SAM – Ship Island Restoration Phase 2
SAM – Ship Island Restoration Phases 3 and 4

Table 6-2 reflects what would be considered a contract cost prior to applying any additional markups, or owner markups. These additional costs include contingency at 20 percent for the low end and 40 percent for the high end, E&D and S&A are estimated at 15 percent and 12 percent, respectively, for both the high and low ends of the range presented. M&AM costs are estimated at 3 percent for the low end and 4 percent for the high end. The full or total owner cost are reflected as unit prices in **Table 6-3**. To analyze the cost components individually, the user may apply each additional owner markup in the order discussed above in a compounded process. Section 4.2.6.3 contains details regarding cost computations.

Table 6-2: NNBF-1 Cost Components

State / Territory / Planning Reach	Feature Category	Feature	Feature Unit	Quantity Low	Quantity High	Unit Cost Low	Unit Cost High
NNBF1_1: (All)	Unit	Barrier Island Size	Acre (AC)	250	250	–	–
	Construction Unit	Restoration Density	Cubic yard (CY)/Acre (AC)	20800	20800	–	–
	Measure Cost	Mob/Demob	Lump sum	1	1	$4,500,000	$10,400,000
	Measure Cost	Beach Nourishment	$/CY	5,200,000	5,200,000	$6.90	$30.00
	Measure Cost	Planting	$/AC	250	250	$4,100	$4,100
	Measure Cost	Tilling	$/AC	150	150	$750	$750

6.1.5 NNBF-1 Unit Cost Range by Planning Reach

Barrier island restoration may be viable in all reaches within the SACS study area containing existing exposed and eroding barrier islands. **Table 6-3** provides unit costs by planning reach for barrier island restoration.

Table 6-3: NNBF-1 Unit Cost Ranges by Planning Reach

Reach	Mob/Demob Low	Mob/Demob High	Total First Unit Cost Low	Total First Unit Cost High	Equivalent Annual Cost (EAC)-Mob-Low	EAC-Mob-High	EAC/LF-Low	EAC/LF-High
NC_01	$4,500,000	$10,400,000	$231,105	$1,131,163	$166,684	$385,226	$8,560	$41,899
NC_02	$4,500,000	$10,400,000	$231,105	$1,131,163	$166,684	$385,226	$8,560	$41,899
SC_03	$4,500,000	$10,400,000	$231,105	$1,131,163	$166,684	$385,226	$8,560	$41,899
SC_04	$4,500,000	$10,400,000	$231,105	$1,131,163	$166,684	$385,226	$8,560	$41,899
GA_05	$4,500,000	$10,400,000	$231,105	$1,131,163	$166,684	$385,226	$8,560	$41,899
FL_06	$4,500,000	$10,400,000	$231,105	$1,131,163	$166,684	$385,226	$8,560	$41,899
FL_07	$4,500,000	$10,400,000	$231,105	$1,131,163	$166,684	$385,226	$8,560	$41,899
FL_08	$4,500,000	$10,400,000	$231,105	$1,131,163	$166,684	$385,226	$8,560	$41,899
FL_09	$4,500,000	$10,400,000	$231,105	$1,131,163	$166,684	$385,226	$8,560	$41,899
FL_10	$4,500,000	$10,400,000	$231,105	$1,131,163	$166,684	$385,226	$8,560	$41,899
FL_11	$4,500,000	$10,400,000	$231,105	$1,131,163	$166,684	$385,226	$8,560	$41,899
FL_12	$4,500,000	$10,400,000	$231,105	$1,131,163	$166,684	$385,226	$8,560	$41,899
FL_13	$4,500,000	$10,400,000	$231,105	$1,131,163	$166,684	$385,226	$8,560	$41,899
AL_14	$4,500,000	$10,400,000	$231,105	$1,131,163	$166,684	$385,226	$8,560	$41,899
MS_15	$4,500,000	$10,400,000	$231,105	$1,131,163	$166,684	$385,226	$8,560	$41,899
PR_1	$4,500,000	$10,400,000	$231,105	$1,131,163	$166,684	$385,226	$8,560	$41,899
PR_2	$4,500,000	$10,400,000	$231,105	$1,131,163	$166,684	$385,226	$8,560	$41,899
PR_3	$4,500,000	$10,400,000	$231,105	$1,131,163	$166,684	$385,226	$8,560	$41,899
PR_4	$4,500,000	$10,400,000	$231,105	$1,131,163	$166,684	$385,226	$8,560	$41,899
VI_1	$4,500,000	$10,400,000	$231,105	$1,131,163	$166,684	$385,226	$8,560	$41,899
VI_2	$4,500,000	$10,400,000	$231,105	$1,131,163	$166,684	$385,226	$8,560	$41,899
VI_3	$4,500,000	$10,400,000	$231,105	$1,131,163	$166,684	$385,226	$8,560	$41,899

6.1.6 NNBF-1 Assumptions, Sources, Limitations, and Uncertainties

For estimating restoration of a barrier island, placing beach sand, beach tilling, and planting of native species is included. Potential additional items, namely turtle trawling and turbidity curtains, are not included. The assumed size was 250 acres for barrier island restoration based on the average of some recent barrier island restoration efforts within SAD, namely Ship Island and Cat Island. Note that the estimate includes only one mobilization and demobilization. If barrier island restoration is broken into phases or multiple contracts, additional mobilizations would be required. The low end of the cost range assumes a cutterhead dredge piping material directly to the shore over a relatively short distance. The high end of the cost range is representative of the cost of a large hopper dredge hauling the material a longer distance. Because of the relatively small cost of the planting and beach tilling, ranges were not used for those costs.

Design of a barrier island restoration will depend primarily on the existing condition. For the purposes of estimating this measure, a fill of 20,800 cubic yards per acre was used based on an average of recent barrier island restoration efforts within SACS. Dune planting with native vegetation and tilling portions of the newly created profile are included. Planting costs are included as a percentage of the entire placement.

The amount of material required for a barrier island restoration will vary widely depending on the size of the barrier island and the design fill template. As with all estimates including dredged material, the key cost drivers are distance to mobilize and distance to move the sediment. Long-term maintenance cost will be driven by storm climatology and sea level changes. For cost purposes assumptions have been made that compatible sources of sand would be available at reasonable haul distances to sustain a barrier island project.

6.2 NNBF-2: Tidal Flats

6.2.1 NNBF-2 Measure Description

Tidal flats and overwash fans are intertidal areas where sediment has been deposited by rivers, tides, storm surge, or waves. Tidal flats are located between the spring high and low tide levels, lack rooted vegetation, and span a range of composition from mud to sandy flats which are found in sheltered bays, estuaries and coasts that are protected by barrier islands (Schutte et al. 2019). Large coastal storms and their associated high winds, waves, and tides can result in overwash of the beach and dune system. During storm conditions, elevated storm tides and high waves may erode beaches and dunes, and the eroded sand can be carried landward by surging water. The sand and water may wash over or break through the dunes and spill out onto the landward side of peninsulas and barrier islands. This deposit is usually fan-shaped and therefore is known as an overwash (or washover) fan. Engineered overwash fans are implemented to increase overall barrier island stability and back bay coastal storm risk management capacity by increasing its width/volume and providing a substrate suitable for wetland growth. In addition, strategic unconfined placement of finer sediment within nearshore tidal flats to increase widths and heights and net sediment availability to marshes is growing in practice. Sediment could be mined from borrow sources 'outside' the sediment budget system such as offshore borrow sites similar to those used for beach restoration projects. Other sources may include beneficial use of dredged sediments from adjacent back bay and inlet channels.

Figure 6-3: Skidaway Island State Park (Photo Source: Marychild)

6.2.2 NNBF-2 Measure Performance and Applicability

Tidal flats manage risk by helping maintain a minimum distance between hazard and exposed area. They can also assist in moderating shoreline change rates. The depth and width of surrounding tidal flats have a pivoting control on marsh erosion (Mariotti and Fragherazzi 2013) and play an important role in the stability of mangroves and barrier islands. Tidal flats have the ability to attenuate waves at documented rates lower than vegetated foreshores (Vuik et al. 2016; Reed et al. 2018) and have a primary risk management and performance function in reducing coastal erosion. Secondary risk management function is that it can reduce wave attack impacts. This measure has been growing in popularity and application within regional sediment management practice. Tidal flats can be appropriate for low to mixed wave energy environments. Although tidal flats can be an applicable measure to reduce erosion, they are typically applicable only where there is an existing or historical tidal flat with a natural source of sediment to help sustain them.

6.2.3 NNBF-2 Coastal Storm Risk Management Effects and Adaptability

6.2.3.1 NNBF-2 Physical and Temporal Effects

Tidal flats provide immediate and intermediate risk management effects for environmental resources and property and infrastructure, respectively. The risk management effects are greatest when wetland growth has occurred on the tidal-flat substrate. The flat itself provides limited risk management effects upon initial construction, but these effects are anticipated to grow over time.

6.2.3.2 NNBF-2 National Economic Development, Regional Economic Development, Other Social Effects, and Environmental Quality Effects

The primary benefit of tidal flats and overwash fans is to increase net sediment availability and offset coastal erosion. Consequences of natural overwash processes may include loss of, or damage to, property, or loss of access to property, roads, and infrastructure as a result of flooding and sediment intrusion. If existing dunes are lowered by overwash, a peninsula or barrier island may be more susceptible to breaching and therefore lose some of its coastal storm risk management capacity (Donnelly, Kraus and Magnus 2004). Overwash fans are a component of the sediment budget of barrier islands (Pierce 1969) and are also believed to be a relevant process in the rollover or retreat mechanism of some coastal barriers in response to relative sea level change (Dillon 1970; Kraft et al. 1973) by increasing the island width and providing a new foundation for back bay wetland growth. However, new inlet and flood tidal delta formation are believed to be a larger contributor to barrier island migration (Leatherman 1976) along the Atlantic coast. Prevention of overwash and breaching may eliminate sand transport to the lagoon system and possibly preclude the ability of barrier islands to adapt to rising sea levels (Smith et al. 2008). Overtime, the lack of cross-barrier sediment transport may lead to a relatively narrow barrier island fronting relatively deep back bay water depths and, therefore, more susceptible to catastrophic breaching and back bay flooding. Allowing for natural overwash processes in developed barriers or barrier and back bay systems that are already very susceptible to breaching and flooding is risky and rarely feasible. A potential, albeit not yet commonly implemented, alternative is to construct overwash fans that mimic the beneficial effects of natural overwash without the damages typically associated with overwash. In addition, in areas experiencing wetland erosion placement of sediment in the nearshore, to construct tidal flats is becoming more prevalent as a means to increase sediment availability and reduce loss of wetlands. **Table 6-4** shows the potential benefits and costs for each of the four national accounts.

Table 6-4: NNBF-2 National Economic Development, Regional Economic Development, Other Social Effects, and Environmental Quality Effects

Account	Potential Benefits	Potential Costs
NED	• Manage risk of property and critical infrastructure loss; vehicle damage; land loss; protective measure costs; emergency costs; transportation delay costs; incidental recreation in the intermediate term	• Measure total investment cost, M&AM cost
RED	• Manage risk to regional revenue and employment in event of commercial property damage with time/ direct, indirect and induced effects of measure construction expenditure	• Potential revenue losses or employment disruptions as a result of the measure
OSE	• Manage risk to urban and community socioeconomic conditions • Emergency preparedness	–
EQ	• Manages risk to habitat and species	• Possibility for adverse environmental impacts

6.2.3.3 NNBF-2 Sea Level Change Adaptability

Potentially adaptable to sea level change by changing the elevation and width of the tidal flat. The flat should naturally recover some post storm and becomes more resilient once wetland growth has become established.

6.2.4 NNBF-2 Design and Cost Components

6.2.4.1 NNBF-2 Generic Design

For the purposes of the MCL, the tidal-flat design consists of a 2,000-foot-long by 200-foot-wide fill placement area. To account for tidal variation, a total average fill height of 5 feet was used for the Gulf Coast reaches and 9 feet was used along the Atlantic Coast.

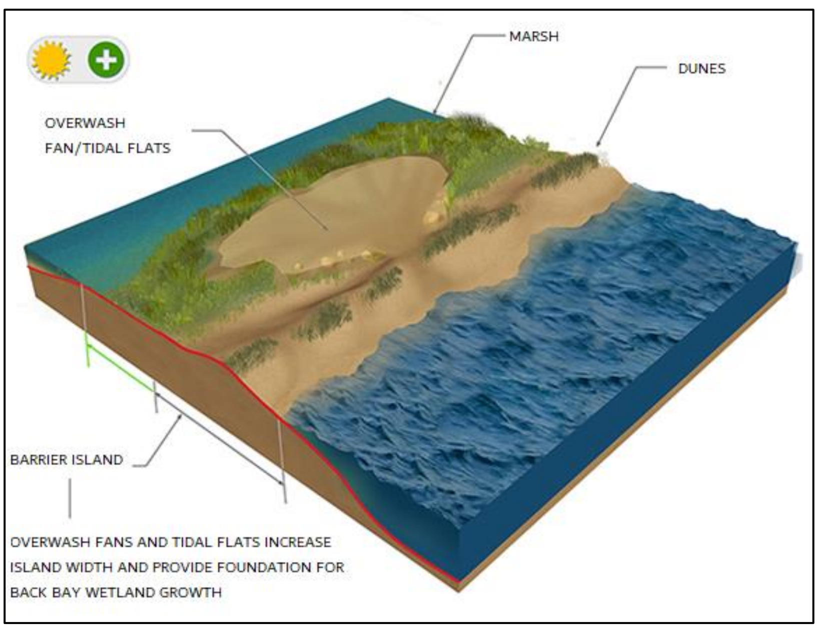

Figure 6-4: Conceptual Overwash/Tidal-Flat Layout (USACE 2015a)

6.2.4.2 NNBF-2 Design and Cost Components

The components of the unit cost for placement include mobilization of the dredge equipment, a unit cost for moving material, and markups for contingency, E&D, and S&A.

The costs for this measure are parametric unit prices and calculated based upon historical bid data from a variety of coastal dredging projects from Mobile District, with all cost data normalized and escalated to FY20 levels. The projects selected were a variety of IDIQ MATOCS that were averaged and weighted to give more recent examples more emphasis.

Table 6-5 reflects what would be considered a contract cost prior to applying any additional markups, or owner markups. These additional costs include contingency at 20 percent for the low end and 40 percent for the high end, E&D and S&A are estimated at 15 percent and 12 percent, respectively, for both the high and low ends of the range presented. M&AM costs are estimated at 3 percent for the low end and 4 percent for the high end. The full or total owner cost are reflected as unit prices in **Table 6-6**. If the user prefers to analyze the cost components individually it is recommended that they considering apply each additional owner markup in the order discussed above in a compounded process. Section 4.2.6.3 contains details regarding cost computations.

Table 6-5: NNBF-2 Cost Components

<table>
<tr><th>State / Territory / Planning Reach</th><th>Feature Category</th><th>Feature</th><th>Feature Unit</th><th>Quantity Low</th><th>Quantity High</th><th>Unit Cost Low</th><th>Unit Cost High</th></tr>
<tr><td rowspan="5">NNBF2_1: (NC, SC, GA, FL_06, FL_07, FL_08, FL_09, PR, VI)</td><td>Construction Unit</td><td>Placement Length</td><td>Linear foot (LF)</td><td>2000</td><td>2000</td><td>–</td><td>–</td></tr>
<tr><td>Construction Unit</td><td>Placement Depth</td><td>LF</td><td>9</td><td>9</td><td>–</td><td>–</td></tr>
<tr><td>Unit</td><td>Tidal-Flat Area</td><td>Square foot (SF)</td><td>18000</td><td>18000</td><td>–</td><td>–</td></tr>
<tr><td>Measure Cost</td><td>Mob/Demob</td><td>Lump sum (LS)</td><td>1</td><td>1</td><td>$400,000</td><td>$500,000</td></tr>
<tr><td>Measure Cost</td><td>Placement</td><td>$/Cubic yards (CY)</td><td>133,333</td><td>133,333</td><td>$7.60</td><td>$16.49</td></tr>
<tr><td rowspan="5">NNBF2_2: (FL_10, FL_11, FL_12, FL_13, AL_14, MS_15)</td><td>Construction Unit</td><td>Placement Length</td><td>LF</td><td>2000</td><td>2000</td><td>–</td><td>–</td></tr>
<tr><td>Construction Unit</td><td>Placement Depth</td><td>LF</td><td>5</td><td>5</td><td>–</td><td>–</td></tr>
<tr><td>Unit</td><td>Tidal-Flat Area</td><td>SF</td><td>18000</td><td>18000</td><td>–</td><td>–</td></tr>
<tr><td>Measure Cost</td><td>Mob/Demob</td><td>LS</td><td>1</td><td>1</td><td>$400,000</td><td>$500,000</td></tr>
<tr><td>Measure Cost</td><td>Placement</td><td>$/CY</td><td>74074</td><td>74074</td><td>$7.60</td><td>$16.49</td></tr>
</table>

6.2.5 NNBF-2 Unit Cost Range by Planning Reach

Tidal flats may be viable in all reaches within the SACS study area in more sheltered back bay systems. **Table 6-6** provides unit costs by planning reach for tidal flats.

Table 6-6: NNBF-2 Unit Cost Ranges by Planning Reach

Reach	Mob/ Demob Low	Mob/ Demob High	Total First Unit Cost Low	Total First Unit Cost High	Equivalent Annual Cost (EAC)-Mob-Low	EAC-Mob-High	EAC/Linear Foot (LF)-Low	EAC/LF-High
NC_01	$400,000	$500,000	$96	$235	$14,816	$18,520	$3.54	$8.69
NC_02	$400,000	$500,000	$96	$235	$14,816	$18,520	$3.54	$8.69
SC_03	$400,000	$500,000	$96	$235	$14,816	$18,520	$3.54	$8.69
SC_04	$400,000	$500,000	$96	$235	$14,816	$18,520	$3.54	$8.69
GA_05	$400,000	$500,000	$96	$235	$14,816	$18,520	$3.54	$8.69
FL_06	$400,000	$500,000	$96	$235	$14,816	$18,520	$3.54	$8.69
FL_07	$400,000	$500,000	$96	$235	$14,816	$18,520	$3.54	$8.69
FL_08	$400,000	$500,000	$96	$235	$14,816	$18,520	$3.54	$8.69
FL_09	$400,000	$500,000	$96	$235	$14,816	$18,520	$3.54	$8.69
FL_10	$400,000	$500,000	$58	$140	$14,816	$18,520	$2.15	$5.17
FL_11	$400,000	$500,000	$58	$140	$14,816	$18,520	$2.15	$5.17
FL_12	$400,000	$500,000	$58	$140	$14,816	$18,520	$2.15	$5.17
FL_13	$400,000	$500,000	$58	$140	$14,816	$18,520	$2.15	$5.17
AL_14	$400,000	$500,000	$58	$140	$14,816	$18,520	$2.15	$5.17
MS_15	$400,000	$500,000	$58	$140	$14,816	$18,520	$2.15	$5.17
PR_1	$400,000	$500,000	$96	$235	$14,816	$18,520	$3.54	$8.69
PR_2	$400,000	$500,000	$96	$235	$14,816	$18,520	$3.54	$8.69
PR_3	$400,000	$500,000	$96	$235	$14,816	$18,520	$3.54	$8.69
PR_4	$400,000	$500,000	$96	$235	$14,816	$18,520	$3.54	$8.69
VI_1	$400,000	$500,000	$96	$235	$14,816	$18,520	$3.54	$8.69
VI_2	$400,000	$500,000	$96	$235	$14,816	$18,520	$3.54	$8.69
VI_3	$400,000	$500,000	$96	$235	$14,816	$18,520	$3.54	$8.69

6.2.6 NNBF-2 Assumptions, Sources, Limitations, and Uncertainties

To calculate the volume, a rectangular prism, highly unlikely to be encountered in the field, was used.

Because of the relatively high mobilization costs for dredge plant, the use of tidal flats will probably be limited to combinations or as a beneficial use of dredged material.

As with all estimates including dredged material, the key cost drivers will be distance to mobilize and distance to move the sediment. Because of nearshore shallow placement, this estimate assumes the use of a 20- to 24-inch cutterhead pipeline dredge. Use of a different sized dredge will certainly affect the unit costs. The actual shape and size of the tidal flat needed will vary from the quantities used in this estimate.

The level of risk management associated with engineered tidal flats or overwash features could vary significantly depending on the size and specific site conditions. For example, a large overwash fan behind an existing low, narrow, barrier island could significantly reduce the likelihood of a breach and therefore the risk of back bay flooding during extreme events (up to a 1-percent AEP flood). However, generally back bay flooding is mostly a function of the storm tide penetrating through existing inlets, particularly for the more frequent, smaller, coastal flood events. Combined with reasonable limitations in the size and elevation, this means that in most cases tidal flats and overwash fans will have relatively low risk management capacity. Nonetheless, over the long term, engineered tidal flats and overwash fans may be essential to the overall resiliency of marshes and barrier islands, particularly those with altered sediment availability, high levels of development, and limited opportunity for natural barrier island rollover and marsh migration processes.

6.3 NBF-3: Wetland Restoration

6.3.1 NNBF-3 Measure Description

Figure 6-5: Bayou Caddy Wetland Restoration

Wetlands, also referred to as tidal fringe, tidal-flat or estuarine wetlands, and as brackish or saltwater marsh, occur along the intertidal zone of marine, estuarine, or riverine systems. Specifically, these wetlands occur along the fringe of drowned river valleys, barrier islands, lagoons, and other coastal waterways. The wetlands receive their water primarily from marine or estuarine sources, and are affected by astronomical tidal action (Shafer et al. 2002). Although this definition includes a broad group of wetlands commonly known as intertidal marshes, salt marshes, forested riverine swamps, and mangrove swamps and correspond to the emergent, scrub-shrub, and forested wetland class designations used by (Cowardin 1979), in the MCL it is more narrowly defined as intertidal and salt marsh.

6.3.2 NNBF-3 Measure Performance and Applicability

Wetland restoration manages risk by establishing a minimum distance between the CSRM hazard and the exposed area. Primary and secondary risk management functions include reducing erosion and wave attack impacts. Coastal wetlands may contribute to CSRM through wave attenuation and sediment stabilization. The dense vegetation and shallow waters within wetlands can slow the advance of storm surge somewhat and slightly reduce the surge landward of the wetland or slow its arrival time (Wamsley et al. 2010). Wetlands can also dissipate wave energy, potentially reducing the amount of destructive wave energy. However, evidence suggests that slow-moving storms and those with long periods of high winds that produce marsh flooding can reduce this benefit (Resio and Westerink 2008). The magnitude of these effects depends on the specific characteristics of the wetlands, including the type of vegetation, its rigidity and structure, as well as the extent of the wetlands and their position relative to the storm track.

Functionally, restored wetlands act in the same manner as natural wetlands, though design features may be included to enhance risk management or account for adaptive capacity considering future conditions (e.g., by allowing for migration due to changing sea levels).

6.3.3 NNBF-3 Coastal Storm Risk Management Effects and Adaptability

6.3.3.1 NNBF-3 Physical and Temporal Effects

Wetland restoration creates immediate risk management effects for environmental resources upon completion. Risk management for other categories are more intermediate as the wetland needs time to become established to act in the same manner as natural wetlands.

6.3.3.2 NNBF-3 National Economic Development, Regional Economic Development, Other Social Effects, and Environmental Quality Effects

Coastal storm risk management benefits include storm surge reduction, wave attenuation, and erosion reduction to mainland areas. Other socioeconomic and environmental benefits include groundwater recharge, removal of pollution, improved water quality, storage and filtration of water, carbon sequestration, supporting diverse flora and fauna, ecosystem diversification, aesthetic landscapes, tourism, recreation, and educational sites. **Table 6-7** shows the potential benefits and costs for each of the four national accounts.

Table 6-7: NNBF-3 National Economic Development, Regional Economic Development, Other Social Effects, and Environmental Quality Effects

Account	Potential Benefits	Potential Costs
NED	• Manage risk to property and infrastructure in the long term	• Measure total investment cost • M&AM cost
RED	• Manage risk to regional revenue and employment in event of commercial property damage in the long term • Direct, indirect, and induced effects of measure construction expenditure	• Potential revenue losses or employment disruptions as a result of the measure
OSE	• Manage risk to urban and community Impacts in the long term • Emergency preparedness • Educational, cultural, and recreational opportunities	–
EQ	• Manages risk to habitat and species • Manage risk to cultural resource assets in the long term	• Possibility for adverse environmental impacts

6.3.3.3 NNBF-3 Sea Level Change Adaptability

Wetland restoration projects are potentially able to adapt to some sea level change through natural secession and by changing elevation overtime through management actions such as thin layer placement. Wetlands should exhibit some natural recovery post-storm event.

6.3.4 NNBF-3 Design and Cost Components

6.3.4.1 NNBF-3 Generic Design

It is assumed that the wind fetch distance is relatively short (on the order of 1 to 2 miles) and the average waves are about 1 to 2 feet so that wave risk containment measures along the exposed wetland perimeter are not required for the low cost range (as discussed in Section 6.3.4.2). For the high cost range, permanent bioengineered containment is assumed. It is assumed that a typical tidal-flat wetland restoration would consist of a platform area at least 300 feet wide with depths for placement no greater than 5 feet. Once filled, the restoration site would be planted with native species (i.e., *Juncus Roemarianus* and *Spartina alterniflora*) spaced at 1.5-foot centers.

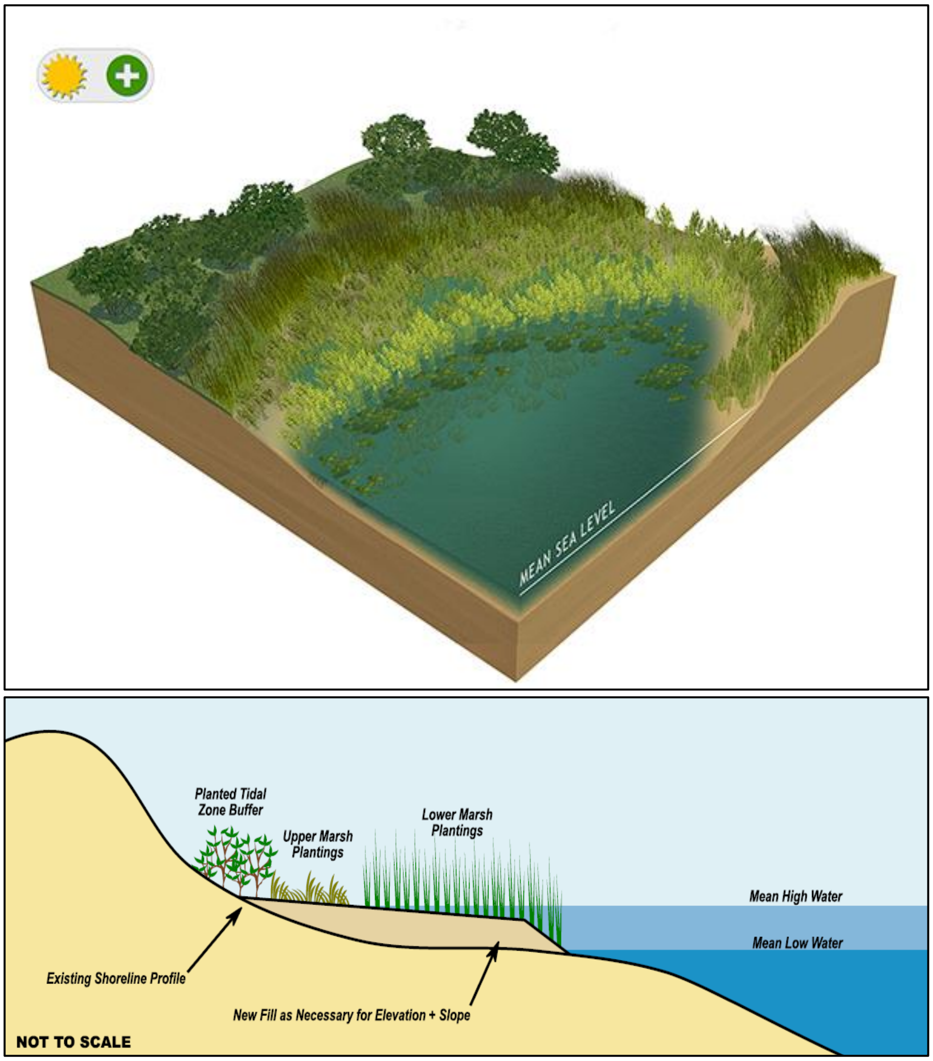

Figure 6-6: Conceptual Wetland Restoration Layout (USACE 2015a) and Design Schematic (Webb et al. 2019)

6.3.4.2 NNBF-3 Cost Components

The estimated costs for wetland restoration are provided as a range of high and low. The estimated costs for a wetland restoration include mobilization and demobilization to the site, containment with bioengineered structural units (high cost range only), fill placement, grading, construction of tidal creeks, and planting of native species (i.e., *Juncus Roemarianus* and *Spartina alterniflora*) spaced at 1.5-foot centers. Also considered are the costs associated with designing and administering a contract.

Table 6-8 reflects what would be considered a contract cost prior to applying any additional markups, or owner markups. These additional costs include contingency at 20 percent for the low end and 40 percent for the high end. E&D and S&A are estimated at 15 percent and 12 percent, respectively, for both the high and low ends of the range presented. M&AM costs are estimated at 3 percent for the low end and 4 percent for the high end. The full or total owner cost are reflected as unit prices in **Table 6-9**. If the user prefers to analyze the cost components individually it is recommended that they considering apply each additional owner markup in the order discussed above in a compounded process. Section 4.2.6.3 contains details regarding cost computations.

Table 6-8: NNBF-3 Cost Components

State / Territory / Planning Reach	Feature Category	Feature	Feature Unit	Quantity Low	Quantity High	Unit Cost Low	Unit Cost High
NNBF3_1: (All)	Measure Cost	Bioengineered Breakwater/ Containment	$/Linear foot (LF)	2,000	4,000	$800	$3,100
	Measure Cost	Fill Placement	$/Cubic yard (CY)	133,000	865,000	$7.00	$30
	Measure Cost	Mob/Demob	Lump sum (LS)	1	1	$400,000	$1,500,000
	Measure Cost	Vegetation	$/Acre (AC)	22	55	$11,500	$20,200
	Unit	Wetland Area	AC	22	55	–	–

6.3.5 NNBF-3 Unit Cost Range by Planning Reach

Wetlands may be viable in all reaches within the SACS study area in more sheltered back bay systems. **Table 6-9** provides unit costs by planning reach for wetland restoration.

Table 6-9: NNBF-3 Unit Cost Ranges by Planning Reach

Reach	Mob/ Demob Low	Mob/Demob High	Total First Unit Cost Low	Total First Unit Cost High	Equivalent Annual Cost (EAC)-Mob-Low	EAC-Mob-High	EAC/LF-Low	EAC/LF-High
NC_01	$400,000	$1,500,000	$198,002	$1,276,032	$14,816	$55,561	$7,334	$47,265
NC_02	$400,000	$1,500,000	$198,002	$1,276,032	$14,816	$55,561	$7,334	$47,265
SC_03	$400,000	$1,500,000	$198,002	$1,276,032	$14,816	$55,561	$7,334	$47,265
SC_04	$400,000	$1,500,000	$198,002	$1,276,032	$14,816	$55,561	$7,334	$47,265
GA_05	$400,000	$1,500,000	$198,002	$1,276,032	$14,816	$55,561	$7,334	$47,265
FL_06	$400,000	$1,500,000	$198,002	$1,276,032	$14,816	$55,561	$7,334	$47,265
FL_07	$400,000	$1,500,000	$198,002	$1,276,032	$14,816	$55,561	$7,334	$47,265
FL_08	$400,000	$1,500,000	$198,002	$1,276,032	$14,816	$55,561	$7,334	$47,265
FL_09	$400,000	$1,500,000	$198,002	$1,276,032	$14,816	$55,561	$7,334	$47,265
FL_10	$400,000	$1,500,000	$198,002	$1,276,032	$14,816	$55,561	$7,334	$47,265
FL_11	$400,000	$1,500,000	$198,002	$1,276,032	$14,816	$55,561	$7,334	$47,265
FL_12	$400,000	$1,500,000	$198,002	$1,276,032	$14,816	$55,561	$7,334	$47,265
FL_13	$400,000	$1,500,000	$198,002	$1,276,032	$14,816	$55,561	$7,334	$47,265
AL_14	$400,000	$1,500,000	$198,002	$1,276,032	$14,816	$55,561	$7,334	$47,265
MS_15	$400,000	$1,500,000	$198,002	$1,276,032	$14,816	$55,561	$7,334	$47,265
PR_1	$400,000	$1,500,000	$198,002	$1,276,032	$14,816	$55,561	$7,334	$47,265
PR_2	$400,000	$1,500,000	$198,002	$1,276,032	$14,816	$55,561	$7,334	$47,265
PR_3	$400,000	$1,500,000	$198,002	$1,276,032	$14,816	$55,561	$7,334	$47,265
PR_4	$400,000	$1,500,000	$198,002	$1,276,032	$14,816	$55,561	$7,334	$47,265
VI_1	$400,000	$1,500,000	$198,002	$1,276,032	$14,816	$55,561	$7,334	$47,265
VI_2	$400,000	$1,500,000	$198,002	$1,276,032	$14,816	$55,561	$7,334	$47,265
VI_3	$400,000	$1,500,000	$198,002	$1,276,032	$14,816	$55,561	$7,334	$47,265

6.3.6 NNBF-3 Assumptions, Sources, Limitations, and Uncertainties

The costs for this measure are paramedic unit prices and calculated based upon bid data received from many projects within the southeastern United States.

Specifically, costs related to the bioengineered breakwaters/containment and vegetation were based upon bid prices received on a project in Jacksonville, Florida. The project is known as Mile Point. The project is of similar scope with a project area of approximately 55 acres and contains similar wetland restoration features. The wetland area was exposed on two sides which required bioengineered containment on the more exposed front due to wave and vessel impacts. The sheltered side contained geotubes as a temporary containment until the system had equilibrated. Prices for the mobilization and demobilization were based on prices received on a project in the Gulf of Mexico know as Bayou Caddy Shoreline Stabilization.

Prices for the fill placement are average dredging prices received across the region over the last several years.

Site-specific shoreline characteristics will dictate design, specifically regarding cost. Factors to consider include, but are not limited to, staging/access, water or land-based construction, placement area tidal influence, and establishment of vegetation species.

The level of risk management associated with engineered wetland features could vary significantly depending on the size and specific site conditions. Wamsley et al. (2010) found that variations in surge reduction depended on landscape character (including bathymetry and wetland type) as well as storm characteristics including size, speed, track, and intensity.

6.4 NNBF-4: Maritime Forest Restoration

6.4.1 NNBF-4 Measure Description

Maritime forest refers to an upland coastal forest of trees and shrubs that is influenced by wind, sea-spray and topography. Maritime forest consists of locally associated but very different vegetation types that accompany dunes and swales. A typical maritime forest for this study would consist of non-wetland maritime forest species dominated by live oaks and pines with the exception of Florida where pines are uncommon in maritime forests (U.S. Forest Service 2019). The measure would require a fairly wide footprint to incorporate the beach and dune and provide an effective region for wave breaking and wave energy reduction.

Figure 6-7: St. Simons Martime Forest (Photo Source: Eliot VanOtteren)

6.4.2 NNBF-4 Measure Performance and Applicability

Maritime forests of a sufficient size are a natural coastal defense and may be effective in providing wave dissipation, flow impedance, and sediment retention. Consequently, these measures can improve erosion control and mitigate shoreline retreat. Mei et al. (2014) shows wave height reductions of up to 40 percent when the forest width is at least equal to the wavelength, but no substantial reductions as the size of the forest grows larger. A study by Das et al. (2010) suggests that reductions in storm surge and flow velocity could be as high as 22 percent and 49 percent, respectively, over a 1,000-foot-wide stand of vegetation perpendicular to the coast. Shorelines with established forests can reduce flooded areas by as much as 30 percent when compared to shorelines without forests (Kalakan et al. 2016). The implementation of coastal forests for tsunami run-up mitigation also shows positive benefits (Irish et al. 2014), as did their presence during a major tsunami event in Japan (Nateghi et al. 2016).

6.4.3 NNBF-4 Coastal Storm Risk Management Effects and Adaptability

6.4.3.1 NNBF-4 Physical and Temporal Effects

Maritime forest restoration has immediate risk management effects for EQ. Maritime forests play an important role in coastal resilience when displacing or discouraging development in high hazard areas. As a coastal storm risk management tool, their implementation may be less desirable as their benefits accrue slowly. Benefits to coastal storm risk management come as the restored forest takes root and continues to grow. Benefits should increase over time as the forest grows and acts more as a buffer to wave energy.

6.4.3.2 NNBF-4 National Economic Development, Regional Economic Development, Other Social Effects, and Environmental Quality Effects

Maritime forests provide wave dissipation, stabilize the shoreline, soil retention, ground water storage, and shelter for the marsh that naturally occurs behind the maritime forest. In addition, constructed maritime forests may provide ecosystem services like water purification, carbon sequestration, wildlife habitat, and biodiversity. **Table 6-10** shows the potential benefits and costs for each of the four national accounts.

Table 6-10: NNBF-4 National Economic Development, Regional Economic Development, Other Social Effects, and Environmental Quality Effects

Account	Potential Benefits	Potential Costs
NED	• Intermediate reduction in property and critical infrastructure loss, vehicle damage, land loss, protective measure costs, emergency costs, and transportation delay costs • Incidental recreation	• Measure total investment cost • M&AM cost
RED	• Manage risk to regional revenue and employment in event of commercial property damage in the long term • Direct, indirect, and induced effects of measure construction expenditure	• Potential revenue losses or employment disruptions as a result of the measure
OSE	• Intermediate risk management effects on urban and community socioeconomic conditions • Potential educational, cultural, and recreational opportunities	–
EQ	• Manages risk to habitat and species • Manage risk to cultural resource assets in the long term	• Possibility for adverse environmental impacts

6.4.3.3 Sea Level Change Adaptability

Currently, the science is inconclusive on the ability of these landscapes to adjust with increasing sea levels.

6.4.4 NNBF-4 Design and Cost Components

6.4.4.1 NNBF-4 Generic Design

For the MCL, the maritime forest restoration design consists of planting a range of 50 and 500 acres of land with native live oak (*Quercus virginiana*) seedlings. The seedlings spacing is assumed at 100-foot centers with a root collar at grade and in sandy topsoils in 20 centimeter soil-amended raised beds to improve tree quality after establishment.

6.4.4.2 NNBF-4 Cost Components

Costs are based on restoring maritime forest areas with native live oak (*Quercus virginiana*) seedlings obtained from a local nursery. Costs assume seedlings are planted at 100-foot centers with a root collar at grade and in sandy topsoils. Soil amendments include sand (30 percent by volume) and composted peat (30 percent by volume) with sandy topsoil to raise the planting area bed 20 centimeters is also included in the calculation.

Table 6-11 reflects what would be considered a contract cost prior to applying any additional markups, or owner markups. These additional costs include contingency at 20 percent for the low end and 40 percent for the high end, E&D and S&A are estimated at 15 percent and 12 percent, respectively, for both the high and low ends of the range presented. M&AM costs are estimated at 3 percent for the low end and 4 percent for the high end. The full or total owner cost are reflected as unit prices in **Table 6-12**. If the user prefers to analyze the cost components individually it is recommended that they considering apply each additional owner markup in the order discussed above in a compounded process. Section 4.2.6.3 contains details regarding cost computations.

Table 6-11: NNBF-4 Unit Cost Components

State / Territory / Planning Reach	Feature Category	Feature	Feature Unit	Quantity Low	Quantity High	Unit Cost Low	Unit Cost High
NNBF4_1: (NC, SC, GA, FL_06, FL_07, FL_08, FL_09, PR,VI)	Unit	Area	Acre (AC)	10	500	–	–
	Measure Cost	Mob/Demob	Lump sum (LS)	1	1	$10,000	$100,000
	Measure Cost	Site Preparation	$/AC	10	500	$250	$4,000
	Measure Cost	Planting	$/AC	10	500	$800	$2,300
NNBF4_2: (FL_10, FL_11, FL_12, FL_13, AL_14, MS_15)	Unit	Area	AC	10	500	–	–
	Measure Cost	Mob/Demob	LS	1	1	$10,000	$100,000
	Measure Cost	Site Preparation	$/AC	10	500	$250	$4,000
	Measure Cost	Planting	$/AC	10	500	$800	$2,300

6.4.5 NNBF-4 Unit Cost Range by Planning Reach

Maritime forest may be viable in all reaches within the CONUS of SACS. **Table 6-12** provides unit costs by planning reach for maritime forest restoration.

Table 6-12: NNBF-4 Unit Cost Ranges by Planning Reach

Reach	Mob/Demob Low	Mob/Demob High	Total First Unit Cost Low	Total First Unit Cost High	Equivalent Annual Cost (EAC)-Mob-Low	EAC-Mob-High	EAC/Linear Foot (LF)-Low	EAC/LF-High
NC_01	$10,000	$100,000	$2,075	$11,175	$370	$3,704	$77	$414
NC_02	$10,000	$100,000	$2,075	$11,175	$370	$3,704	$77	$414
SC_03	$10,000	$100,000	$2,075	$11,175	$370	$3,704	$77	$414
SC_04	$10,000	$100,000	$2,075	$11,175	$370	$3,704	$77	$414
GA_05	$10,000	$100,000	$2,075	$11,175	$370	$3,704	$77	$414
FL_06	$10,000	$100,000	$2,075	$11,175	$370	$3,704	$77	$414
FL_07	$10,000	$100,000	$2,075	$11,175	$370	$3,704	$77	$414
FL_08	$10,000	$100,000	$2,075	$11,175	$370	$3,704	$77	$414
FL_09	$10,000	$100,000	$2,075	$11,175	$370	$3,704	$77	$414

Reach	Mob/Demob Low	Mob/Demob High	Total First Unit Cost Low	Total First Unit Cost High	Equivalent Annual Cost (EAC)-Mob-Low	EAC-Mob-High	EAC/Linear Foot (LF)-Low	EAC/LF-High
FL_10	$10,000	$100,000	$2,075	$11,175	$370	$3,704	$77	$414
FL_11	$10,000	$100,000	$2,075	$11,175	$370	$3,704	$77	$414
FL_12	$10,000	$100,000	$2,075	$11,175	$370	$3,704	$77	$414
FL_13	$10,000	$100,000	$2,075	$11,175	$370	$3,704	$77	$414
AL_14	$10,000	$100,000	$2,075	$11,175	$370	$3,704	$77	$414
MS_15	$10,000	$100,000	$2,075	$11,175	$370	$3,704	$77	$414
PR_1	$10,000	$100,000	$2,075	$11,175	$370	$3,704	$77	$414
PR_2	$10,000	$100,000	$2,075	$11,175	$370	$3,704	$77	$414
PR_3	$10,000	$100,000	$2,075	$11,175	$370	$3,704	$77	$414
PR_4	$10,000	$100,000	$2,075	$11,175	$370	$3,704	$77	$414
VI_1	$10,000	$100,000	$2,075	$11,175	$370	$3,704	$77	$414
VI_2	$10,000	$100,000	$2,075	$11,175	$370	$3,704	$77	$414
VI_3	$10,000	$100,000	$2,075	$11,175	$370	$3,704	$77	$414

6.4.6 NNBF-4 Assumptions, Sources, Limitations, and Uncertainties

The costs developed for this measure take into consideration research performed on maritime forest and assumes similarities in scope to the wet pine savannah, assuming they are similar in level of effort. Mobilization and demobilization costs are assumed amounts based upon projects of similar scope requiring limited equipment after initial site work is performed. The low unit cost for site preparation would assume a relatively clear site that may require burning, tilling, and possible chemical treatments to prepare the site for vegetation. The higher unit cost for site preparation would assume additional efforts may be necessary, such as clearing and grubbing to prepare the site for vegetation.

Maritime forests are especially limited by the space requirements because a potentially large footprint is necessary to create a sustainable strategy. In the study on Target Ecosystem Characteristics (TEC) for the Hudson River Estuary, it was suggested that the creation of maritime forests requires a sufficient size (estimated at 200 acres or more) to maintain the minimum viable populations of the basic vegetative species (Bain et al. 2007). Additionally, size and siting conditions are further complicated by the fact that wetland and forest connectivity (e.g., fragmentation due to natural creeks or urban highway development) is an important factor to determining ecological benefits and hazard mitigation potential. Hence, the integration of constructed or restored forests into the existing ecosystem is often critical to maximize the benefits of this strategy.

The level of risk management associated with engineered maritime forest features could vary significantly depending on the size and specific site conditions. Variations coastal storm risk management, as with tidal-flat wetlands, will depend on landscape character (including bathymetry and forest type), age and health of the forest as well as storm characteristics including size, speed, track and intensity. Maritime forest requires at least 15 to 20 years to reach maturity. With the stem and canopy density being key factors in storm risk management, it is likely that the maximum benefits of these landscape features will accrue slowly over time.

6.5 NNBF-5: Wet Pine Savannah

6.5.1 NNBF-5 Measure Description

Figure 6-8: Mississippi Sandhill Crane Wet Pine Savannah (Photo Source: USFWS)

Wet pine savannahs, also commonly known as wet pine flats and wetland forest, are found on hydric soils, poorly drained with long periods (days or weeks) of soil saturation (USFWS 2010). Pine is typically a component of the canopy. Longleaf pine, pond pine, and, occasionally, slash or loblolly pine are naturally associated with wet pine flats, but pine composition in any given site reflects the site wetness, the natural biogeographic distribution of the four pine species, and fire return interval (Rheinhardt 2002). Pond pine (*Pinus serotina*) inhabits the wetter end of the wetness gradient in the Carolinas, while longleaf pine (*Pinus palustris*) inhabits the more mesic end. Slash pine (*P.elliottii*) sometimes shares the canopy with longleaf pine from southern South Carolina to coastal Alabama (Penfound and Watkins 1937). Most common restoration techniques include restoring the hydrology and implementation of control burns to facilitate natural regeneration. If determined necessary, natural regeneration can also be augmented with planting of primary pine canopy species. In highly urbanized areas, restoring flow paths through artificial embankments or ditches could entail earth work and structural measures such as additions of culverts and/or weirs.

6.5.2 NNBF-5 Measure Performance and Applicability

As with coastal wetlands, forest wet pine savannahs may contribute to coastal storm risk management through slowing the advance of storm surge and sediment stabilization. The magnitude of these effects depends on the specific characteristics of the habitat, including the type of vegetation, its rigidity and structure, as well as the extent their position is relative to the storm track.

6.5.3 NNBF-5 Coastal Storm Risk Management Effects and Adaptability

6.5.3.1 NNBF-5 Physical and Temporal Effects

Wet pine savannah may have immediate risk management effects for EQ. Benefits to coastal storm risk management come as the restored forest takes root and continues to grow. Benefits should increase over time as the forest grows and acts more as a buffer to wave energy.

6.5.3.2 NNBF-5 National Economic Development, Regional Economic Development, Other Social Effects, and Environmental Quality Effects

Wet pine savannah wetlands are commonly referred to as sponges that provide floodwater retention, groundwater recharge, and water purification. Wet pine savannah wetlands provide diverse habitat for a number of plants and animals, including many threatened and endangered species found only in these unique habitats. **Table 6-13** shows the potential benefits and costs for each of the four national accounts.

Table 6-13: NNBF-5 National Economic Development, Regional Economic Development, Other Social Effects, and Environmental Quality Effects

Account	Potential Benefits	Potential Costs
NED	• Intermediate reduction in property and critical infrastructure loss, vehicle damage, land loss, protective measure costs, emergency costs, and transportation delay costs • Incidental recreation	• Measure total investment cost • M&AM cost
RED	• Manage risk to regional revenue and employment in event of commercial property damage in the long term • Direct, indirect and induced effects of measure construction expenditure	• Potential revenue losses or employment disruptions as a result of the measure
OSE	• Intermediate risk management effects on urban and community socioeconomic conditions • Potential educational, cultural, and recreational opportunities	–
EQ	• Manages risk to habitat and species • Manage risk to cultural resource assets in the long term	• Possibility for adverse environmental impacts

6.5.4 NNBF-5 Design and Cost Components

6.5.4.1 NNBF-5 Generic Design

The wet pine savannah restoration design consists of restoring site hydrology and planting a range of 50 to 500 acres of land with containerized long leaf pines at 8-foot intervals.

6.5.4.2 NNBF-5 Cost Components

Costs are based on restoring wet pine savannah areas with long leaf pines obtained from a local nursery. Costs assume earthwork to restore hydrology, controlled burns and planting of containerized long leaf pines at 8-foot intervals. Mobilization and demobilization costs are assumed amounts based on projects of similar scope requiring limited equipment after initial site work is performed. The low unit cost for site preparation would assume a relatively clear site that may require burning, tilling, and possible chemical treatments to prepare the site for vegetation. The higher unit cost for site preparation would assume additional efforts may be necessary, such as clearing and grubbing to prepare the site for vegetation. **Table 6-14** reflects what would be considered a contract cost prior to applying any additional markups, or owner markups. These additional costs include contingency at 20 percent for the low end and 40 percent for the high end, E&D and S&A are estimated at 15 percent and 12 percent, respectively, for both the high and low ends of the range presented. M&AM costs are estimated at 3 percent for the low end and 4 percent for the high end. The full or total owner cost are reflected as unit prices in **Table 6-15**. To analyze the cost components individually, the use may apply each additional owner markup in the order discussed above in a compounded process. Section 4.2.6.3 contains details regarding cost computations.

Table 6-14: NNBF-5 Cost Components

State / Territory / Planning Reach	Feature Category	Feature	Feature Unit	Quantity Low	Quantity High	Unit Cost Low	Unit Cost High
NNBF5_1: (NC, SC, GA, FL_06, FL_07, FL_08, FL_09, PR, VI)	Unit	Area	AC	10	500	–	–
	Measure Cost	Mob/Demob	Lump sum (LS)	1	1	$10,000	$100,000
	Measure Cost	Site Preparation	$/AC	10	500	$250	$4,000
	Measure Cost	Planting	$/AC	10	500	$800	$2,300
NNBF5_2: (FL_10, FL_11, FL_12, FL_13, AL_14, MS_15)	Unit	Area	AC	10	500	–	–
	Measure Cost	Mob/Demob	LS	1	1	$10,000	$100,000
	Measure Cost	Site Preparation	$/AC	10	500	$250	$4,000
	Measure Cost	Planting	$/AC	10	500	$800	$2,300

6.5.5 NNBF-5 Unit Cost Range by Planning Reach

Wet pine savannahs may be viable in all reaches within the SACS study area, except for the Florida peninsula.[20] **Table 6-15** provides unit costs by planning reach for wet pine savannah.

Table 6-15: NNBF-5 Unit Cost Ranges by Planning Reach

Reach	Mob/Demob Low	Mob/Demob High	Total First Unit Cost Low	Total First Unit Cost High	Equivalent Annual Cost (EAC)-Mob-Low	EAC-Mob-High	EAC/ Linear Foot (LF)-Low	EAC/LF-High
NC_01	$10,000	$100,000	$2,075	$11,175	$370	$3,704	$77	$414
NC_02	$10,000	$100,000	$2,075	$11,175	$370	$3,704	$77	$414
SC_03	$10,000	$100,000	$2,075	$11,175	$370	$3,704	$77	$414
SC_04	$10,000	$100,000	$2,075	$11,175	$370	$3,704	$77	$414
GA_05	$10,000	$100,000	$2,075	$11,175	$370	$3,704	$77	$414
FL_06	$10,000	$100,000	$2,075	$11,175	$370	$3,704	$77	$414
FL_07	$10,000	$100,000	$2,075	$11,175	$370	$3,704	$77	$414
FL_08	$10,000	$100,000	$2,075	$11,175	$370	$3,704	$77	$414
FL_09	$10,000	$100,000	$2,075	$11,175	$370	$3,704	$77	$414
FL_10	$10,000	$100,000	$2,075	$11,175	$370	$3,704	$77	$414
FL_11	$10,000	$100,000	$2,075	$11,175	$370	$3,704	$77	$414
FL_12	$10,000	$100,000	$2,075	$11,175	$370	$3,704	$77	$414
FL_13	$10,000	$100,000	$2,075	$11,175	$370	$3,704	$77	$414
AL_14	$10,000	$100,000	$2,075	$11,175	$370	$3,704	$77	$414
MS_15	$10,000	$100,000	$2,075	$11,175	$370	$3,704	$77	$414
PR_1	$10,000	$100,000	$2,075	$11,175	$370	$3,704	$77	$414
PR_2	$10,000	$100,000	$2,075	$11,175	$370	$3,704	$77	$414
PR_3	$10,000	$100,000	$2,075	$11,175	$370	$3,704	$77	$414
PR_4	$10,000	$100,000	$2,075	$11,175	$370	$3,704	$77	$414
VI_1	$10,000	$100,000	$2,075	$11,175	$370	$3,704	$77	$414
VI_2	$10,000	$100,000	$2,075	$11,175	$370	$3,704	$77	$414
VI_3	$10,000	$100,000	$2,075	$11,175	$370	$3,704	$77	$414

[20] Based on the regional guide book for applying the hydrogeomorphic approach to assessing wetland functions of wet pine flats on coastal mineral soils in the Atlantic and Gulf Coastal Plains, this habitat is found within the following SACS planning reaches: NC_01, NC_02, SC_03, SC_04, GA_05, FL_06, FL_12, FL_13, AL_14, MS_15.

6.5.6 NNBF-5 Sea Level Cost Adaptability

Currently, the science is inconclusive on the ability of these landscapes to adjust with increasing sea levels.

6.5.7 NNBF-5 Limitations and Uncertainties

Wet pine savannahs play an important role in coastal resilience when displacing or discouraging development in high hazard areas. As a coastal storm risk management tool, their implementation may be less desirable because their benefits accrue slowly. This wetland habitat is under increased developmental pressures and becoming fragmented. With the increased development, fire maintenance is increasingly harder to perform, which is an essential element of habitat sustainability.

For cost purposes, it is assumed restoration sites have sufficient space and are located where flow paths through artificial embankments and structural measures, such as additions of culverts and/or weirs, would not be required. If restoration is occurring in highly urbanized areas with significantly altered hydrology, the cost of restoration will likely be higher than those assumed.

The level of risk management associated with engineered wet pine savannah features could vary significantly depending on the size and specific site conditions. Variations of coastal storm risk management will depend on landscape character (including bathymetry and forest type) as well as storm characteristics including size, speed, track and intensity. Adequate site preparation, good quality seedlings, proper handling of seedlings and proper planting depths are all critical to restoration success.

6.6 NNBF-6: Mangrove Restoration

6.6.1 NNBF-6 Measure Description

Mangroves, also known as coastal wetland forest, are found in the subtropical and tropical climates of the United States, typically located between mean sea level and mean higher high water. Worldwide, there are more the 50 species of mangroves (FDEP 2020c). In the United States, the most common species are the red mangrove (*Rhizophora mangle*), which grow along the edge of the shoreline where conditions are harshest, black mangrove (*Avicennia germinans*) that grow at elevations slightly higher than the red mangrove, and the white mangrove (*Lagunacularia racemosa*) that grow at the higher mangrove zones.

Figure 6-9: Estero Beach Mangrove Restoration (Photo Source: Kevin Erwin Consulting Ecologist, Inc.)

Most common restoration techniques include restoring the hydrology to facilitate natural regeneration where sources of propagules exist. In highly urbanized areas, restoring flow paths through artificial embankments or ditches could entail significant earthwork and structural measures such as additions of culverts and/or weirs. If determined necessary, natural regeneration can also be augmented with planting mangrove saplings, which are small scrubs or trees adapted to grow in brackish water, develop into coastal vegetation, and provide coastal protection through wave attenuation and/or dissipation and mitigation of sediment loss. Along high-energy shorelines where natural recruitment no longer occurs and where conventional planting methods are ineffective, Riley Encasement Methodologies have been applied. This method of planting is specifically for areas where higher wave energy exists and where sediment loss may occur. This method involves inserting propagules into a long tube previous driven into the substrate. The tube is driven into the substrate to prevent washing away during high-energy events. This is an alternative to traditional planting methods of inserting the propagules into the substrate or inserting them and tying them to a supporting wooden stake.

6.6.2 NNBF-6 Measure Performance and Applicability

Nature-based approaches, such as mangrove habitats, can reduce coastal erosion and wave damage and augment other structural and/or nonstructural coastal storm risk management strategies. Mangroves are capable of dampening incident waves, reducing wind speed within the canopy, and potentially reducing storm surge, depending on their lateral extent (McIvor et al. 2012; Zhang et al. 2012). Recent studies, such as Narayan et al. (2017), have documented potential storm surge reduction benefits of mangroves within the United States over multiple storms, including reduced storm surge impacts of catastrophic events like Hurricane Irma. This study found that the highest potential benefits occur in areas where there are larger swaths of mangroves remaining and moderate development, but also found significant benefits in areas of small belts of mangroves in some of the densest urban corridors evaluated.

6.6.3 NNBF-6 Coastal Storm Risk Management Effects and Adaptability

6.6.3.1 NNBF-6 Physical and Temporal Effects

Similar to maritime forests and wet pine savannah, mangroves provide immediate risk management effects for EQ when healthy. Benefits to coastal storm risk management come as the restored mangroves take root and continue to grow. Benefits should increase over time as the forest grows and acts more as a buffer to wave energy.

6.6.3.2 NNBF-6 National Economic Development, Regional Economic Development, Other Social Effects, and Environmental Quality Effects

Mangrove forests stabilize the coastline, reducing erosion from storm surges, currents, waves, and tides. The intricate root system of mangroves also provides ecosystem services to fish and other organisms seeking food and shelter from predators. These coastal habitats play an important role in water quality and carbon sequestration, and they have the capacity to adapt to sea level rise (Duarte et al. 2013; Rodriguez et al. 2014). Other social and economic benefits include enhanced commercial and recreational fisheries, ecotourism, and educational sites. **Table 6-16** shows the potential benefits and costs for each of the four national accounts.

Table 6-16: NNBF-6 National Economic Development, Regional Economic Development, Other Social Effects, and Environmental Quality Effects

Account	Potential Benefits	Potential Costs
NED	• Intermediate reduction in property and critical infrastructure loss, vehicle damage, land loss, protective measure costs, emergency costs, and transportation delay costs • Incidental recreation	• Measure total investment cost • M&AM costs
RED	• Manage risk to regional revenue and employment in event of commercial property damage in the long term • Direct, indirect and induced effects of measure construction expenditure	• Possibility of revenue losses or employment disruptions as a result of measure (situational)

Account	Potential Benefits	Potential Costs
OSE	• Intermediate risk management effects on urban and community socioeconomic conditions • Potential educational, cultural, and recreational opportunities	–
EQ	• Manages risk to habitat and species • Manage risk to cultural resource assets over time	• Possibility for adverse environmental impacts (situational)

6.6.3.3 NNBF-6 Sea Level Change Adaptability

Mangroves are potentially able to adapt to some sea level change through natural secession as well as changing elevation through sediment diversion applications and thin layer placement. Mangroves do exhibit natural recovery after a storm impact.

6.6.4 NNBF-6 Design and Cost Components

6.6.4.1 NNBF-6 Generic Design

Mangrove restoration design consists of restoring site hydrology throughout the restoration site and distributing red, black, and white mangrove propagules along appropriate tidal zones along a 1,000-foot stretch of coast at 5-foot intervals. For higher wave energy coastlines, the Riley Encasement Methodologies were assumed which incorporates inserting the propagules into long tubes driven into the substrate prior to plant installation.

6.6.4.2 NNBF-6 Cost Components

Costs are based on restoring mangrove hydrology and distributing red, black, and white mangrove propagules throughout the restoration site along appropriate tidal zones. Costs assume clear cutting and earthwork to restore hydrology and planting of propagules that are obtained from nearby local sources at 5-foot intervals.

The costs for this measure are parametric unit prices and calculated based on information developed for a Jacksonville District Deep Draft Navigation Project, Port Everglades Harbor that as a result of dredging impacts will need to mitigate for the acreage of mangroves impacted. The cost of the Riley Encasement Method and other varying planting methods are assumed to be accounted for in the cost ranges and contingencies assumed.

Cost drivers associated with mangrove restoration are influenced by location and accessibility. If potential projects for coastal storm risk management impact existing mangroves, then purchasing mitigation bank credits may be necessary instead of restoration, depending on the degree of impact and available areas to restore and/or create mangroves. This can be considered a cost driver and potential project risk.

Table 6-17 reflects what would be considered a contract cost prior to applying any additional markups, or owner markups. These additional costs include contingency at 20 percent for the low end and 40 percent for the high end, E&D and S&A are estimated at 15 percent and 12 percent, respectively, for both the high and low ends of the range presented. M&AM costs are estimated at 3 percent for the low end and 4 percent for the high end. The full or total owner cost are reflected as unit prices in **Table 6-18**. To analyze the cost components individually, the user may apply each additional owner markup in the order discussed above in a compounded process. Section 4.2.6.3 contains details regarding cost computations.

Table 6-17: NNBF-6 Cost Components

State / Territory / Planning Reach	Feature Category	Feature	Feature Unit	Quantity Low	Quantity High	Unit Cost Low	Unit Cost High
NNBF6_1: (All)	Unit	Mangrove Shoreline Length	Linear feet (LF)	1000	1000	–	–
	Measure Cost	Mob/Demob	Lump sum	1	1	$10,000	$150,000
	Measure Cost	Mangrove Restoration	$/Acre (AC)	1	1	$1,260,000	$1,700,000
	Construction Unit	Mangrove Area	AC	1	1	–	–

6.6.5 NNBF-6 Unit Cost Ranges by Planning Reach

Mangroves are likely only viable within some Florida, Puerto Rico, and Virgin Island planning reaches within sheltered coast, deltas, lagoons, and estuaries. **Table 6-18** provides unit costs by planning reach for mangrove restoration.

Table 6-18: NNBF-6 Unit Cost Ranges by Planning Reach

Reach	Mob/Demob Low	Mob/Demob High	Total First Unit Cost Low	Total First Unit Cost High	Equivalent Annual Cost (EAC)-Mob-Low	EAC-Mob-High	EAC/Linear Foot (LF)-Low	EAC/LF-High
NC_01	$10,000	$150,000	$1,895	$3,088	$370	$5,556	$70	$114
NC_02	$10,000	$150,000	$1,895	$3,088	$370	$5,556	$70	$114
SC_03	$10,000	$150,000	$1,895	$3,088	$370	$5,556	$70	$114
SC_04	$10,000	$150,000	$1,895	$3,088	$370	$5,556	$70	$114
GA_05	$10,000	$150,000	$1,895	$3,088	$370	$5,556	$70	$114
FL_06	$10,000	$150,000	$1,895	$3,088	$370	$5,556	$70	$114
FL_07	$10,000	$150,000	$1,895	$3,088	$370	$5,556	$70	$114
FL_08	$10,000	$150,000	$1,895	$3,088	$370	$5,556	$70	$114
FL_09	$10,000	$150,000	$1,895	$3,088	$370	$5,556	$70	$114
FL_10	$10,000	$150,000	$1,895	$3,088	$370	$5,556	$70	$114
FL_11	$10,000	$150,000	$1,895	$3,088	$370	$5,556	$70	$114
FL_12	$10,000	$150,000	$1,895	$3,088	$370	$5,556	$70	$114
FL_13	$10,000	$150,000	$1,895	$3,088	$370	$5,556	$70	$114
AL_14	$10,000	$150,000	$1,895	$3,088	$370	$5,556	$70	$114
MS_15	$10,000	$150,000	$1,895	$3,088	$370	$5,556	$70	$114
PR_1	$10,000	$150,000	$1,895	$3,088	$370	$5,556	$70	$114
PR_2	$10,000	$150,000	$1,895	$3,088	$370	$5,556	$70	$114
PR_3	$10,000	$150,000	$1,895	$3,088	$370	$5,556	$70	$114
PR_4	$10,000	$150,000	$1,895	$3,088	$370	$5,556	$70	$114
VI_1	$10,000	$150,000	$1,895	$3,088	$370	$5,556	$70	$114
VI_2	$10,000	$150,000	$1,895	$3,088	$370	$5,556	$70	$114
VI_3	$10,000	$150,000	$1,895	$3,088	$370	$5,556	$70	$114

6.6.6 NNBF-6 Assumptions, Sources, Limitations, and Uncertainties

Mangrove restoration is typically applicable only where mangroves species have previously occurred and where there are suitable soil types and fluctuations in salinity, temperature and tides. For sustainability and higher species biodiversity of the system, adequate supply of sediment and a natural source of propagules are necessary.

Mangroves may be limited by the space requirements because a potentially large footprint is necessary to create a sustainable strategy. Research has documented reductions in peak water levels from mangroves, but certain storm conditions and large expanses of habitat are likely needed for these to be most effective (Narayan et al. 2019).

The level of risk management associated with engineered mangrove features could vary significantly, depending on the size and specific site conditions. Variations in coastal storm risk management will depend on landscape character (including bathymetry and forest type), the age and health of the mangroves, as well as storm characteristics including size, speed, track, and intensity. Mangroves require at least 20 to 25 years to reach maturity (Lugo and Snedaker 1974; Odum 1975) with natural succession occurring over periods of 15 to 30 years if hydrology has not been disrupted and supply of natural propagules is provided (Field 1998; Lewis 2005). With the stem and canopy density being key factors in storm risk management, it is likely that the maximum benefits of these landscape features will accrue slowly over time.

For cost purposes, it is assumed restoration sites have sufficient space, a natural source of propagules, and are located where flow paths through artificial embankments and structural measures such as additions of culverts and/or weirs would not be required. If restoration is occurring in highly urbanized areas with significantly altered hydrology, the cost of restoration will likely be higher than those assumed.

6.7 NNBF-7: Living Shoreline Vegetation

6.7.1 NNBF-7 Measure Description

Living shoreline vegetation consists of planting existing slopes with hardy native vegetation to stabilize the shoreline. This measure may include vegetation types associated with dune enhancement and tidal and forest wetland restoration but can also incorporate additional shrub and herbaceous species.

This measure often includes earthwork to generate milder slopes along existing shorelines but typically does not consist of bringing in-fill to construct new land.

Figure 6-10: State Road 196 Bayfront Parkway Gabion Baskets and Vegetation Shoreline Stabilization (Photo Source: PennaGroup)

6.7.2 NNBF-7 Measure Performance and Applicability

Vegetation provides a buffer for upland areas and provides friction which helps dissipate small wave energy. Suitable for use in low wave energy environments. This measure is often used to restore floodplain in riparian areas and along levee, dike, and road embankments.

6.7.3 NNBF-7 Coastal Storm Risk Management Effects and Adaptability

6.7.3.1 NNBF-7 Physical and Temporal Effects

Living shoreline vegetation provides intermediate risk management effects. Upon planting, the vegetation is susceptible to damage from storm events, pedestrian traffic, and other sources. As the vegetation becomes established and grows taller and denser, it helps hold the substrate in place to reduce erosion.

6.7.3.2 NNBF-7 National Economic Development, Regional Economic Development, Other Social Effects, and Environmental Quality Effects

Numerous studies have documented how marine vegetation can attenuate water flow, reduce wave propagation, and stabilize sediment (e.g., Kobayashi et al. 1993; Nepf 1999; Duarte et al. 2013), thereby potentially lessening storm impacts (Gedan et al. 2011).

Bioengineering, also known as biotechnical planting, utilizes plants in specifically designed features to retain earth and prevent soil loss. This method can be used with plants as the main component or in combination with other earth-retaining structures to create attractive, cost-effective, and environmentally compatible solutions to slope stability. **Table 6-19** shows the potential benefits and costs for each of the four national accounts.

Table 6-19: NNBF-7 National Economic Development, Regional Economic Development, Other Social Effects, and Environmental Quality Effects

Account	Potential Benefits	Potential Costs
NED	• Intermediate reduction in property and critical infrastructure loss, vehicle damage, land loss, protective measure costs, emergency costs, and transportation delay costs • Incidental recreation	• Measure total investment cost • M&AM Cost
RED	• Manage risk to regional revenue and employment in event of commercial property damage in the long term • Direct, indirect and induced effects of measure construction expenditure	• Possibility of revenue losses or employment disruptions as a result of measure (situational)
OSE	• Intermediate risk management effects on urban and community socioeconomic conditions • Potential educational, cultural, and recreational opportunities	–
EQ	• Manage risk to habitat and species in the long term • Manage risk to cultural resource assets in the long term	• Possibility for adverse environmental impacts (situational)

6.7.3.3 Sea Level Change Adaptability

The measure is potentially able to adapt to some sea level change through some natural secession as well as elevation changes.

6.7.4 NNBF-7 Design and Cost Components

6.7.4.1 NNBF-7 Generic Design

It is assumed that the wind fetch distance is relatively short (on the order of 1 to 2 miles) and the average waves are about 1 to 2 feet so that wave risk containment measures along the exposed shoreline are not required. The design consists of grading of existing slopes and planting natural subaquatic species (such as *Juncus Roemarianus* and *Spartina alterniflora*) at 1.5-foot intervals along 1,000 feet of shoreline.

6.7.4.2 NNBF-7 Cost Components

The estimated costs for a living shoreline include mobilization and demobilization of the site and grading of existing slopes and planting of natural subaquatic species (i.e., *Juncus Roemarianus* and *Spartina alterniflora*) spaced at 1.5-foot intervals.

Cost factors to consider include, but are not limited to, staging/access, water versus land-based construction, amount of site preparation required, placement area tidal influence, establishment of vegetation species, in-water operations, and the potential for diving requirements.

Table 6-20 reflects what would be considered a contract cost prior to applying any additional markups, or owner markups. These additional costs include contingency at 20 percent for the low end and 40 percent for the high end, E&D and S&A are estimated at 15 percent and 12 percent, respectively, for both the high and low ends of the range presented. M&AM costs are estimated at 3 percent for the low end and 4 percent for the high end. The full or total owner cost are reflected as unit prices in **Table 6-21**. To analyze the cost components, the user may apply each additional owner markup in the order discussed above in a compounded process. Section 4.2.6.3 contains details regarding cost computations.

Table 6-20: NNBF-7 Cost Components

State / Territory / Planning Reach	Feature Category	Feature	Feature Unit	Quantity Low	Quantity High	Unit Cost Low	Unit Cost High
NNBF7_1: (All)	Unit	Shoreline Length	Linear feet (LF)	1,000	1,000	–	–
	Measure Cost	Mob/Demob	Lump sum	1	1	$10,000	$150,000
	Measure Cost	Vegetation	$/Acre (AC)	1	60	$11,500	$20,200

6.7.5 NNBF-7 Unit Cost Range by Planning Reach

Living shoreline vegetation measures may be viable in all reaches within the SACS study area in more sheltered systems. **Table 6-21** provides unit costs by planning reach for living shoreline vegetation.

Table 6-21: NNBF-7 Unit Cost Ranges by Planning Reach

Reach	Mob/Demob Low	Mob/Demob High	Total First Unit Cost Low	Total First Unit Cost High	Equivalent Annual Cost (EAC)-Mob-Low	EAC-Mob-High	EAC/Linear Foot (LF)-Low	EAC/ LF-High
NC_01	$10,000	$150,000	$22	$2,234	$370	$5,556	$0.82	$82.73
NC_02	$10,000	$150,000	$22	$2,234	$370	$5,556	$0.82	$82.73
SC_03	$10,000	$150,000	$22	$2,234	$370	$5,556	$0.82	$82.73
SC_04	$10,000	$150,000	$22	$2,234	$370	$5,556	$0.82	$82.73
GA_05	$10,000	$150,000	$22	$2,234	$370	$5,556	$0.82	$82.73
FL_06	$10,000	$150,000	$22	$2,234	$370	$5,556	$0.82	$82.73
FL_07	$10,000	$150,000	$22	$2,234	$370	$5,556	$0.82	$82.73
FL_08	$10,000	$150,000	$22	$2,234	$370	$5,556	$0.82	$82.73
FL_09	$10,000	$150,000	$22	$2,234	$370	$5,556	$0.82	$82.73
FL_10	$10,000	$150,000	$22	$2,234	$370	$5,556	$0.82	$82.73
FL_11	$10,000	$150,000	$22	$2,234	$370	$5,556	$0.82	$82.73
FL_12	$10,000	$150,000	$22	$2,234	$370	$5,556	$0.82	$82.73

Reach	Mob/Demob Low	Mob/Demob High	Total First Unit Cost Low	Total First Unit Cost High	Equivalent Annual Cost (EAC)-Mob-Low	EAC-Mob-High	EAC/Linear Foot (LF)-Low	EAC/ LF-High
FL_13	$10,000	$150,000	$22	$2,234	$370	$5,556	$0.82	$82.73
AL_14	$10,000	$150,000	$22	$2,234	$370	$5,556	$0.82	$82.73
MS_15	$10,000	$150,000	$22	$2,234	$370	$5,556	$0.82	$82.73
PR_1	$10,000	$150,000	$22	$2,234	$370	$5,556	$0.82	$82.73
PR_2	$10,000	$150,000	$22	$2,234	$370	$5,556	$0.82	$82.73
PR_3	$10,000	$150,000	$22	$2,234	$370	$5,556	$0.82	$82.73
PR_4	$10,000	$150,000	$22	$2,234	$370	$5,556	$0.82	$82.73
VI_1	$10,000	$150,000	$22	$2,234	$370	$5,556	$0.82	$82.73
VI_2	$10,000	$150,000	$22	$2,234	$370	$5,556	$0.82	$82.73
VI_3	$10,000	$150,000	$22	$2,234	$370	$5,556	$0.82	$82.73

6.7.6 NNBF-7 Assumptions, Sources, Limitations, and Uncertainties

The costs for this measure are paramedic unit prices and calculated based on information developed from multiple projects in Jacksonville District. Jacksonville Harbor Mile Point Project and Pahokee Ecosystem Restoration Continuing Authorities Project were considered. Both projects included beneficial use of dredge material to establish a shoreline sill and restoration of areas where shoreline vegetation was previously present.

As previously stated, vegetation is not typically implemented as a stand-alone coastal storm risk management measure; therefore, the true implementation cost would be incorporated as a hybrid alterative.

6.8 NNBF-8: Submerged Aquatic Vegetation Restoration

6.8.1 NNBF-8 Measure Description

Submerged aquatic vegetation (SAV) are grasses that grow to the surface of shallow water, but do not emerge from the water surface. SAVs occur in protected bays and lagoons but also in deeper waters along the continental shelf in the Gulf of Mexico (FDEP 2020a). SAVs are limited by depth and water clarity levels. They are typically found in shallower waters that allow for sufficient light. Worldwide, there are more the 52 species of SAVs (FDEP 2020a).

Figure 6-11: Indian Key State Park Seagrass Restoration (Photo Source: FDEP)

6.8.2 NNBF-8 Measure Performance and Applicability

Seagrasses have the ability to attenuate wave energy (Fonseca and Cahalan 1992; Koch et al. 2006) by forming meadows which reduce more energy than canopy style seagrass (Verduin and Backhaus 2000). Because seagrass canopies are relatively short (generally <20 inches [50 centimeters]) and flexible, substantial modification of water flow is most effective when seagrasses are found in high-density and distributed over a wide area in shallow water depths (e.g., Fonseca et al. 1982).

SAV species require habitats typically deeper than strong wave orbitals, or protected from waves completely, with current velocities between 5 and 100 centimeters per second (Koch 2001). SAVs can have high variation in coverage given seasonal and long-term water quality variations. While SAVs function to stabilized sediments in the near shore and dissipate low-energy waves, they have not historically been designed and incorporated into coastal storm risk management projects.

6.8.3 NNBF-8 Coastal Storm Risk Management Effects and Adaptability

6.8.3.1 NNBF-8 Physical and Temporal Effects

SAV provides environmental benefits immediately. Other benefits occur over longer time scales. Like other vegetation, SAV provides better erosion control the longer it is established. Similarly, to provide noticeable attenuation of wave energy, the SAV must be tall relative to the water depth which requires time to grow.

6.8.3.2 NNBF-8 National Economic Development, Regional Economic Development, Other Social Effects, and Environmental Quality Effects

Table 6-22 shows the potential benefits and costs for each of the four national accounts.

Table 6-22: NNBF-8 National Economic Development, Regional Economic Development, Other Social Effects, and Environmental Quality Effects

Account	Potential Benefits	Potential Costs
NED	• Long-term reduction in property and critical infrastructure loss, vehicle damage, land loss, protective measure costs, emergency costs, and transportation delay costs • Incidental recreation	• Measure total investment cost • M&AM Cost
RED	• Manage risk to regional revenue and employment in event of commercial property damage in the long term • Direct, indirect and induced effects of measure construction expenditure	• Possibility of revenue losses or employment disruptions as a result of measure (situational)
OSE	• Intermediate to long-term risk management effects on urban and community socioeconomic conditions • Potential educational, cultural, and recreational opportunities	–
EQ	• Manage risk to habitat and species • Manage risk to cultural resource assets in the long term	• Possibility for adverse environmental impacts (situational)

SAV performs many important ecosystem functions, including wave attenuation and sediment stabilization, water quality improvement, primary production, food web support for secondary consumers, critical nursery and refuge habitat for fisheries species, and the attachment of epiphytic organisms (USACE 2008).

6.8.3.3 Sea Level Change Adaptability

Science is uncertain on the ability of these landscapes to adjust with climate change.

6.8.4 NNBF-8 Design and Cost Components

6.8.4.1 NNBF-8 Generic Design

For the MCL, the design for SAV restoration assumed that the top elevation for a clean sandy substrate will be established at -1 feet mean lower low water (MLLW) to maintain the SAV vegetation underwater for most of the time while placing it as high as possible to reduce wave energy during low-energy storms. The design assumed that the SAV bed would be constructed over an existing bottom at -5 feet MLLW and has a fill width of roughly 300 feet with a generally flat slope. A 3-foot spacing on SAV plantings was assumed.

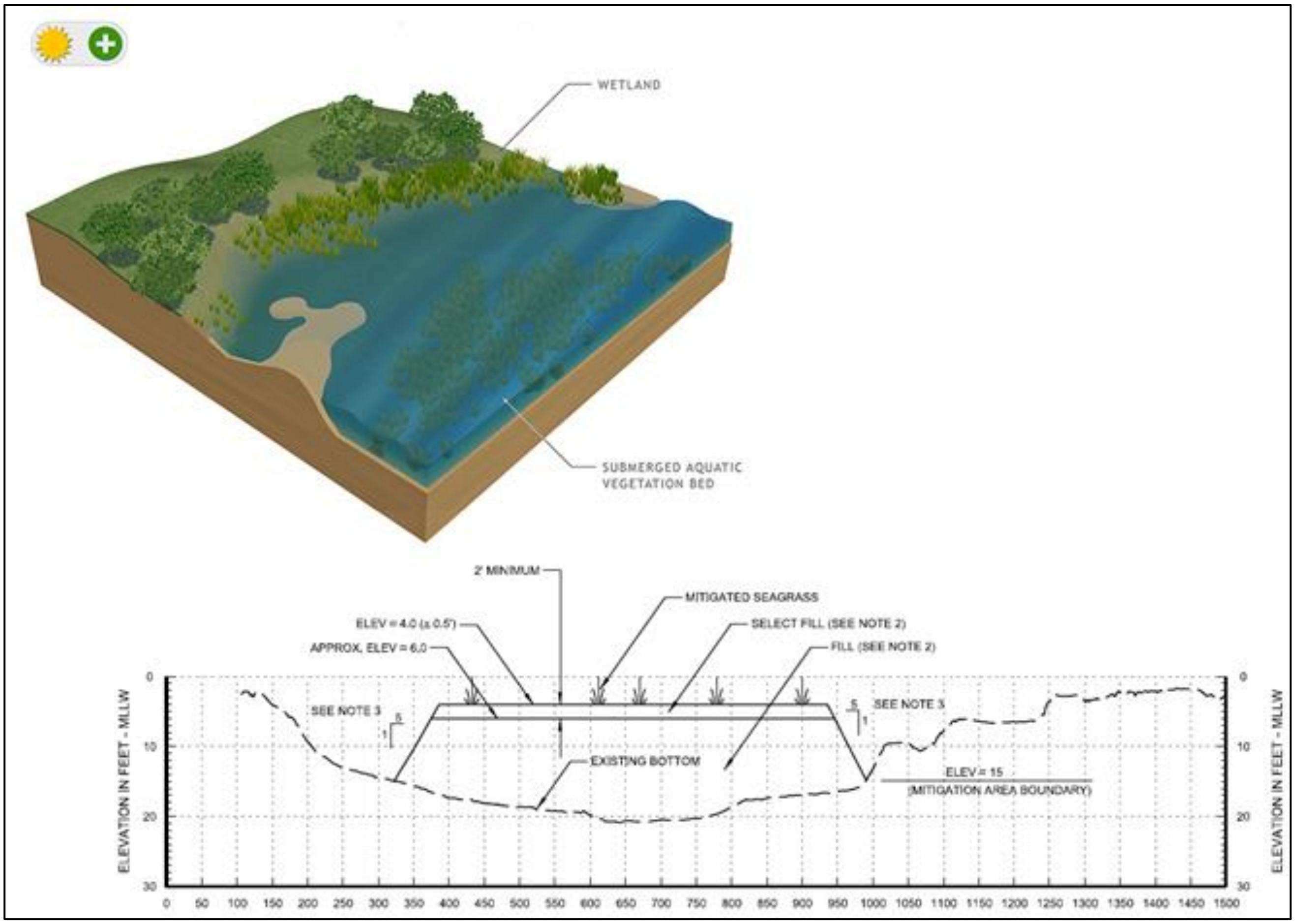

Figure 6-12: Conceptual Layout and Example of a Typical Cross Section of Seagrass Mitigation (USACE 2015a)

6.8.4.2 NNBF-8 Cost Components

To construct the SAV bed, sand would be placed in a layer on the bottom with a small hydraulic dredge to build it up and the individual plants would be installed using snorkel. The depth of the final elevation would be shallow enough to permit snorkel versus scuba. This would require scheduling placement around low tide. Alternatively, scuba could be used if it is desired to plant SAV at any phase of the tide.

It is assumed that the SAV bed is constructed over an existing bottom at -5 feet MLLW and has a fill elevation of -1 feet MLLW and width of approximately 300 feet with a generally flat slope.

Table 6-23 reflects what would be considered a contract cost prior to applying any additional markups, or owner markups. These additional costs include contingency at 20 percent for the low end and 40 percent for the high end, E&D and S&A are estimated at 15 percent and 12 percent, respectively, for both the high and low ends of the range presented. M&AM costs are estimated at 3 percent for the low end and 4 percent for the high end. The full or total owner costs are reflected as unit prices in **Table 6-24**. To analyze the cost components individually, the user may apply each additional owner markup in the order discussed above in a compounded process. Section 4.2.6.3 contains details regarding cost computations.

Table 6-23: NNBF-8 Cost Components

State / Territory / Planning Reach	Feature Category	Feature	Feature Unit	Quantity Low	Quantity High	Unit Cost Low	Unit Cost High
NNBF8_1: (All)	Measure Cost	Mob/Demob	Lump sum	1	1	$100,000	$300,000
	Measure Cost	Flow Improvement Earthwork	$/Acre (AC)	1	1	$57,000	$76,000
	Measure Cost	Vegetation	$/AC	1	1	$25,000	$130,000
	Unit	Submerged Aquatic Vegetation (SAV) Area	AC	1	1	–	–

6.8.5 NNBF-8 Unit Cost Ranges by Planning Reach

SAVs may be viable in all reaches within the SACS study area in more sheltered back bay systems. **Table 6-24** provides unit costs by planning reach for SAVs.

Table 6-24: NNBF-8 Unit Cost Ranges by Planning Reach

Reach	Mob/Demob Low	Mob/Demob High	Total First Unit Cost Low	Total First Unit Cost High	Equivalent Annual Cost (EAC)-Mob-Low	EAC-Mob-High	EAC/Linear Foot (LF)-Low	EAC/LF-High
NC_01	$100,000	$300,000	$173,000	$585,500	$3,704	$11,112	$6,408	$21,687
NC_02	$100,000	$300,000	$173,000	$585,500	$3,704	$11,112	$6,408	$21,687
SC_03	$100,000	$300,000	$173,000	$585,500	$3,704	$11,112	$6,408	$21,687
SC_04	$100,000	$300,000	$173,000	$585,500	$3,704	$11,112	$6,408	$21,687
GA_05	$100,000	$300,000	$173,000	$585,500	$3,704	$11,112	$6,408	$21,687
FL_06	$100,000	$300,000	$173,000	$585,500	$3,704	$11,112	$6,408	$21,687
FL_07	$100,000	$300,000	$173,000	$585,500	$3,704	$11,112	$6,408	$21,687
FL_08	$100,000	$300,000	$173,000	$585,500	$3,704	$11,112	$6,408	$21,687
FL_09	$100,000	$300,000	$173,000	$585,500	$3,704	$11,112	$6,408	$21,687
FL_10	$100,000	$300,000	$173,000	$585,500	$3,704	$11,112	$6,408	$21,687
FL_11	$100,000	$300,000	$173,000	$585,500	$3,704	$11,112	$6,408	$21,687
FL_12	$100,000	$300,000	$173,000	$585,500	$3,704	$11,112	$6,408	$21,687
FL_13	$100,000	$300,000	$173,000	$585,500	$3,704	$11,112	$6,408	$21,687
AL_14	$100,000	$300,000	$173,000	$585,500	$3,704	$11,112	$6,408	$21,687
MS_15	$100,000	$300,000	$173,000	$585,500	$3,704	$11,112	$6,408	$21,687
PR_1	$100,000	$300,000	$173,000	$585,500	$3,704	$11,112	$6,408	$21,687
PR_2	$100,000	$300,000	$173,000	$585,500	$3,704	$11,112	$6,408	$21,687

Reach	Mob/Demob Low	Mob/Demob High	Total First Unit Cost Low	Total First Unit Cost High	Equivalent Annual Cost (EAC)-Mob-Low	EAC-Mob-High	EAC/Linear Foot (LF)-Low	EAC/LF-High
PR_3	$100,000	$300,000	$173,000	$585,500	$3,704	$11,112	$6,408	$21,687
PR_4	$100,000	$300,000	$173,000	$585,500	$3,704	$11,112	$6,408	$21,687
VI_1	$100,000	$300,000	$173,000	$585,500	$3,704	$11,112	$6,408	$21,687
VI_2	$100,000	$300,000	$173,000	$585,500	$3,704	$11,112	$6,408	$21,687
VI_3	$100,000	$300,000	$173,000	$585,500	$3,704	$11,112	$6,408	$21,687

6.8.6 NNBF-8 Limitations and Uncertainties

The costs for this measure are paramedic unit prices and calculated based on information developed from multiple projects within the State of Florida. Jacksonville Harbor Mile Point Project and the Perico Preserve Sea Grass Mitigation Bank were considered. Both of these projects included earthwork associated with flow improvement and establishment of vegetation and specifically seagrasses.

SAVs have high light requirements compared to phytoplankton (Kenworthy and Haunert 1991). They occur in shallow, nearshore waters, a situation that makes them extremely susceptible to damage by human activity such as nutrient loading (Short and Burdick 1996), light reduction (Dennsion et al. 1993; Kenworthy and Fonseca 1996), and propeller scarring (Sargent et al. 1995). Transplanting into areas experiencing seagrass loss due to decreased water transparency without independent improvements in water quality have been unsuccessful.

6.9 NNBF-9: Coral Reefs

6.9.1 NNBF-9 Measure Description

Coral reefs are underwater ecosystems characterized by reef-building corals. They are found in areas with relatively high water temperatures, good water clarity, low phosphates and nitrogen nutrients, and moderate wave energy (FDEP 2020b). The most common coral reefs found in Florida, Puerto Rico, and the U.S. Virgin Islands are fringing, shelf, bank, patch, and deepwater reefs.

Figure 6-13: Miami Dade Limerock Bolder Artificial Reef (Photo Source: Miami Dade)

Structural restoration of coral reefs has included boulders, sinking of wrecks, or relocation of rocks/dead coral heads. Additional engineering options, such as the bioengineered breakwater units discussed below under living shoreline reefs, are still an emerging technology for use in coral reef restoration projects along with recent advances in custom-designed three-dimensional printed reefs. Biological restoration includes transplanting living coral colonies either onto existing damaged reefs and/or the incorporation of structures into restoration.

6.9.2 NNBF-9 Measure Performance and Applicability

Coral reefs serve as natural, low-crested, submerged breakwaters, which provide flood reduction benefits through wave breaking and wave energy attenuation (Beck et al. 2018). Reefs provide more benefits against lower intensity, frequent storms, but even during more extreme events, the benefits of reefs to people and property are substantial (Beck et al. 2018). Recent studies (USGS 2019) have documented potential storm surge reduction benefits of coral reefs within the United States over multiple storms. This study found a reduction in inundation extents and associated societal and economic impacts including reduced impacts to critical infrastructure from not only the higher frequency events (i.e., 10-percent AEP event) but also lower frequency events (i.e., the 1-percent AEP and 0.2-percent AEP year). Although recent studies are showing these systems are effective in reducing storm damage to the areas in their lee, coral reef restoration projects are typically applicable only where there are existing or historic reefs with water temperatures, clarity, nutrients, and wave energy necessary to sustain the reef.

6.9.3 NNBF-9 Coastal Storm Risk Management Effects and Adaptability

6.9.3.1 NNBF-9 Physical and Temporal Effects

Coral reefs provide immediate environmental benefits. The addition of submerged substrate provides immediate attenuation of wave energy. As the reef system grows the reduction in wave energy grows as well leading to increasing benefits with time.

6.9.3.2 NNBF-9 National Economic Development, Regional Economic Development, Other Social Effects, and Environmental Quality Effects

Coral reefs can reduce coastal erosion and wave damage and augment other structural and/or nonstructural coastal storm risk management strategies. Additional ecosystem services of reefs include providing complex diverse ecosystems that support food and shelter to a variety of marine life, providing habitat that enhances commercial and recreational fisheries, improving water quality, and promoting tourism. These coastal habitats play an important role in carbon sequestration and they have the capacity to adapt to sea level rise (Duarte et al. 2013; Rodriguez et al. 2014). The following table shows the potential benefits and costs for each of the four national accounts.

Table 6-25: NNBF-9 National Economic Development, Regional Economic Development, Other Social Effects, and Environmental Quality Effects

Account	Potential Benefits	Potential Costs
NED	• Long-term reduction in property and critical infrastructure loss, vehicle damage, land loss, protective measure costs, emergency costs, and transportation delay costs • Incidental recreation	• Measure total investment cost • M&AM cost
RED	• Manage risk to regional revenue and employment in event of commercial property damage in the long term • Direct, indirect and induced effects of measure construction expenditure	• Possibility of revenue losses or employment disruptions as a result of measure (situational)
OSE	• Intermediate to long-term risk management effects on urban and community socioeconomic conditions • Potential educational, cultural, and recreational opportunities	–
EQ	• Manage risk to habitat and species • Manage risk to cultural resource assets in the long term	• Possibility for adverse environmental impacts (situational)

6.9.3.3 Sea Level Change Adaptability

Coral reefs are potentially able to adapt to some sea level change through natural secession as well as changing elevation. Science is uncertain to the ability of these landscapes to adjust with climate change.

6.9.4 NNBF-9 Design and Cost Components

6.9.4.1 NNBF-9 Generic Design

Reef design and restoration technology has advanced to a state of practice in which reef products that are specifically designed and proven to achieve biological objectives have demonstrated a significant potential to provide three-dimensional structures for colonization by benthic marine organisms, cover for crabs and juvenile and small fish, and foraging sites for larger fish. Modification of the reef design to also consider shoreline erosion risk management can readily be accomplished using the technology components available for reef construction.

The water depth in which the reef would be located is an important cost factor for achieving the goal of shoreline risk management. Deeper water would require more material to create a reef with a top elevation high enough to break large waves that would occur during the storm events with high water elevations. For the MCL, it is assumed that the top elevation of the reef would be established at -1 feet MLLW which will ensure that the structure is underwater most of the time while placing it as high as possible to reduce wave energy during storms.

For generic design purposes, it is assumed that the reef is located at a depth of -8 feet MLLW and has a width relative to the shoreline of about 40 feet. The reef is constructed using 6.5-foot-high articulated bioengineering reef units over marine mattress.

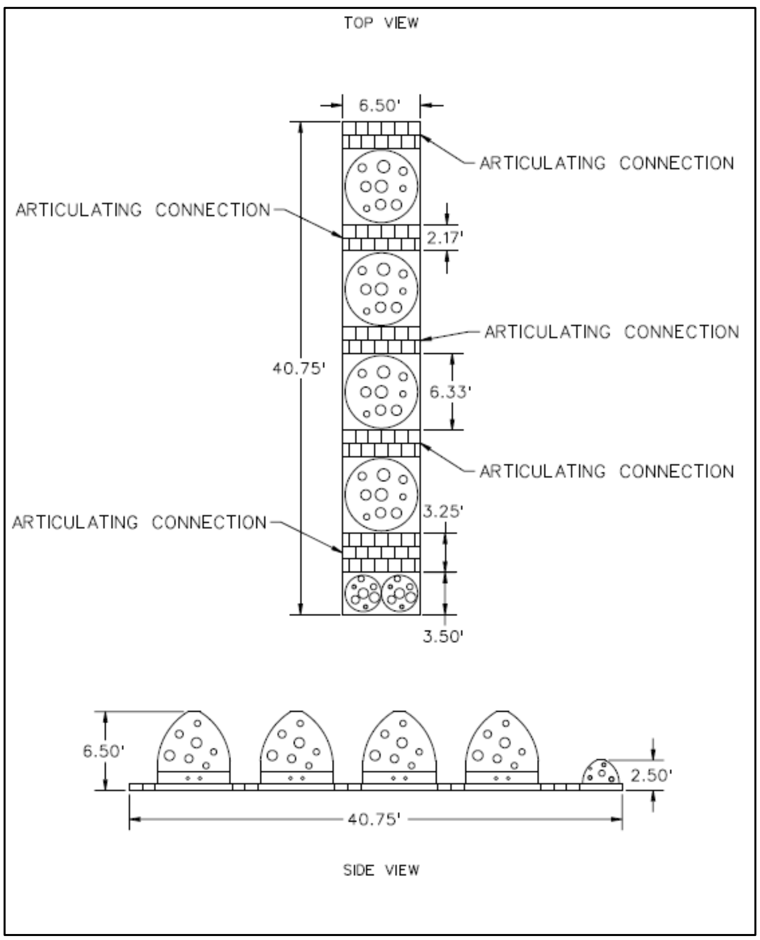

Figure 6-14: Example of a Reef Ball Breakwater Design (USACE)

6.9.4.2 NNBF-9 Cost Components

The cost drivers associated with these measures are site access and availability of materials to serve as the substrate. Prices could vary dramatically on these types of projects if they are constructed for research or environmental restoration purposes instead of their primary function being storm risk management purposes. In many cases, if a bioengineered substrate is designed, this work could be done through partnerships at the local level to save cost if volunteer labor or materials are donated.

Table 6-26 reflects what would be considered a contract cost prior to applying any additional markups, or owner markups. These additional costs include contingency at 20 percent for the low end and 40 percent for the high end. E&D and S&A are estimated at 15 percent and 12 percent, respectively, for both the high and low ends of the range presented. M&AM costs are estimated at 3 percent for the low end and 4 percent for the high end. The full or total owner cost are reflected as unit prices in **Table 6-26**. To analyze the cost components individually, the user may apply each additional owner markup in the order discussed above in a compounded process. Section 4.2.6.3 contains details regarding cost computations.

Table 6-26: NNBF-9 Cost Components

State / Territory / Planning Reach	Feature Category	Feature	Feature Unit	Quantity Low	Quantity High	Unit Cost Low	Unit Cost High
NNBF9_1(FL_07, FL_08, F_09, PR, VI) - Rubble	Unit	Reef Length	Linear feet (LF)	400	400	–	–
	Measure Cost	Mob/Demob	Lump sum (LS)	1	1	$400,000	$1,200,000
	Measure Cost	Reef Substrate Only	$/Acre (AC)	1	1	$1,400,000	$3,586,000
	Measure Cost	Coral Relocations	$/LF	2000	2000	$175	$1,000
NNBF9_2 (NC,SC,GA,FL_06, FL_10, FL_11, FL_12, FL_13, AL_14, MS_15) - Mattresses	Unit	Reef Length	LF	500	500	–	–
	Measure Cost	Mob/Demob	LS	1	1	$400,000	$1,200,000
	Measure Cost	Reef Mattresses	$/Each	135	180	$5,687	$9,958

6.9.5 NNBF-9 Unit Cost Ranges by Planning Reach

Coral reef measures may be viable in the southern reaches of Florida, Puerto Rico, and U.S. Virgin Islands. **Table 6-27** provides unit costs by planning reach for coral reefs.

Table 6-27: NNBF-9 Unit Cost Ranges by Planning Reach

Reach	Mob/Demob Low	Mob/Demob High	Total First Unit Cost Low	Total First Unit Cost High	Equivalent Annual Cost (EAC)-Mob-Low	EAC-Mob-High	EAC/Linear Foot (LF)-Low	EAC/ LF-High
NC_01	$400,000	$1,200,000	$2,703	$8,074	$14,816	$44,449	$100	$299
NC_02	$400,000	$1,200,000	$2,703	$8,074	$14,816	$44,449	$100	$299
SC_03	$400,000	$1,200,000	$2,703	$8,074	$14,816	$44,449	$100	$299
SC_04	$400,000	$1,200,000	$2,703	$8,074	$14,816	$44,449	$100	$299
GA_05	$400,000	$1,200,000	$2,703	$8,074	$14,816	$44,449	$100	$299

Reach	Mob/Demob Low	Mob/Demob High	Total First Unit Cost Low	Total First Unit Cost High	Equivalent Annual Cost (EAC)-Mob-Low	EAC-Mob-High	EAC/Linear Foot (LF)-Low	EAC/ LF-High
FL_06	$400,000	$1,200,000	$2,703	$8,074	$14,816	$44,449	$100	$299
FL_07	$400,000	$1,200,000	$7,063	$26,689	$14,816	$44,449	$262	$989
FL_08	$400,000	$1,200,000	$7,063	$26,689	$14,816	$44,449	$262	$989
FL_09	$400,000	$1,200,000	$7,063	$26,689	$14,816	$44,449	$262	$989
FL_10	$400,000	$1,200,000	$2,703	$8,074	$14,816	$44,449	$100	$299
FL_11	$400,000	$1,200,000	$2,703	$8,074	$14,816	$44,449	$100	$299
FL_12	$400,000	$1,200,000	$2,703	$8,074	$14,816	$44,449	$100	$299
FL_13	$400,000	$1,200,000	$2,703	$8,074	$14,816	$44,449	$100	$299
AL_14	$400,000	$1,200,000	$2,703	$8,074	$14,816	$44,449	$100	$299
MS_15	$400,000	$1,200,000	$2,703	$8,074	$14,816	$44,449	$100	$299
PR_1	$400,000	$1,200,000	$7,063	$26,689	$14,816	$44,449	$262	$989
PR_2	$400,000	$1,200,000	$7,063	$26,689	$14,816	$44,449	$262	$989
PR_3	$400,000	$1,200,000	$7,063	$26,689	$14,816	$44,449	$262	$989
PR_4	$400,000	$1,200,000	$7,063	$26,689	$14,816	$44,449	$262	$989
VI_1	$400,000	$1,200,000	$7,063	$26,689	$14,816	$44,449	$262	$989
VI_2	$400,000	$1,200,000	$7,063	$26,689	$14,816	$44,449	$262	$989
VI_3	$400,000	$1,200,000	$7,063	$26,689	$14,816	$44,449	$262	$989

6.9.6 NNBF-9 Limitations and Uncertainties

The costs for this measure are paramedic unit prices and calculated based on information developed from multiple projects within Jacksonville District. The Port Everglades Harbor Project and the Brevard Mid-Reach Mitigation Project were considered. The Port Everglades project is still in the design phase, but the Brevard Mid-Reach Project is completed. Both of these projects contain construction of reef substrate. However, only the Port Everglades project included relocation of corals. The Brevard Mitigation Project assumes that the mattresses with variable elevation from reef balls would stimulate coral recruitment. The low and high mobilization and demobilization prices are directly from Brevard Mid-Reach Mitigation Project. The range of unit prices for substrate takes into consideration of both projects. The low cost is more representative of rubble limestone structure. The higher unit cost is more representative of a bioengineered structure, such as a combination of mattresses and reef balls.

Siting is a critical factor in any coral reef project. Site conditions, including hydrodynamics, substrate type, foundation, water quality, and sedimentation can all play pivotal roles in the applicability, costs, and success of coral reef projects. It is impossible given the regional scale of the study to account for these local, site-specific conditions to determine the applicability of this measure at any particular location. If existing threats to the ecological function of the reef, such as degraded water quality exists, the measure may not be applicable at a given location or there may be additional costs.

6.10 NNBF-10: Oyster Reefs

6.10.1 NNBF-10 Measure Description

Oysters can be found living in salty or brackish waters along all United States coasts, clustering on older shells, rock, piers, or any hard, submerged surface. They fuse together as they grow, forming rock-like reefs that provide habitat for other marine animals and plants (NOAA 2020).

Figure 6-15: South Carolina Oyster Shell Living Shoreline Reef (Photo Source: South Carolina Department of Natural Resources)

There are several methods of reef construction including three-dimensional reefs, intertidal (fringing reefs) and broad scale low-profile reefs. These reefs have been developed with multiple natural material types, such as oyster shells, clam shells, or rock. La Peyre et al. (2014) documented that rock-based materials accounted for more than half of the created reefs (51 percent) across the northern Gulf of Mexico and included crushed limestone, limestone boulders, and various forms of concrete (e.g., culverts, crushed concrete, bridge and roadbed rubble, reef-dome forms, etc.). La Peyre et al. (2014) found shell, usually from oysters and sometimes clams (*Rangia*), to be the second most commonly used material (20 percent).

Engineering options such as the bioengineered breakwater units discussed in Section 6.11 are an emerging technology for uses in oyster reef restoration projects along with recent advances in custom-designed three-dimensional printed reefs.

6.10.2 NNBF-10 Measure Performance and Applicability

Oyster reefs can help stabilize shorelines by promoting sediment deposition and buffering wave energy, thereby allowing other habitats such as sea grass beds and marsh areas to form while simultaneously decreasing erosion of the shoreline (La Peyre et al. 2014; Brown et al. 2014; Dillon et al. 2015; George et al. 2015). The magnitude of these effects depends on the specific characteristics of the oyster reef, including the structure crest elevation relative to the mean sea level tidal datum, surface roughness, its location relative to the shoreline, and the size of the structure relative to the incident wavelength.

Oyster reef viability and long-term sustainability may be affected by numerous factors including reef height, size, complexity and local water quality characteristics (Lenihan 1999; Coen and Luckenbach 2000; O'Beirn et al. 2000; Gregalis et al. 2008; Gregalis 2009; Powers et al. 2009; La Peyre et al. 2013a; La Peyre et al. 2013b). Similarly, shoreline protection services may vary as a function of local site bathymetry, energy exposure, and reef height (Piazza et al. 2005; Scyphers et al. 2011). However, given the regional scale of the study, it is impossible to account for these local, site-specific, conditions to determine existing or future threats that may impact the applicability at any potential location.

While these structures can provide a reduction in shoreline loss in areas with low to moderate wave climates and can provide ecological benefits, they historically have not specifically been designed for coastal storm risk management and may need to be incorporated with other reef structures and materials to achieve this goal.

6.10.3 NNBF-10 Coastal Storm Risk Management Effects and Adaptability

6.10.3.1 NNBF-10 Physical and Temporal Effects

Upon construction, the measure reduces erosion and wave energy to exposed areas in its lee. This reduction in erosion is expected to increase over time. The measure provides immediate habitat. Reef breakwaters have also been known to provide support for fisheries.

6.10.3.2 NNBF-10 National Economic Development, Regional Economic Development, Other Social Effects, and Environmental Quality Effects

The restoration of natural three-dimensional reefs in the salty or brackish coastal waters in the SACS study area would provide a means to reestablish and enhance reef communities, while at the same time potentially providing shoreline erosion risk management. This erosion risk management could serve two beneficial purposes: managing risk to fastland and structures, and preventing sediment from covering the reef. Other environmental and socioeconomic benefits of restored oyster reefs include carbon sequestration, water quality improvements, including excess nutrient uptake, and commercial and recreational fishing. Oyster reef restoration in particular provides spatially complex substrate and benthic structure that is important for many estuarine organisms. The structural material provides suitable surfaces for attachment of small filter feeders, such as barnacles and marine vegetation, whereas voids and passages in the reef structures provide cover from predators for crabs and juvenile or small fish. Sedimentation effects are also reduced, as the vertical height of artificial reef structures provides longevity relative to existing reefs that are relatively level, near the bottom and more susceptible to the effects of sedimentation. **Table 6-28** shows the potential benefits and costs for each of the four national accounts.

Table 6-28: NNBF-10 National Economic Development, Regional Economic Development, Other Social Effects and Environmental Quality Effects

Account	Potential Benefits	Potential Costs
NED	• Manage risk to property and critical infrastructure loss, vehicle damage, land loss, protective measure costs, emergency costs, and transportation delay costs • Incidental recreation in the intermediate term	• Measure total investment cost • M&AM cost
RED	• Manage risk to regional revenue and employment in event of commercial property damage in the long term • Direct, indirect and induced effects of measure construction expenditure	• Possibility of revenue losses or employment disruptions because of measure (situational)
OSE	• Intermediate term risk management effects on urban and community socioeconomic conditions • Potential to provide educational, cultural, and recreational opportunities	–
EQ	• Manage risk to habitat and species • Manage risk to cultural resource assets with time	• Possibility for adverse environmental impacts (situational)

6.10.3.3 Sea Level Change Adaptability

Oyster reefs are potentially able to adapt to some sea level change through natural secession as well as changing elevation. Science is uncertain to the ability of these landscapes to adjust with climate change.

6.10.4 NNBF-10 Design and Cost Components

6.10.4.1 NNBF-10 Generic Design

Reef design and restoration technology has advanced to a state of practice in which reef products that are specifically designed and proven to achieve biological objectives have demonstrated a significant potential to provide three-dimensional structures for colonization by benthic marine organisms, cover for crabs and juvenile and small fish, and foraging sites for larger fish. Modification of the reef design to also consider shoreline erosion risk management can readily be accomplished using the technology components available for reef construction.

The water depth in which the reef would be located is an important cost factor for achieving the goal of coastal storm risk management. Deeper water would require more material to create a reef with a top elevation high enough to break the large waves that occur during storm events. For the MCL, it is assumed that the top elevation of the reef would be established at -1 feet MLLW, which will ensure that the structure is underwater most of the time, while placing it as high as possible to reduce wave energy during storms. Generally, wave reduction is not the controlling design factor in oyster reef projects. Instead, these are typically driven by ecological restoration goals. Therefore, in most cases restored reefs are relatively low relief (1 to 2 feet above the existing bottom elevation). A higher relief reef will be more effective at reducing waves but it will also be significantly more costly for the same restoration area.

For generic design purposes it is assumed that the reef is located at -5 feet MLLW and has a width relative to the shoreline of about 100 feet. The reef is constructed using riprap as a base material up to elevation -2 feet MLLW, then placing a 1-foot layer of oyster shell on top to bring the final elevation up to -1 feet MLLW (4 feet above the bottom). The riprap would have a median weight of 50 pounds.

6.10.4.2 NNBF-10 Design and Cost Components

Cost estimations assume riprap would to be obtained from a local quarry and oyster shell would be hauled by rail from a quarry in Florida (near Tallahassee) that currently is the only location to obtain large sources of the material. Both the riprap and the oyster material would be transferred to a shallow-draft barge for placement in the water.

Table 6-29 reflects what would be considered a contract cost prior to applying any additional markups, or owner markups. These additional costs include contingency at 20 percent for the low end and 40 percent for the high end, E&D and S&A are estimated at 15 percent and 12 percent, respectively, for both the high and low ends of the range presented. M&AM costs are estimated at 3 percent for the low end and 4 percent for the high end. The full or total owner costs are reflected as unit prices in **Table 6-30**. To analyze the cost components individually, the user may apply each additional owner markup in the order discussed above in a compounded process. Section 4.2.6.3 contains details regarding cost computations.

Table 6-29: NNBF-10 Cost Components

State / Territory / Planning Reach	Feature Category	Feature	Feature Unit	Quantity Low	Quantity High	Unit Cost Low	Unit Cost High
NNBF10_1: (All)	Unit	Reef Length	Linear feet (LF)	400	400	–	–
	Measure Cost	Mob/Demob	Lump sum	1	1	$100,000	$300,000
	Measure Cost	Flow Improvement Earthwork	$/Acre (AC)	1	1	$1,500.00	$5,000.00
	Measure Cost	Underlayer/Core Stone	$/Ton	1240	2869	$180.00	$270.00
	Measure Cost	Oyster Reefs	$/Square feet (SF)	100	1200	$14.85	$17.10

6.10.5 NNBF-10 Unit Cost Ranges by Planning Reach

Table 6-30 provides unit costs by planning reach for oyster reefs.

Table 6-30: NNBF-10 Unit Cost Ranges by Planning Reach

Reach	Mob/Demob Low	Mob/Demob High	Total First Unit Cost Low	Total First Unit Cost High	Equivalent Annual Cost (EAC)-Mob-Low	EAC-Mob-High	EAC/Linear Foot (LF)-Low	EAC/ LF-High
NC_01	$100,000	$300,000	$973	$4,063	$3,704	$11,112	$36	$151
NC_02	$100,000	$300,000	$973	$4,063	$3,704	$11,112	$36	$151
SC_03	$100,000	$300,000	$973	$4,063	$3,704	$11,112	$36	$151
SC_04	$100,000	$300,000	$973	$4,063	$3,704	$11,112	$36	$151
GA_05	$100,000	$300,000	$973	$4,063	$3,704	$11,112	$36	$151
FL_06	$100,000	$300,000	$973	$4,063	$3,704	$11,112	$36	$151
FL_07	$100,000	$300,000	$973	$4,063	$3,704	$11,112	$36	$151
FL_08	$100,000	$300,000	$973	$4,063	$3,704	$11,112	$36	$151
FL_09	$100,000	$300,000	$973	$4,063	$3,704	$11,112	$36	$151
FL_10	$100,000	$300,000	$973	$4,063	$3,704	$11,112	$36	$151
FL_11	$100,000	$300,000	$973	$4,063	$3,704	$11,112	$36	$151
FL_12	$100,000	$300,000	$973	$4,063	$3,704	$11,112	$36	$151
FL_13	$100,000	$300,000	$973	$4,063	$3,704	$11,112	$36	$151
AL_14	$100,000	$300,000	$973	$4,063	$3,704	$11,112	$36	$151
MS_15	$100,000	$300,000	$973	$4,063	$3,704	$11,112	$36	$151
PR_1	$100,000	$300,000	$973	$4,063	$3,704	$11,112	$36	$151
PR_2	$100,000	$300,000	$973	$4,063	$3,704	$11,112	$36	$151
PR_3	$100,000	$300,000	$973	$4,063	$3,704	$11,112	$36	$151
PR_4	$100,000	$300,000	$973	$4,063	$3,704	$11,112	$36	$151
VI_1	$100,000	$300,000	$973	$4,063	$3,704	$11,112	$36	$151
VI_2	$100,000	$300,000	$973	$4,063	$3,704	$11,112	$36	$151
VI_3	$100,000	$300,000	$973	$4,063	$3,704	$11,112	$36	$151

6.10.6 NNBF-10 Assumptions, Sources, Limitations, and Uncertainties

The costs for this measure are parametric unit prices and calculated taking into consideration information from multiple projects. Recent bid data from a shore protection project known as Sarasota County Lido Key Segment was considered for the majority of the itemized cost features. That project was awarded in FY20 and two groins are being constructed. This project is assumed to be of similar enough nature, level of effort, and risk to assume comparable construction costs. Recent estimates developed on the Puerto Rico Coastal Storm Risk Management Study were also considered because of their focus on the toe protection features that are needed to prevent undermining of the structural measure. The unit prices for construction of the oyster reefs were developed based on research and quotes received.

Siting is a critical factor in any oyster reef project. Site conditions, including hydrodynamics, substrate type, foundation, water quality, sedimentation, inter reef connectivity and threats of predation, can all play pivotal roles in the applicability, costs, and success of oyster reef projects. It is impossible given the regional scale of the study to account for these local, site-specific conditions to determine the applicability of this measure at any location. If existing threats to the ecological function of the reef exist, such as degraded water quality, the measure may not be applicable at a given location or there may be additional costs.

6.11 NNBF-11: Living Shoreline Reefs

6.11.1 NNBF-11 Measure Description

A living shoreline reef is a structure that provides potential habitat within it and functions like a low-crested breakwater to reduce wave energy on the shoreline. Living shoreline reefs, also referred to as bioengineered breakwaters, may be obtained from discarded construction debris, such as clean, rebar-free concrete, but are now more commonly being accomplished using structures specifically designed for reef creation. These include but are not limited to the use of Wave Attenuation Devices (WADs™) and reef balls which are made of concrete, or other similar designs.

Figure 6-16: Coffee Island Nearshore Reefs (Photo Source: EWN Atlas)

6.11.2 NNBF-11 Measure Performance and Applicability

The use of the latest generation of designed reef structures with specific biologically oriented features provides a significant improvement over debris materials and earlier designed structures. One benefit is that their design and performance are increasingly being supported by readily available engineering, and scientific and monitoring data. There is a proven track record of providing valuable habitat and fishing opportunities throughout the SACS reaches.

Alternatives to traditional breakwater materials and traditional coastal structures are growing in practice. These materials are presented as alternatives that provide performance, habitat value, or an ecosystem service. The use of artificial reef units as ‘living breakwaters’ is becoming more common (Allen and Webb 2011; Webb and Allen 2015), even in lieu of accepted performance criteria and design standards (Webb et al. 2019).

While these structures can provide wave energy reduction in low to moderate wave climates while providing ecological benefits, they are not specifically designed for coastal storm risk management and may need to be incorporated with other reef structures and materials to achieve this goal.

6.11.3 NNBF-11 Coastal Storm Risk Management Effects and Adaptability

6.11.3.1 NNBF-11 Physical and Temporal Effects

Upon construction, the measure reduces erosion and wave energy to the exposed areas in its lee. It provides immediate increases in habitat and provides support for fisheries over the longer term.

6.11.3.2 NNBF-11 National Economic Development, Regional Economic Development, Other Social Effects, and Environmental Quality Effects

Table 6-31 shows the potential benefits and costs for each of the four national accounts.

Table 6-31: NNBF-11 National Economic Development, Regional Economic Development, Other Social Effects, and Environmental Quality Effects

Account	Potential Benefits	Potential Costs
NED	• Intermediate term reduction in property and critical infrastructure loss, vehicle damage, land loss, protective measure costs, emergency costs, and transportation delay costs • Incidental recreation	• Measure total investment cost • M&AM cost
RED	• Manage risk to regional revenue and employment in event of commercial property damage in the long term • Direct, indirect, and induced effects of measure construction expenditure	• Possibility of revenue losses or employment disruptions as a result of measure (situational)
OSE	• Intermediate term risk management effects on urban and community socioeconomic conditions • Potential to provide educational, cultural, and recreational opportunities	–
EQ	• Manage risk to habitat and species • Manage risk to cultural resource assets in the long term	• Possibility for adverse environmental impacts (situational)

6.11.3.3 NNBF-11 Sea Level Change Adaptability

Living shoreline reefs are potentially able to adapt to some sea level change through future changes in elevation.

6.11.4 NNBF-11 Design and Cost Components

6.11.4.1 NNBF-11 Generic Design

Offshore water depths, erosion rates, soil conditions, currents, waves, as well as other physical, environmental, and economic factors will typically dictate the applicability of a bioengineered reef as well as the material type and structure profile. However, given the regional scale of the study, it is impossible to account for these local, site-specific conditions to determine the type or size of breakwater that may be most appropriate at each location.

Living shoreline reefs are typically constructed offshore in areas where the offshore depths are between 3 to 5 feet. Shallow offshore depths are one of the factors that limits wave exposure and creates the low-medium energy conditions required. Living shoreline reefs are intended to be low-crested structures with a freeboard of between 0 and 1 feet above mean high water and are generally constructed at sites with a small to moderate tidal range. Factors that influence reef unit spacing are similar to traditional breakwater structures.

For generic design purposes, it is assumed that the living shoreline segmented reef would be constructed using bioengineering reef units. The design assumes placement of units over marine mattress in 5 to 6 feet of water depth to achieve a final elevation of +1 feet MLLW.

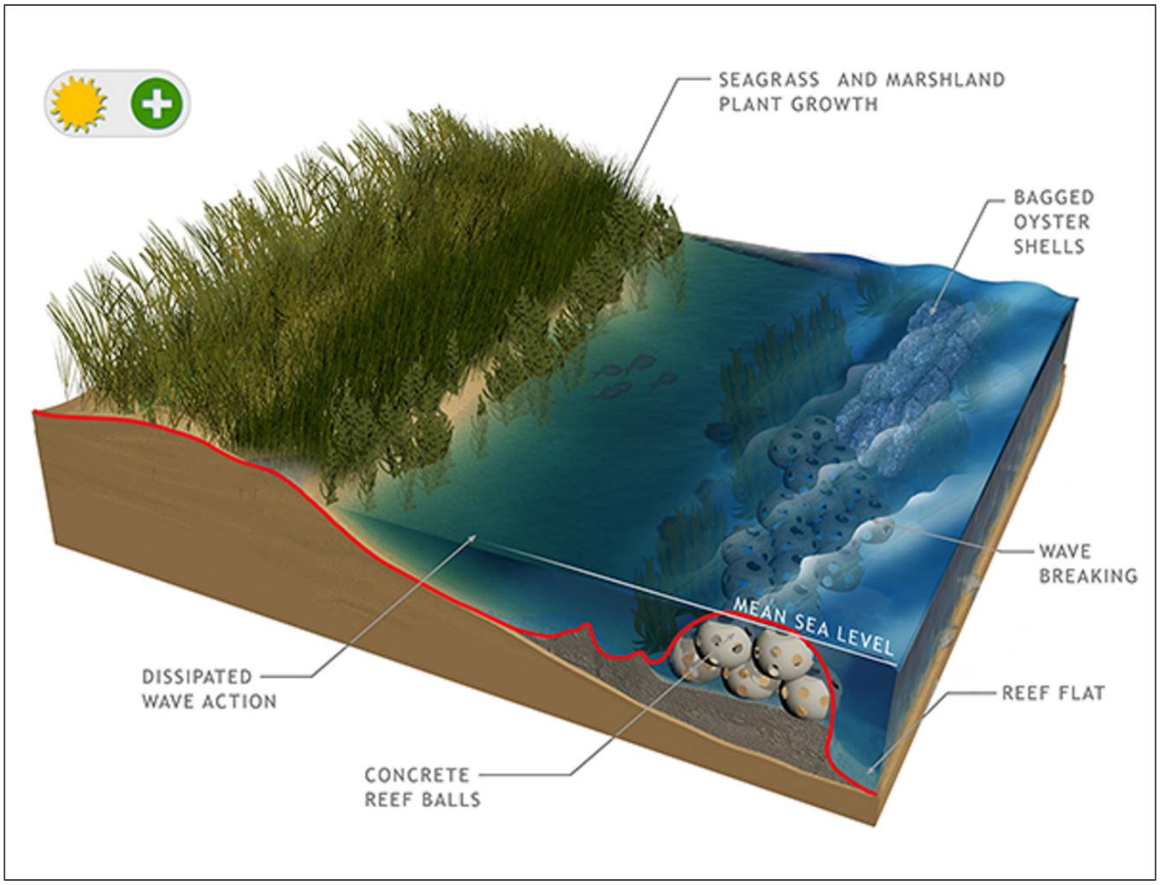

Figure 6-17: Conceptual Living Shoreline and Oyster Reef Layout (USACE 2015a)

6.11.4.2 NNBF-11 Cost Components

Costs are provided as individual units. Therefore, a user should estimate the number of reef units necessary to construct a segmented reef system in order to determine the cost range. Each reef unit is assumed to be approximately 400 feet in length and 8 feet in width at the crest and constructed with bioengineered units built upon marine mattresses.

The cost drivers associated with these measures can be site access and availability of materials to serve as the substrate. Prices could vary dramatically on these types of projects if they are constructed for research or environmental restoration purposes instead of their primary function being storm risk management purposes. In many cases, if a bioengineered substrate is designed and constructed off-site, this work could be done through partnerships at the local level to save cost if volunteer labor or materials are donated.

Table 6-32 reflects what would be considered a contract cost prior to applying any additional markups, or owner markups. These additional costs include contingency at 20 percent for the low end and 40 percent for the high end. E&D and S&A are estimated at 15 percent and 12 percent, respectively, for both the high and low ends of the range presented. M&AM costs are estimated at 3 percent for the low end and 4 percent for the high end. The full or total owner costs are reflected as unit prices in **Table 6-33**. To analyze the cost components individually, the user may apply each additional owner markup in the order discussed above in a compounded process. Section 4.2.6.3 contains details regarding cost computations.

Table 6-32: NNBF-11 Cost Components

State / Territory / Planning Reach	Feature Category	Feature	Feature Unit	Quantity Low	Quantity High	Unit Cost Low	Unit Cost High
NNBF11_1: (All)	Unit	Reef Length	Linear Feet (LF)	400	400	–	–
	Measure Cost	Mob/Demob	Lump sum	1	1	$250,000	$1,200,000
	Measure Cost	Rubble-Mound Substrate	$/Acre (AC)	1	1	$700,000	$1,400,000
	Measure Cost	Coral Relocations	$/LF	2000	2000	$175	$1,000
	Measure Cost	Monitoring	$/AC	1	1	$500,000	$500,000

6.11.5 NNBF-11 Unit Cost Ranges by Planning Reach

Living shoreline reefs may be viable in all reaches within the SACS study area along more sheltered coastlines. **Table 6-33** provides unit costs by planning reach for living shoreline reefs.

Table 6-33: NNBF-11 Unit Cost Ranges by Planning Reach

Reach	Mob/Demob Low	Mob/Demob High	Total First Unit Cost Low	Total First Unit Cost High	Equivalent Annual Cost (EAC)-Mob-Low	EAC-Mob-High	EAC/Linear Foot (LF)-Low	EAC/ LF-High
NC_01	$250,000	$1,200,000	$6,125	$19,313	$9,260	$44,449	$227	$715
NC_02	$250,000	$1,200,000	$6,125	$19,313	$9,260	$44,449	$227	$715
SC_03	$250,000	$1,200,000	$6,125	$19,313	$9,260	$44,449	$227	$715
SC_04	$250,000	$1,200,000	$6,125	$19,313	$9,260	$44,449	$227	$715
GA_05	$250,000	$1,200,000	$6,125	$19,313	$9,260	$44,449	$227	$715
FL_06	$250,000	$1,200,000	$6,125	$19,313	$9,260	$44,449	$227	$715
FL_07	$250,000	$1,200,000	$6,125	$19,313	$9,260	$44,449	$227	$715
FL_08	$250,000	$1,200,000	$6,125	$19,313	$9,260	$44,449	$227	$715
FL_09	$250,000	$1,200,000	$6,125	$19,313	$9,260	$44,449	$227	$715
FL_10	$250,000	$1,200,000	$6,125	$19,313	$9,260	$44,449	$227	$715
FL_11	$250,000	$1,200,000	$6,125	$19,313	$9,260	$44,449	$227	$715
FL_12	$250,000	$1,200,000	$6,125	$19,313	$9,260	$44,449	$227	$715
FL_13	$250,000	$1,200,000	$6,125	$19,313	$9,260	$44,449	$227	$715
AL_14	$250,000	$1,200,000	$6,125	$19,313	$9,260	$44,449	$227	$715
MS_15	$250,000	$1,200,000	$6,125	$19,313	$9,260	$44,449	$227	$715
PR_1	$250,000	$1,200,000	$6,125	$19,313	$9,260	$44,449	$227	$715
PR_2	$250,000	$1,200,000	$6,125	$19,313	$9,260	$44,449	$227	$715

Reach	Mob/Demob Low	Mob/Demob High	Total First Unit Cost Low	Total First Unit Cost High	Equivalent Annual Cost (EAC)-Mob-Low	EAC-Mob-High	EAC/Linear Foot (LF)-Low	EAC/LF-High
PR_3	$250,000	$1,200,000	$6,125	$19,313	$9,260	$44,449	$227	$715
PR_4	$250,000	$1,200,000	$6,125	$19,313	$9,260	$44,449	$227	$715
VI_1	$250,000	$1,200,000	$6,125	$19,313	$9,260	$44,449	$227	$715
VI_2	$250,000	$1,200,000	$6,125	$19,313	$9,260	$44,449	$227	$715
VI_3	$250,000	$1,200,000	$6,125	$19,313	$9,260	$44,449	$227	$715

6.11.6 NNBF-11 Assumptions, Sources, Limitations, and Uncertainties

No universal type of living shoreline reef can be prescribed because of the wide variation in conditions at each location as well as the growing available bioengineered units available on the market. Site-specific foundation conditions, exposure to wave action, availability of materials as well as structural and functional performance criteria will influence the type of reef, the structure profile, and cost.

The costs for this measure are paramedic unit prices and calculated based on information developed from multiple projects within Jacksonville District. The Port Everglades Harbor Project and the Brevard Mid-Reach Mitigation Project were considered. The Port Everglades project is still in the design phase, but the Brevard Mid-Reach Project is completed. Both of these projects contain construction of reef substrate and relocation of corals. The low and high mobilization and demobilization prices are directly from Brevard Mid-Reach. The range of unit prices for substrate takes into consideration both projects. The prices were reduced based on estimator judgment taking into consideration that the living shoreline reef may require smaller stone and also may be constructed in more sheltered environments. Both the low and the high estimates are representative of rubble limestone structure.

6.12 NNBF-12: Living Shoreline Sills

6.12.1 NNBF-12 Measure Description

A living shoreline sill is a coast-parallel, low-profile structure built with the objective of reducing the wave action on the shoreline. These structures are designed to dissipate wave energy and reduce bank erosion, causing waves to break on the offshore structure, rather than on the natural, more fragile shore (Miller et al. 2015). Sills can be designed using a number of different materials, including rock, armor stone, grout-filled bags, geotubes, rock gabion baskets and natural materials such as oysters.

Figure 6-18: Morris Landing Stone Sill (Photo Source: Webb et al. 2019)

6.12.2 NNBF-12 Measure Performance and Applicability

Sills manage risk by maintaining a minimum distance between the hazard and the exposed areas and by moderating shoreline change rates. Primary and secondary risk management functions include reducing wave attack and erosion impacts respectively. Sills are applicable in low and mixed wave energy environments. Sills reduce waves and stabilize the shoreline in its lee providing reduction in shoreline erosion. These structures are effective at minimizing gradual erosion but are susceptible to event-based hazards, such as storm surge flooding during extreme storm events (Webb et al. 2019). The position of the crest relative to the water level plays an important role in the amount of energy dissipation that can be expected as well as the amount of force the structure is subjected to (Webb et al. 2019). Theoretically, there is no sill design limitation based on storm surge; however large storm surges will lead to increased overtopping and wave transmission (Webb et al. 2019). Once the freeboard reaches approximately 1.25 times the incident wave height, the wave energy dissipation is minimal (d'Angremond et al. 1996).

6.12.3 NNBF-12 Coastal Storm Risk Management Effects and Adaptability

6.12.3.1 NNBF-12 Physical and Temporal Effects

Upon construction, the measure can reduce erosion and wave energy to exposed area in its lee. It provides immediate increases in habitat.

6.12.3.2 NNBF-12 National Economic Development, Regional Economic Development, Other Social Effects, and Environmental Quality Effects

The quiescent area of water that is created by the sill often allows sand and sediment to accumulate between the structure and the shoreline. With time, this process can eventually raise the elevation of the bottom and create a perched beach. This unique effect not only serves to further stabilize the shoreline or marsh behind the sill but replaces lost and eroded land. Construction of sills and marsh can remove sand from the sediment transport system, which may impact neighboring shorelines and habitats. **Table 6-34** shows the potential benefits and costs for each of the four national accounts.

Table 6-34: NNBF-12 National Economic Development, Regional Economic Development, Other Social Effects, and Environmental Quality Effects

Account	Potential Benefits	Potential Costs
NED	• Intermediate term reduction in property and critical infrastructure loss, vehicle damage, land loss, protective measure costs, emergency costs, and transportation delay costs • Incidental recreation	• Measure total investment cost • M&AM cost
RED	• Manage risk to regional revenue and employment in event of commercial property damage with time • Direct, indirect, and induced effects of measure construction expenditure	• Possibility of revenue losses or employment disruptions as a result of measure (situational)
OSE	• Intermediate term risk management effects on urban and community socioeconomic conditions • Potential to provide educational, cultural, and recreational opportunities	–
EQ	• Manage risk to habitat and species • Manage risk to cultural resource assets with time	• Possibility for adverse environmental impacts (situational)

6.12.3.3 NNBF-12 Sea Level Change Adaptability

The measure is potentially able to adapt to some sea level change through changing elevation.

6.12.4 NNBF-12 Design and Cost Components

6.12.4.1 NNBF-12 Generic Design

Offshore water depths, erosion rates, soil conditions, currents, waves, as well as other physical, environmental and economic factors will typically dictate the applicability of a sill as well as the material type and structure profile. However, given the regional scale of the study, it is impossible to account for these local, site-specific conditions to determine the type or size of sill that may be most appropriate at each location.

Sills are typically constructed in areas where the offshore depths are between 3 to 5 feet. Shallow offshore depths are one of the factors that limit wave exposure and create the low-medium energy conditions required for the project. Living shoreline sills are intended to be low-crested structures with a freeboard of between 0 and 1 feet above mean high water and are generally constructed at sites with a small to moderate tidal range. Limited research has been performed to determine optimum gap width and frequency, but a general empirical guide recommends windows at least every 100 feet along the length of the project (Hardaway Jr., Milligan and Duhring 2010). Factors that influence window spacing include drainage, elevation change, recreational access, and bends in the project.

For generic design purposes, it is assumed the sill is a rubble-mound structure placed at crest elevations of 1 foot above mean high water with 2 (Horizontal): 1 (Vertical) side slopes and integrated on a geotextile filter fabric. Structural heights and stone weights range based on variations in regional hydrodynamics from one planning reach to another. The structure was assumed to be 2 to 3 stones wide at the crest.

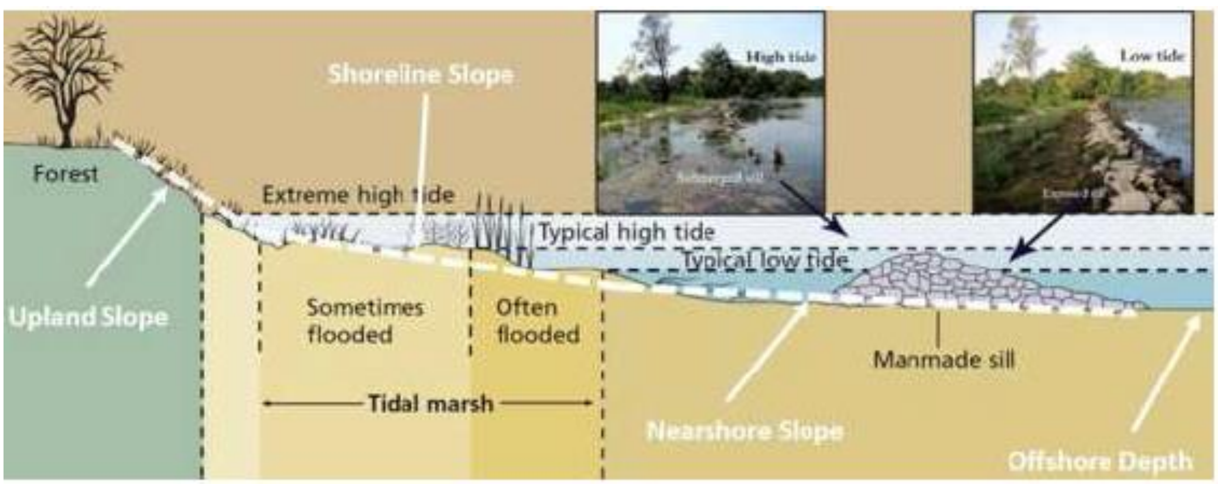

Figure 6-19: A Conceptual Marsh Sill Layout (Webb, Dix, et al. 2019)

6.12.4.2 NNBF-12 Cost Components

The cost drivers associated with these measures are site access and availability of material for sill creation if there is not already a natural shelf or contour change along the shoreline. Prices could vary dramatically on these types of projects if they are constructed for research or environmental restoration purposes instead of their primary function being storm risk management purposes. Growing and planting of the vegetation could be done through partnerships at the local level to save cost if volunteer labor or materials are donated.

Table 6-35 reflects what would be considered a contract cost prior to applying any additional markups, or owner markups. These additional costs include contingency at 20 percent for the low end and 40 percent for the high end. E&D and S&A are estimated at 15 percent and 12 percent, respectively, for both the high and low ends of the range presented. M&AM costs are estimated at 3 percent for the low end and 4 percent for the high end. The full or total owner cost are reflected as unit prices in **Table 6-36**. To analyze the cost components individually, the user may apply each additional owner markup in the order discussed above in a compounded process. Section 4.2.6.3 contains details regarding cost computations.

Table 6-35: NNBF-12 Cost Components

State / Territory / Planning Reach	Feature Category	Feature	Feature Unit	Quantity Low	Quantity High	Unit Cost Low	Unit Cost High
NNBF12_1: (All)	Unit	Shoreline Length	Linear feet (LF)	1000	1000	–	–
	Measure Cost	Mob/Demob	Lump sum	1	1	$250,000	$1,200,000
	Measure Cost	Sill Creation	$/LF	1	1	$1,000,000	$3,700,000
	Measure Cost	Vegetation	$/Acre (AC)	40	60	$3,000	$11,000

6.12.5 NNBF-12 Unit Cost Ranges by Planning Reach

Living shoreline reefs may be viable in all reaches within the SACS study area along more sheltered coastlines. **Table 6-36** provides unit costs by planning reach for living shoreline sills.

Table 6-36: NNBF-12 Unit Cost Ranges by Planning Reach

Reach	Mob/Demob Low	Mob/Demob High	Total First Unit Cost Low	Total First Unit Cost High	Equivalent Annual Cost (EAC)-Mob-Low	EAC-Mob-High	EAC/ Linear Feet (LF)-Low	EAC/ LF-High
NC_01	$250,000	$1,200,000	$1,805	$8,530	$9,260	$44,449	$67	$316
NC_02	$250,000	$1,200,000	$1,805	$8,530	$9,260	$44,449	$67	$316
SC_03	$250,000	$1,200,000	$1,805	$8,530	$9,260	$44,449	$67	$316
SC_04	$250,000	$1,200,000	$1,805	$8,530	$9,260	$44,449	$67	$316
GA_05	$250,000	$1,200,000	$1,805	$8,530	$9,260	$44,449	$67	$316
FL_06	$250,000	$1,200,000	$1,805	$8,530	$9,260	$44,449	$67	$316
FL_07	$250,000	$1,200,000	$1,805	$8,530	$9,260	$44,449	$67	$316
FL_08	$250,000	$1,200,000	$1,805	$8,530	$9,260	$44,449	$67	$316
FL_09	$250,000	$1,200,000	$1,805	$8,530	$9,260	$44,449	$67	$316
FL_10	$250,000	$1,200,000	$1,805	$8,530	$9,260	$44,449	$67	$316
FL_11	$250,000	$1,200,000	$1,805	$8,530	$9,260	$44,449	$67	$316
FL_12	$250,000	$1,200,000	$1,805	$8,530	$9,260	$44,449	$67	$316
FL_13	$250,000	$1,200,000	$1,805	$8,530	$9,260	$44,449	$67	$316
AL_14	$250,000	$1,200,000	$1,805	$8,530	$9,260	$44,449	$67	$316
MS_15	$250,000	$1,200,000	$1,805	$8,530	$9,260	$44,449	$67	$316
PR_1	$250,000	$1,200,000	$1,805	$8,530	$9,260	$44,449	$67	$316
PR_2	$250,000	$1,200,000	$1,805	$8,530	$9,260	$44,449	$67	$316
PR_3	$250,000	$1,200,000	$1,805	$8,530	$9,260	$44,449	$67	$316
PR_4	$250,000	$1,200,000	$1,805	$8,530	$9,260	$44,449	$67	$316
VI_1	$250,000	$1,200,000	$1,805	$8,530	$9,260	$44,449	$67	$316
VI_2	$250,000	$1,200,000	$1,805	$8,530	$9,260	$44,449	$67	$316
VI_3	$250,000	$1,200,000	$1,805	$8,530	$9,260	$44,449	$67	$316

6.12.6 NNBF-12 Assumptions, Sources, Limitations, and Uncertainties

Depending on the size of the structure and the strength of the underlying soils, the foundation layer may consist of a geotextile membrane, a gravel base, or a flexible gabion mattress.

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SECTION 7

Nonstructural Measures

7.1 Physical Nonstructural Measures

7.1.1 NS-1: Buyout / Acquisition

7.1.1.1 NS-1 Measure Description

Buyout/acquisition involves the purchase and elimination of flood damageable structures, allowing for inhabitants to relocate away from flood hazards. This measure is the most dependable method of protection and provides the benefit of use of the evacuated floodplain.

7.1.1.2 NS-1 Measure Method, Performance, and Applicability

NS-1 manages risk through permanent retreat from the exposed area or floodplain. The primary risk management functions of buyouts are to reduce harm caused from inundation, wave attack, and erosion impacts of coastal storms. Buyouts are applicable in low, mixed, and high wave energy environments. The measure is effective at reducing coastal storm risk because it removes assets from the exposed area. As the exposed assets are removed from harm's way, there is less need for roads, electricity, and water infrastructure within the exposed area. This measure is applicable to all shoreline types and is effective at reducing and/or removing risk from inundation, wave attack, and erosion hazards for all coastal storm event magnitudes considered.

7.1.1.3 NS-1 Coastal Storm Risk Management Measure Effects

7.1.1.3.1 NS-1 Physical and Temporal Effects

NS-1 provides immediate risk management effects for NED. NS-1 provides intermediate risk management effects for RED and OSE. For intermediate EQ risk management effects, NS-1 must be combined with other measures.

7.1.1.3.2 NS-1 National Economic Development, Regional Economic Development, Other Social Effects, and Environmental Quality Effects

Depending on how relocation is structured, there could be adverse impacts to community cohesion and local tax revenues, which is an OSE cost. Relocating businesses out of the exposed area would result in fewer disruptions to the local economy which may be a RED gain. However, disruptions to RED could occur depending on how crucial location is for any impacted business. Success in one location does not guarantee success in another. Businesses that may not be under threat from the coastal storm risk could be adversely impacted by a change in local traffic patterns due to evacuation of the long-term population. Buyout/acquisition does not in and of itself manage risk to habitats and species. However, an evacuated floodplain has the potential to be used for environmentally beneficial purposes. It is unlikely that this measure would produce any cultural resource risk management benefits. Measure NS-1 could achieve NED benefits by reducing long-term risk to property and infrastructure. Removal of the population from the exposed area reduces coastal storm risk to public safety which is an OSE benefit. **Table 7-1** shows the potential benefits and costs for each of the four national accounts.

Table 7-1: NS-1 National Economic Development, Regional Economic Development, Other Social Effects, and Environmental Quality Effects

Account	Potential Benefits	Potential Costs
NED	• Manage risk of public and private property loss, vehicle damage and increased emergency costs	• Buyout and acquisition measure costs (Demolition, replacement, moving, appraisals, etc.)
RED	• If buyout is aimed at commercial assets, it can manage risk to employment and output in the intermediate to long term • Direct, indirect, and induced effects from measure implementation expenditures	• Lost revenue and economic activity during move • Potential risks to economic activity in new location • Potential loss of regional economic activity if people and/or businesses relocate from the region
OSE	• Potential positive risk management effects on urban and community socioeconomic conditions • Manage risk to security of life, health, and safety • Emergency preparedness	• Potential loss of community tax revenue, income, and cohesion
EQ	• Can be used in conjunction with other measures to provide future habitat in the intermediate to long term	–

7.1.1.4 NS-1 Assumptions, Cost Components, and Cost Drivers

7.1.1.4.1 NS-1 Assumptions and Information Sources

Buyout measures are constrained primarily to single-family residential structures and do not include commercial structures. The outline for evaluating costs for measure NS-1 comes from the Florida Keys Coastal Storm Risk Management Study (USACE 2020b). The National Structure Inventory (NSI) is used for estimating values in the continental United States, while the Flood Assessment Structure Tool (FAST) is used for Puerto Rico and the U.S. Virgin Islands. Additional data come from the Civil Works Construction Cost Index.

7.1.1.4.2 NS-1 Cost Components and Cost Drivers

The planners in the Florida Keys Coastal Storm Risk Management Study estimate that the cost of buying out each asset would be equal to the structure's market value plus demolition, replacement housing, moving cost, potential last resort housing, survey costs, appraisal review, full-service support (including administration costs, appraisals, title works, etc.), and potential condemnation all totaling $176,780 per structure in addition to its market value.

In the below tables, all costs are updated to national equivalents (from the original Florida study) and then to FY20 values appropriate for the overall study. This was done using the CWCCIS. The market value for properties comes from the NSI, specific to single-family residences in the specified planning reach.

Table 7-2: NS-1 Buyout/Acquisition Cost Components

Cost Component	Unit	Low Value	High Value
Market Value	$	Varies by Planning Reach	Varies by Planning Reach
Demolition	$	$15,000	$15,000
Replacement Housing	$	$31,000	$31,000
Moving Fee	$	$10,000	$10,000
Last Resort Housing	$	$25,000	$25,000
Survey Cost	$	$5,000	$5,000
Review Appraisal	$	$3,000	$3,000
Full-Service Report	$	$72,780	$72,780
Condemnation	$	$15,000	$15,000
Total Fixed Cost	$	$176,780	$176,780
Contingency	%	20%	30%

7.1.1.5 NS-1 Unit Cost Ranges by Planning Reach

Structure buyouts and acquisition are viable in all reaches within SACS contingent upon local sponsor(s) support.

Table 7-3: NS-1 Buyout/Acquisition Cost per Asset by Planning Reach

Planning Reach	Buyout Cost per Asset		Annualized Buyout Cost per Asset	
	Low	High	Low	High
NC_01	$324,210	$691,333	$12,009	$25,608
NC_02	$331,464	$745,880	$12,278	$27,628
SC_03	$330,505	$725,993	$12,242	$26,891
SC_04	$344,539	$831,511	$12,762	$30,800
GA_05	$323,139	$729,501	$11,969	$27,021
FL_06	$330,704	$758,334	$12,250	$28,089
FL_07	$336,664	$772,412	$12,470	$28,611
FL_08	$332,301	$799,622	$12,309	$29,619
FL_09	$341,513	$724,967	$12,650	$26,853
FL_10	$339,314	$789,558	$12,569	$29,246
FL_11	$328,798	$771,367	$12,179	$28,572
FL_12	$318,577	$717,009	$11,800	$26,559
FL_13	$323,474	$710,237	$11,982	$26,308
AL_14	$325,175	$741,915	$12,045	$27,481
MS_15	$326,644	$712,842	$12,099	$26,404
PR_1	$268,256	$421,361	$9,936	$15,608
PR_2	$266,246	$424,152	$9,862	$15,711
PR_3	$266,685	$412,806	$9,878	$15,291
PR_4	$281,440	$453,920	$10,425	$16,814
VI_1	$355,850	$738,680	$13,181	$27,361
VI_2	$372,928	$959,442	$13,814	$35,539
VI_3	$350,106	$866,581	$12,968	$32,099

7.1.1.6 NS-1 Sea Level Change Adaptability

Buyout and acquisition removes the asset of concern out of the floodplain. Sea level change should be considered when deciding the buyout footprint. Asset removal from the exposed area eliminates residual risk and the need for sea level change adaptability.

7.1.1.7 NS-1 Limitations and Uncertainties

The primary limitation of measure NS-1 is the data source for market values, especially for Puerto Rico and the U.S. Virgin Islands. The market values for planning reaches in the continental United States come from the NSI, specific to single-family residences in the specified planning reach. Given the limitations of the dataset, the low cost is calculated using the value of residential structures at the 5th percentile of the NSI, while the high cost uses the 95th percentile. Puerto Rico and the U.S. Virgin Islands use the FAST dataset and the 20th and 80th percentiles. Supplementing the MCL methodology with project-specific market values would greatly decrease the uncertainty surrounding estimates for NS-1.

7.1.2 NS-2: Structure Elevation

Figure 7-1: Downtown Charleston Structural Elevating

7.1.2.1 NS-2 Measure Description

Structure elevation involves raising the assets in place so that the structure sees a reduction in frequency and/or depth of flooding during high water events. Elevation can be done on fill, foundation walls, piers, piles, posts, or columns. Selection of proper elevation method depends on flood characteristics, such as flood depth or velocity.

7.1.2.2 NS-2 Measure Method, Performance, and Applicability

Structure elevation reduces risk by effectively increasing the distance between the exposed asset and the harm. However, the extent of the risk management is limited because the assets remain within the exposed area. As such, there would still be a certain amount of infrastructure such as roads, power, and water needed to support elevated assets that remain. In addition, more severe coastal storm events than those used to justify elevating the structure would be able to impact assets. Structure elevation is applicable to all shoreline types and is effective at managing risk from inundation and wave attack hazards produced by less severe coastal storm events.

7.1.2.3 NS-2 Coastal Storm Risk Management Measure Effects

7.1.2.3.1 NS-2 Physical and Temporal Effects

NS-2 provides immediate risk management effects for NED, RED, OSE, and EQ.

7.1.2.3.2 NS-2 National Economic Development, Regional Economic Development, Other Social Effects, and Environmental Quality Effects

NS-2 could achieve NED benefits by managing risk to property. The measure may provide some OSE benefits by affording some degree of protection for populations that may be forced to shelter in place. Structure elevation could reduce the potential for damage to structures and capital; however, there is still significant RED risk because public sector infrastructure would remain exposed. Elevating assets does not manage risk to habitats, species, or cultural resource sites. **Table 7-4** shows the potential benefits and costs for each of the four national accounts.

Table 7-4: NS-2 National Economic Development, Regional Economic Development, Other Social Effects, and Environmental Quality Effects

Account	Potential Benefits	Potential Costs
NED	• Manages risk of public and private property loss	• Replacement housing, elevation costs
RED	• Manages risk to regional output and employment by elevating assets out of harm, reducing the length of business disruptions • Direct, indirect, and induced effects from the measure	• Elevation of commercial assets could temporarily disrupt economic activity
OSE	• Manages risk to security of life, health, and safety by elevating the portion of the population at risk that shelters in place	–
EQ	• Manages risks to cultural resources by making them more resilient to inundation harm	–

7.1.2.4 NS-2 Assumptions, Cost Components, and Cost Drivers

7.1.2.4.1 NS-2 Assumptions and Information Sources

Structure elevations are constrained primarily to residential wood frame structures and do not include commercial structures. The outline for evaluating costs for measure NS-2 comes from the Southwest Coastal Louisiana Study (SCLS) (USACE 2016). The cost per square foot in the low cost estimate assumes 6 feet of raising at the minimum cost reported for a one-story pier foundation building. The cost per square foot in the high cost estimate assumes 13 feet of raising at the maximum cost reported for a two-story slab foundation building. Both estimates originate from the SCLS. Replacement housing was sourced from the NS-1 measure and added to the estimated cost. The NSI is used for square footage in the continental United States while the FAST dataset is used for Puerto Rico and the U.S. Virgin Islands (USVI). Additional data comes from the Civil Works Construction Cost Index.

7.1.2.4.2 NS-2 Design and Cost Components

The planners in the SCLS estimated the cost of raising a one-story slab, two-story slab, one-story pier, two-story pier, and mobile homes from 1 foot to 13 feet. These costs are reported per square foot. In the below tables, all costs are updated to national equivalents (from the original Louisiana study) and then to FY20 values appropriate for the overall study. This was done using the CWCCIS.

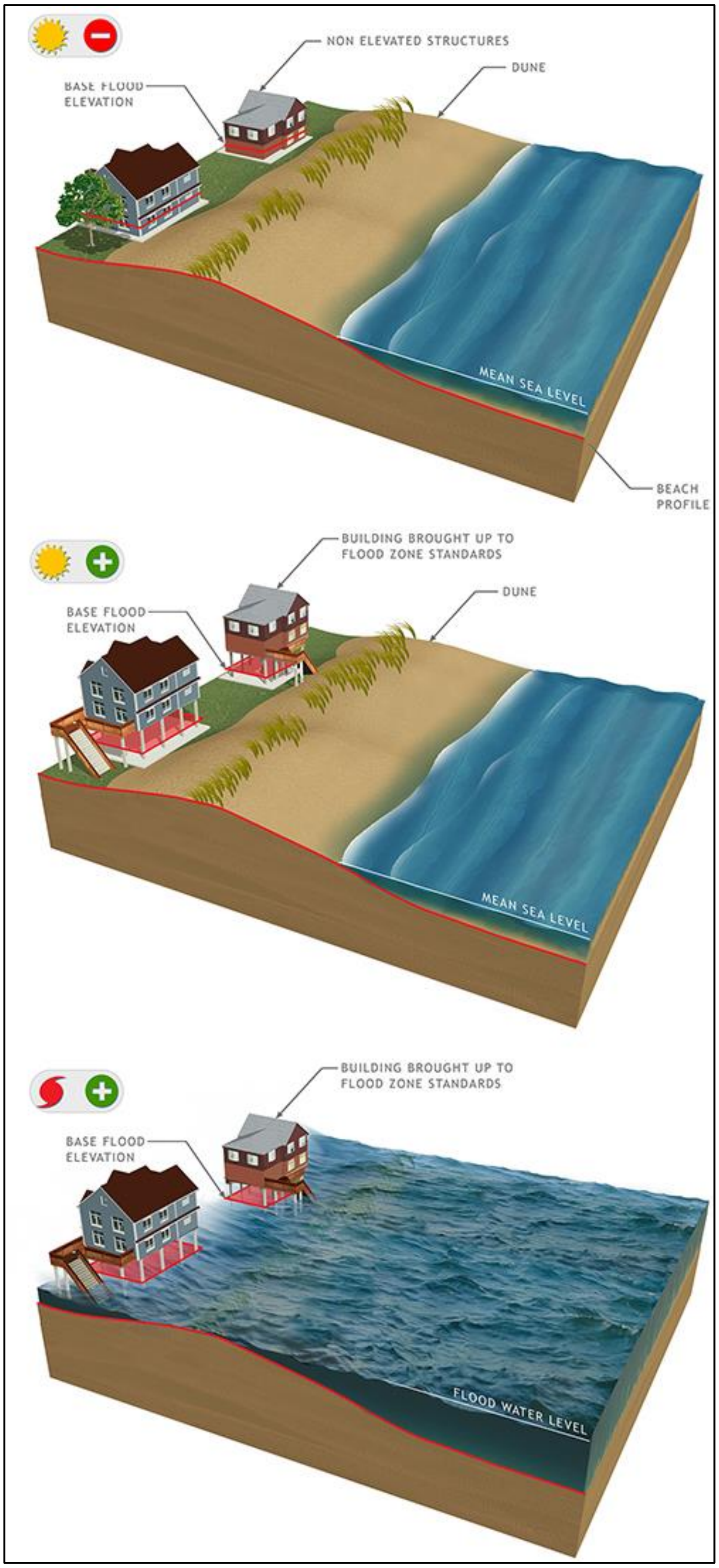

Figure 7-2: Conceptual Structure Elevation (USACE 2015a)

Table 7-5: NS-2 Structure elevation Cost Components

Cost Component	Unit	Low Value	High Value
Square Feet of Asset	Square feet (SQFT)	Varies by Planning Reach	Varies by Planning Reach
Feet Raised	Linear feet (LF)	6 feet	13 feet
Foundation	Type	One-Story Pier Minimum	Two-Story Slab Maximum
Replacement Housing	$	$31,000	$31,000
Contingency	%	20%	30%

7.1.2.5 NS-2 Unit Cost Ranges by Planning Reach

Structure elevation is viable in all reaches within the SACS study area contingent upon local sponsor(s) support.

Table 7-6: NS-2 - Structure elevation Cost per Asset by Planning Reach

Planning Reach	Elevation Cost per Asset		Annualized Elevation Cost per Asset	
	Low	High	Low	High
NC_01	$131,650	$296,067	$4,876	$10,967
NC_02	$131,650	$307,263	$4,876	$11,381
SC_03	$132,312	$307,263	$4,901	$11,381
SC_04	$132,312	$305,339	$4,901	$11,310
GA_05	$131,650	$298,166	$4,876	$11,044
FL_06	$131,650	$298,166	$4,876	$11,044
FL_07	$132,312	$298,166	$4,901	$11,044
FL_08	$128,501	$295,717	$4,760	$10,954
FL_09	$132,312	$296,067	$4,901	$10,967
FL_10	$132,644	$307,263	$4,913	$11,381
FL_11	$131,650	$298,166	$4,876	$11,044
FL_12	$130,821	$296,067	$4,846	$10,967
FL_13	$131,650	$298,166	$4,876	$11,044
AL_14	$131,650	$296,592	$4,876	$10,986
MS_15	$131,650	$298,166	$4,876	$11,044
PR_1	$90,059	$214,718	$3,336	$7,953
PR_2	$87,987	$216,818	$3,259	$8,031
PR_3	$88,319	$205,359	$3,271	$7,607
PR_4	$101,244	$232,563	$3,750	$8,614
VI_1	$119,305	$288,107	$4,419	$10,672
VI_2	$129,910	$396,222	$4,812	$14,676
VI_3	$106,960	$322,746	$3,962	$11,955

7.1.2.6 NS-2 Sea Level Change Adaptability

Sea level change should be considered when deciding structure elevation height. The potential for wind and seismic hazards should also be considered.

7.1.2.7 NS-2 Limitations and Uncertainties

The primary limitation of measure NS-2 is the data source for building footprints, especially for Puerto Rico and the U.S. Virgin Islands. The number of square feet needed to be raised for planning reaches in the continental United States comes from the NSI, specific to single-family residences in the specified planning reach. The low cost is calculated using the value of residential structures at the 5th percentile of the NSI, while the high cost uses the 95th percentile. Puerto Rico and the U.S. Virgin Islands use the FAST and the 20th and 80th percentiles. Houses on the upper end of the distribution are assumed to be two stories of equal footprints. Supplementing the MCL methodology with project-specific footprints would greatly decrease the uncertainty surrounding estimates for NS-2.

7.1.3 NS-3: Dry Floodproofing

7.1.3.1 NS-3 Measure Description

Dry floodproofing involves sealing building walls with waterproofing compounds, impermeable sheeting, or other materials to prevent the entry of floodwaters into damageable structures. Dry floodproofing is applicable in areas of shallow, low velocity flooding.

7.1.3.2 NS-3 Coastal Storm Risk Management Method, Performance, and Applicability

Dry floodproofing reduces risk by reducing the vulnerability of each asset in terms of its susceptibility to damage up to a certain elevation. The structure accrues less damage per foot of flooding. Risk management is limited because each asset must have ingress and egress points that tend to be weak links in the protection provided. Typically, the structure can only be floodproofed up to the windows. This means floodwaters in excess of approximately 30 feet will likely flood the asset and produce damages anyway. As a result, this measure can only provide risk management from higher frequency, lower magnitude flood events. It is ineffective against wave attack and erosion hazards. Like NS-2, risk management is limited because the assets remain within the exposed area. A certain amount of infrastructure such as roads, power, and water is still needed to support floodproofed assets that remain in exposed areas. Dry floodproofing as a risk management measure can be applied in all shoreline types to assets that tend to have concrete-based construction on slab foundations.

7.1.3.3 NS-3 Coastal Storm Risk Management Measure Effects

7.1.3.3.1 NS-3 Physical / Temporal Effects

NS-3 provides immediate risk management effects for NED and RED.

7.1.3.3.2 NS-3 National Economic Development, Regional Economic Development, Other Social Effects, and Environmental Quality Effects

NS-3 could achieve NED benefits by reducing flood damage risk to property. OSE benefits are anticipated to be nonexistent to minimal at best. Some RED benefits may be achievable because dry floodproofing has the potential to reduce damages to structures and capital from higher frequency lower magnitude events. However, significant RED residual risk remains because public sector infrastructure would remain exposed. Dry floodproofing does not manage risk to habitats, species, or cultural resource sites. **Table 7-7** shows the potential benefits and costs for each of the four national accounts.

Table 7-7: NS-3 National Economic Development, Regional Economic Development, Other Social Effects, and Environmental Quality Effects

Account	Potential Benefits	Potential Costs
NED	• Manages risk to property and infrastructure	• Dry floodproofing retrofit costs • Measure deployment costs
RED	• Manages risk to regional output and employment by reducing inundation related business disruptions • Direct, indirect, and induced effects from the measure construction expenditures	–
OSE	• Risk management of urban and community effects	–
EQ	• Manages risks to cultural resources by making them more resilient to inundation harm	–

7.1.3.4 NS-3 Assumptions, Design, Cost Components, and Cost Drivers

7.1.3.4.1 NS-3 Assumptions and Information Sources

Dry floodproofing measures are constrained primarily to single-family residential structures and do not include commercial structures. The outline for evaluating costs for measure NS-3 comes from USACE National Nonstructural Committee. NSI was used for linear feet of perimeter in the continental United States while the FAST dataset was used for Puerto Rico and the U.S. Virgin Islands. Additional data comes from the Civil Works Construction Cost Index.

7.1.3.4.2 NS-3 Cost Components and Cost Drivers

Cost components that differ between the low and high range are the asset perimeter, height of the protected area, and feet of pedestrian doors. All other cost components are fixed between the low and high range. Values for all cost components can be seen in **Table 7-8**. In the following tables, all costs are updated to national equivalents (from the Norfolk Coastal Storm Risk Management Study) and then to FY20 values appropriate for the overall study. This was done using the CWCCIS.

Table 7-8: NS-3 Dry Floodproofing Cost Components

Cost Component	Unit	Low Value	High Value
Asset Perimeter	Linear feet (LF)	Varies by Planning Reach	Varies by Planning Reach
Height of Protected Area	LF	2.5	3
Waterproof Sealant	$/Square feet (SQFT)	$2.44	$2.44
Masonry Veneer	$/SQFT	$18.27	$18.27
CMU Wall	$/SQFT	$21.41	$21.41
Footing & Foundation	$/LF	$96.32	$96.32
Total Costs per Linear Foot	$/LF	$201.63	$222.69
Feet of Ped Doors	LF	3	12
Ped Door Cost per Foot	$/LF	$983.20	$983.20
Feet of Overhead Doors	LF	0	25
Overhead Door Cost per Foot	$/LF	$1,199.51	$1,199.51
Skimmer Pump Unit	$	$185.39	$185.39
Sewer Backflow	$	$1,594.99	$1,594.99
Total Fixed Cost	$	$4,730.00	$43,566.54
Contingency	%	20%	30%

7.1.3.5 NS-3 Unit Cost Ranges by Planning Reach

Dry floodproofing is viable in all reaches within the SACS study area contingent upon local sponsor(s) support.

Table 7-9: NS-3 Dry Floodproofing per Asset by Planning Reach

Planning Reach	Dry Floodproofing Cost per Asset		Annualized Dry Floodproofing Cost per Asset	
	Low	High	Low	High
NC_01	$38,353	$100,913	$1,421	$3,738
NC_02	$38,353	$101,871	$1,421	$3,773
SC_03	$38,467	$101,871	$1,425	$3,773
SC_04	$38,467	$101,708	$1,425	$3,767
GA_05	$38,353	$101,094	$1,421	$3,745
FL_06	$38,353	$101,094	$1,421	$3,745
FL_07	$38,467	$101,094	$1,425	$3,745
FL_08	$37,804	$100,882	$1,400	$3,737
FL_09	$38,467	$100,913	$1,425	$3,738

Planning Reach	Dry Floodproofing Cost per Asset		Annualized Dry Floodproofing Cost per Asset	
	Low	High	Low	High
FL_10	$38,524	$101,871	$1,427	$3,773
FL_11	$38,353	$101,094	$1,421	$3,745
FL_12	$38,209	$100,913	$1,415	$3,738
FL_13	$38,353	$101,094	$1,421	$3,745
AL_14	$38,353	$100,958	$1,421	$3,740
MS_15	$38,353	$101,094	$1,421	$3,745
PR_1	$30,121	$93,200	$1,116	$3,452
PR_2	$29,638	$93,419	$1,098	$3,460
PR_3	$29,716	$92,205	$1,101	$3,415
PR_4	$32,584	$95,024	$1,207	$3,520
VI_1	$36,143	$100,218	$1,339	$3,712
VI_2	$38,050	$108,867	$1,409	$4,033
VI_3	$33,759	$103,165	$1,250	$3,821

7.1.3.6 NS-3 Sea Level Change Adaptability

Dry floodproofing can usually withstand water depths up to 3 feet before hydrostatic loads begin to compromise structural integrity. Measure adaptability to sea level change is limited for most residential structures.

7.1.3.7 NS-3 Limitations and Uncertainties

The primary limitation of measure NS-3 is the data source for building footprints, especially for Puerto Rico and the U.S. Virgin Islands. The number of linear feet of perimeter for planning reaches in the continental United States comes from the NSI, specific to single-family residences in the specified planning reach. The low cost estimate is calculated using the value of residential structures in the 5th percentile of the NSI, while the high cost estimate uses the 95th percentile. Puerto Rico and the U.S. Virgin Islands use the FAST and the 20th and 80th percentiles. Perimeter values are derived from square feet assuming a square building footprint. Houses on the upper end of the distribution are assumed to be two stories of equal footprints. Supplementing the MCL methodology with project-specific footprints would greatly decrease the uncertainty surrounding estimates for NS-3.

7.1.4 NS-4: Wet Floodproofing

7.1.4.1 NS-4 Measure Description

Wet floodproofing measures allows floodwater to enter the structure. Vulnerable items, such as utilities, appliances, and furnaces are waterproofed or elevated to higher locations. Allowing floodwater to enttural damage.

7.1.4.2 NS-4 Measure Method, Performance, and Applicability

Wet floodproofing manages risk by retrofitting the exposed asset to be less vulnerable to inundation hazards, the primary risk management function. This measure is applicable in sheltered, low wave energy environments. The structure accrues less damage per foot of flooding from high frequency, low magnitude coastal events. However, any risk management would be limited to the structure and only to a limited degree. This measure is unlikely to provide risk management to the contents of structures. As with NS-3, risk management is limited because each asset must have ingress and egress points that tend to be weak links in the protection provided. Coastal storm events that generate water levels beyond the structure’s ingress and egress points will likely produce flood damages. As a result, this measure can only provide risk management from higher frequency, lower magnitude flood events and is ineffective against wave attack and erosion hazards. Like NS-2 and NS-3, risk management is limited because the assets remain within the exposure area. There must still be a certain amount of infrastructure such as roads, power, and water needed to support wet floodproofed assets that remain exposed to the flood hazard. Wet floodproofing can be applied in all shoreline types. This measure is anticipated to provide little to no risk management in the face of sea level rise.

7.1.4.3 NS-4 Coastal Storm Risk Management Measure Effects

7.1.4.3.1 NS-4 Physical and Temporal Effects

NS-4 provides immediate risk management effects for NED and RED.

7.1.4.3.2 NS-4 National Economic Development, Regional Economic Development, Other Social Effects, and Environmental Quality Effects

NS-4 could achieve NED benefits by reducing flood damage risk to property. OSE benefits based on managing risk to public safety are anticipated to be minimal at best. Some RED benefits may be achievable because wet floodproofing has the potential to reduce damages to structures and capital from higher frequency lower magnitude events. However, significant RED residual risk remains because public sector infrastructure would remain exposed. Wet floodproofing can manage risk to cultural resource buildings, but does not manage risk to habitats, species, or cultural resource sites. **Table 7-10** shows the potential benefits and costs for each of the four national accounts.

Table 7-10: NS-4 National Economic Development, Regional Economic Development, Other Social Effects, and Environmental Quality Effects

Account	Potential Benefits	Potential Costs
NED	• Manages risk to public and private property	• Wet floodproofing retrofit cost
RED	• Manages risk to regional output and employment by reducing damage to commercial assets • Direct, indirect, and induced effects from the measure construction expenditures	–
OSE	• Risk management of urban and community socioeconomic conditions	–
EQ	• Manage risks to cultural resources buildings by making them more resilient to inundation harm	–

7.1.4.4 NS-4 Assumptions, Design, Cost Components, and Cost Drivers

7.1.4.4.1 NS-4 Assumptions and Information Sources

Wet floodproofing measures are constrained primarily to single-family residential structures and do not include commercial structures. The outline for evaluating costs for measure NS-4 comes from USACE NFPC/NWO Cost Engineering. NSI is used for square footage and linear feet of perimeter in the continental United States while the FAST dataset is used for Puerto Rico and the U.S. Virgin Islands. Additional data comes from the Civil Works Construction Cost Index.

7.1.4.4.2 NS-4 Design and Cost Components

Cost components that differ between the low and high estimates are square feet of the asset, asset perimeter, height of the protected area, and height which utilities are raised. All other cost components are fixed between the low and high estimates. All costs are subject to an additional 8-percent design fee. Values for all cost components can be seen in **Table 7-11**. In the following tables, all costs are updated to national equivalents (from the Norfolk Coastal Storm Risk Management Study) and then to FY20 values appropriate for the overall study. This was done using the CWCCIS.

Table 7-11: NS-4 Wet Floodproofing Cost Components

Cost Component	Unit	Low Value	High Value
Design Fee	%	108%	108%
Square Feet of Asset	Square feet (SQFT)	Varies by Planning Reach	Varies by Planning Reach
Flood Vent	$	$383.49	$383.49
Area Covered per Vent	SQFT	200	200
Total Cost per Square Foot	$/SQFT	$2.07	$2.07
Asset Perimeter	Linear feet (LF)	Varies by Planning Reach	Varies by Planning Reach
Height of Protected Area	LF	2.5	3
Demo	$/SQFT	$1.76	$1.76
Insulation and Steel Walls	$/SQFT	$10.52	$10.52
Total Costs per Linear Foot	$/LF	$33.16	$39.79
Height of Utility Raise	LF	2.5	3
Cost of Utility Raise	$/LF	$15.26	$15.26
Sewer Backwater Unit	$	$1,594.99	$1,594.99
Total Fixed Cost	$	$1,763.79	$1,772.03
Contingency	%	20%	30%

7.1.4.5 NS-4 Unit Costs by Planning Reach

Wet floodproofing is viable in all reaches within the SACS study area contingent upon local sponsor(s) support.

Table 7-12: NS-4 Wet Floodproofing Cost per Asset by Planning Reach

Planning Reach	Wet Floodproofing Cost Per Asset		Annualized Wet Floodproofing Cost Per Asset	
	Low	High	Low	High
NC_01	$10,323	$14,150	$382	$524
NC_02	$10,323	$14,494	$382	$537
SC_03	$10,362	$14,494	$384	$537
SC_04	$10,362	$14,435	$384	$535
GA_05	$10,323	$14,215	$382	$527
FL_06	$10,323	$14,215	$382	$527
FL_07	$10,362	$14,215	$384	$527
FL_08	$10,138	$14,140	$376	$524
FL_09	$10,362	$14,150	$384	$524
FL_10	$10,381	$14,494	$385	$537
FL_11	$10,323	$14,215	$382	$527
FL_12	$10,275	$14,150	$381	$524
FL_13	$10,323	$14,215	$382	$527
AL_14	$10,323	$14,167	$382	$525
MS_15	$10,323	$14,215	$382	$527
PR_1	$7,722	$11,520	$286	$427
PR_2	$7,580	$11,592	$281	$429
PR_3	$7,603	$11,199	$282	$415
PR_4	$8,462	$12,121	$313	$449
VI_1	$9,589	$13,904	$355	$515
VI_2	$10,221	$17,113	$379	$634
VI_3	$8,827	$14,963	$327	$554

7.1.4.6 NS-4 Sea Level Change Adaptability

Wet floodproofing is effective if the flood depths do not exceed the first framed floor. Measure adaptability to sea level change is anticipated to be limited.

7.1.4.7 NS-4 Limitations and Uncertainties

The primary limitation of measure NS-4 is the data source for building footprints, especially for Puerto Rico and the U.S. Virgin Islands. The number of square feet and linear feet of perimeter for planning reaches in the continental United States comes from the NSI, specific to single-family residences in the specified planning reach. The low cost estimate is calculated using the value of residential structures at the 5th percentile of the NSI, while the high cost estimate uses the 95th percentile. Puerto Rico and the U.S. Virgin Islands use the FAST and the 20th and 80th percentiles. Perimeter values are derived from square feet assuming a square building footprint. Houses on the upper end of the distribution are assumed to be two stories of equal footprints. Supplementing the MCL methodology with project-specific footprints would greatly decrease the uncertainty surrounding estimates for NS-4.

7.1.5 NS-5: Relocations

7.1.5.1 NS-5 Measure Description

Relocation involves moving the structure to another location away from flood hazards. Relocation is a very dependable method of protection and provides the benefit of use of the evacuated floodplain.

7.1.5.2 NS-5 Measure Method, Performance, and Applicability

NS-6 is very effective at achieving risk management because it removes assets from the exposed area. As the number of exposed assets decreases, there is less need for road, electricity, and water infrastructure within the exposed area. A greater distance required for relocation increases the complexity and cost of the measure. Relocations are most applicable in instances where assets can be removed from a hazardous area by moving only small distance. When used correctly, this measure is effective at reducing and/or removing risk from inundation, wave attack, and erosion hazards.

7.1.5.3 NS-5 Coastal Storm Risk Management Measure Effects

NS-6 involves physically relocating the asset out of the floodplain, reducing its exposure.

7.1.5.3.1 NS-5 Physical and Temporal Effects

NS-6 provided immediate risk management effects for NED, RED, and OSE. For intermediate EQ risk management effects, NS-6 must be combined with other measures.

7.1.5.3.2 NS-5 National Economic Development, Regional Economic Development, Other Social Effects, and Environmental Quality Effects

NS-6 could achieve NED benefits by managing risk to property and infrastructure. Removal of the population from the exposure reduces coastal storm risk to public safety which is an OSE benefit. However, depending on how relocation is structured, there could be adverse impacts to community cohesion and local tax revenues, which is an OSE cost. Relocating businesses out of the exposed area would result in fewer disruptions to the local economy which may be a RED gain. However, disruptions to RED could occur depending on how crucial location is for any impacted business. **Table 7-13** shows the potential benefits and costs for each of the four national accounts.

Table 7-13: NS-5 National Economic Development, Regional Economic Development, Other Social Effects, and Environmental Quality Effects

Account	Potential Benefits	Potential Costs
NED	• Manages risk to property and infrastructure	• Relocation measure costs
RED	• Manages risk to regional output and employment by reducing damage to commercial assets • Direct, indirect, and induced effects from the measure	–
OSE	• Risk management of urban and community effects	• Lost revenue and economic activity during move • Potential risks to economic activity in new location • Potential loss of regional economic activity if people and/or businesses relocate from the region
EQ	• Removal of development could allow evacuated land to be used for environmentally beneficial purposes	–

Success in one location does not guarantee success in another. Businesses that may not be under threat from the coastal storm risk could be adversely impacted by a change in local traffic patterns due to evacuation of the long-term population. Relocation does not in and of itself manage risk to habitats and species. However, an evacuated floodplain has the potential to be used for environmentally beneficial purposes. It is unlikely that this measure would produce any cultural resource risk management benefits.

7.1.5.4 NS-5 Assumptions, Design, Cost Components, and Cost Drivers

7.1.5.4.1 NS-5 Assumptions and Information Sources

Relocation is constrained primarily to single-family residential structures and do not include commercial structures. The outline for evaluating costs for measure NS-6 comes from USACE NFPC/NWO Cost Engineering (USACE 2017). NSI was used for square footage and linear feet of perimeter in the continental United States while the FAST dataset was used for Puerto Rico and the U.S. Virgin Islands. Additional data comes from the Civil Works Construction Cost Index.

7.1.5.4.2 NS-5 Cost Components and Cost Drivers

Cost components that differ between the low and high range are the square feet of the asset and the cost per square foot for moving the structure. All other cost components are fixed between the low and high cost estimates. Values for all cost components can be seen in **Table 7-14**. In the following tables, all costs are updated to national equivalents (from the Norfolk Coastal Storm Risk Management Study) and then to FY20 values appropriate for the overall study. This was done using the CWCCIS.

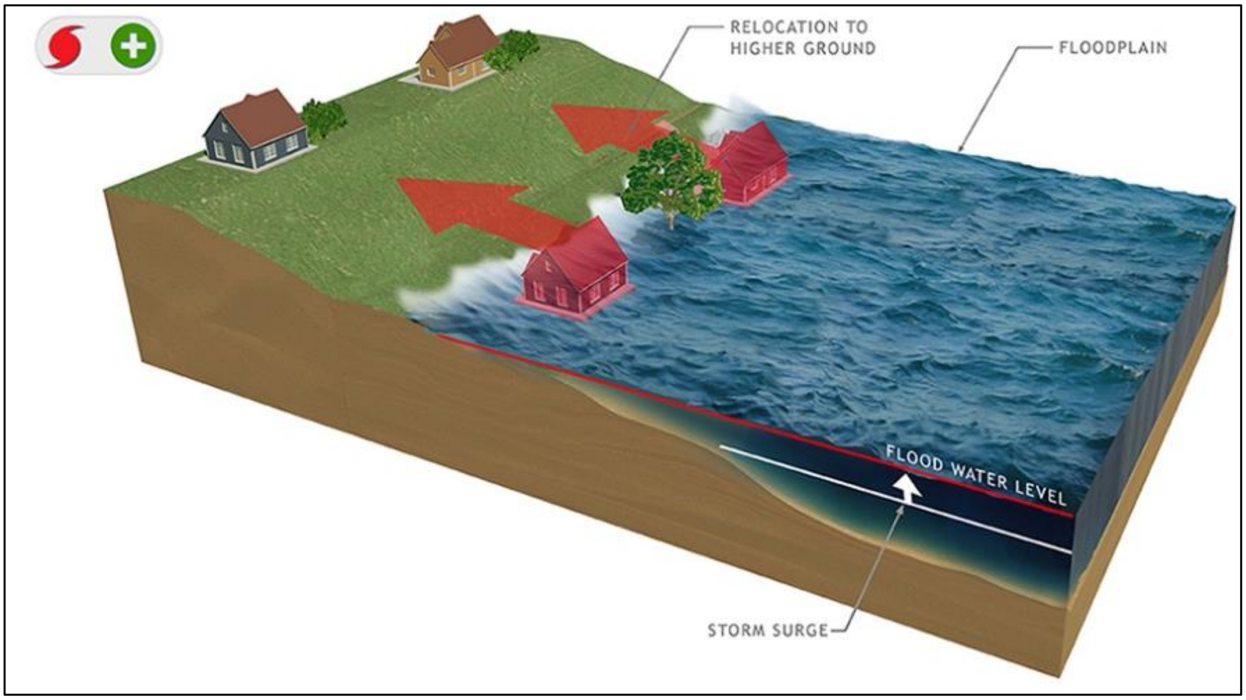

Figure 7-3: Conceptual Relocation (USACE 2015a)

Table 7-14: NS-5 Relocation Cost Components

Cost Component	Unit	Low Value	High Value
Square Feet of Asset	Square feet (SQFT)	Varies by Planning Reach	Varies by Planning Reach
Moving Structure	$/SQFT	$23.09	$31.18
House Demo/In-Fill	$/SQFT	$18.31	$18.31
New Slab Foundation	$/SQFT	$88.31	$88.13
Total Cost per Square Foot	$/SQFT	$129.53	$137.62
Disconnect/Reconnect Utilities	$	$1,983.12	$1,983.12
Site Prep	$	$1,614.42	$1,614.42
Site Restoration	$	$1,377.42	$1,377.42
New Driveway	$	$1,722.57	$1,722.57
Demo Previous Driveway	$	$589.92	$589.92
Landscaping – Stripping/Stockpiling	$	$1,799.26	$1,799.26
Landscaping – Topsoil Placement	$	$946.83	$946.83
Landscaping - Seeding	$	$891.77	$891.77
New Lot	$	$14,748.05	$14,748.05
Total Fixed Cost	$	$25,673.41	$25,673.41
Contingency	%	20%	30%

7.1.5.5 NS-5 Unit Cost Ranges by Planning Reach

Relocations are viable in all reaches within the SACS study area contingent upon local sponsor(s) support.

Table 7-15: NS-5 Relocation Cost per Asset by Planning Reach

Planning Reach	Relocation Cost Per Asset		Annualized Relocation Cost Per Asset	
	Low	High	Low	High
NC_01	$208,001	$294,934	$7,705	$10,925
NC_02	$208,001	$306,384	$7,705	$11,349
SC_03	$209,245	$306,384	$7,751	$11,349
SC_04	$209,245	$304,416	$7,751	$11,276
GA_05	$208,001	$297,081	$7,705	$11,004
FL_06	$208,001	$297,081	$7,705	$11,004
FL_07	$209,245	$297,081	$7,751	$11,004
FL_08	$202,095	$294,576	$7,486	$10,911
FL_09	$209,245	$294,934	$7,751	$10,925
FL_10	$209,867	$306,384	$7,774	$11,349
FL_11	$208,001	$297,081	$7,705	$11,004
FL_12	$206,447	$294,934	$7,647	$10,925
FL_13	$208,001	$297,081	$7,705	$11,004
AL_14	$208,001	$295,471	$7,705	$10,945
MS_15	$208,001	$297,081	$7,705	$11,004
PR_1	$129,974	$211,743	$4,814	$7,843
PR_2	$126,088	$213,890	$4,670	$7,923
PR_3	$126,710	$202,172	$4,693	$7,489
PR_4	$150,958	$229,992	$5,592	$8,519
VI_1	$184,842	$286,794	$6,847	$10,623
VI_2	$204,737	$397,357	$7,584	$14,718
VI_3	$161,682	$322,217	$5,989	$11,935

7.1.5.6 NS-5 Sea Level Change Adaptability

NS-6 Relocation removes the asset of concern out of the floodplain, eliminating coastal storm residual risk, and the need for sea level change adaptability.

7.1.5.7 NS-5 Limitations and Uncertainties

The primary limitation of measure NS-6 is the data source for building footprints, especially for Puerto Rico and the U.S. Virgin Islands. The number of square feet for planning reaches in the continental United States comes from the NSI, specific to single-family residences in the specified planning reach. The low cost is calculated using the value of residential structures at the 5th percentile of the NSI, while the high cost uses the 95th percentile. Puerto Rico and the U.S. Virgin Islands use the FAST and the 20th and 80th percentiles. Houses on the upper end of the distribution are assumed to be two stories of equal footprints. Supplementing the MCL methodology with project-specific footprints would greatly decrease the uncertainty surrounding estimates for NS-6.

7.2 Nonstructural Measures (Nonphysical)

Nonphysical nonstructural measures manage risk by influencing individual and collective decision-making. These decisions influence risk management action, including evacuation of the population at risk on an event-by-event basis, staging of resources to facilitate emergency response and recovery, location and construction standards for future development, and future risk management activities. These measures will be developed more fully in the following sections.

7.2.1 NS-6: Flood Warning Systems

Flood warning systems alert inhabitants in flood-prone areas of impending high water. Depending on the type of warning system and advance time, inhabitants could evacuate damageable property and themselves from the flood-prone area.

These measures provide immediate risk management to security of life, health, and safety (OSE) by alerting the population at risk to begin protective action initiation. The nature of the risk management is immediate, temporary, and works by influencing the decision-making of individuals. It strengthens community resiliency by increasing preparedness.

This measure relies upon stream gauges and rain gauges for collecting hydrologic information, and computer modeling to determine the impacts of flooding for areas of potential flood risk. A flood warning system, when properly installed and calibrated, is able to identify the time available for people occupying the floodplain to safely implement temporary measures or to evacuate the area (USACE 2019b).

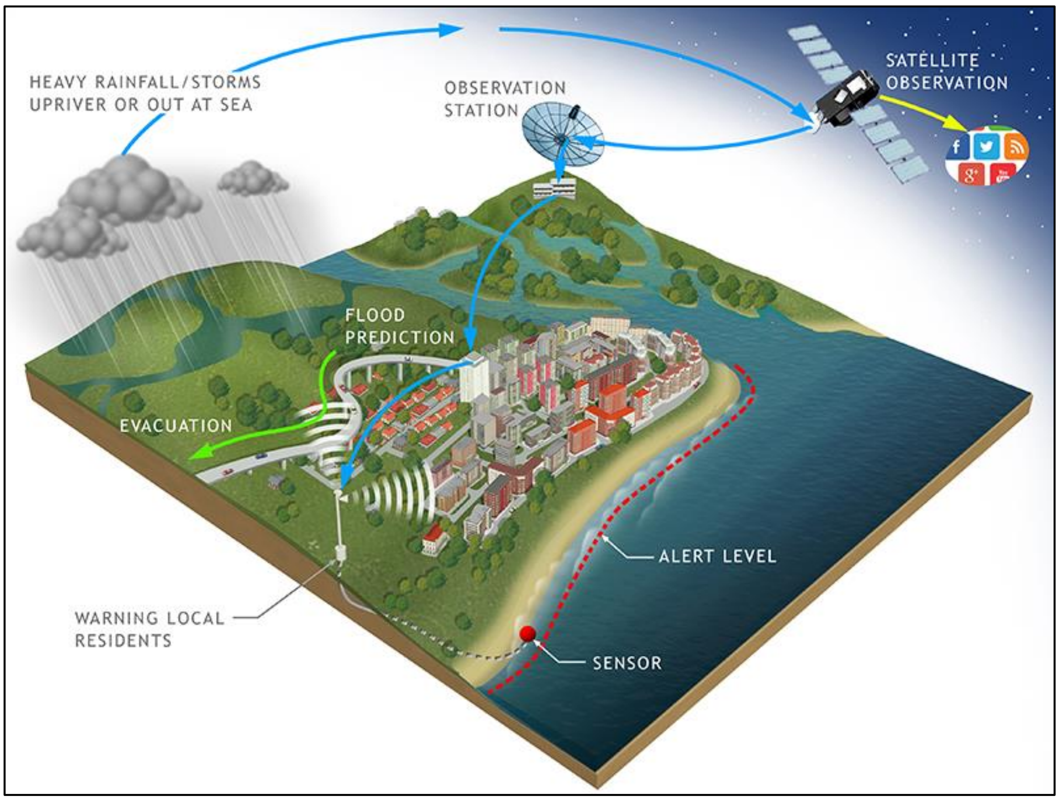

Figure 7-4: Conceptual Flood Warning Systems (USACE 2015a)

7.2.2 NS-7: Flood Insurance

Flood insurance reduces the net financial consequences of flood events to property owners. The primary role of flood insurance is to facilitate recovery, which is a component of community resiliency. Its influence on CSRM is only in the long term and in an indirect manner. Since greater flood risk is associated with higher insurance premiums, municipalities and individuals are incentivized to make future development less vulnerable to coastal storms.

7.2.3 NS-11: Zoning

Zoning is also beneficial in reducing flood risk. A community may determine that certain areas are too hazardous for human habitation and restrict development from occurring. Other areas may be determined to be risk free. This is a long-term investment tool for alleviating flood risk. Local building codes have been established to specify the minimum standards for the construction of buildings, with some specific to flooding (USACE 2019b).

7.2.4 NS-8: Floodplain Mapping

Floodplain mapping is a nonphysical nonstructural measure that identifies flood risk. Whether in the form of a map which portrays flood boundaries, or as an inundation map illustrating the depth of flooding, this measure is a significant tool when addressing flood risk. The measure manages risk by influencing decision-making with respect to future development or future risk management efforts.

7.2.5 NS-9: Flood Emergency Preparedness Plans

Local officials are encouraged to develop and maintain a flood emergency preparedness plan (FEPP) that identifies hazards, risks and vulnerabilities, and encourages the development of local mitigation. The FEPP should include the community's response to flooding, location of evacuation centers, evacuation routes, and flood recovery processes (USACE 2019b).

7.2.6 NS-10: Land Use Regulations

Land use regulations are effective tools in reducing flood risk and flood damage. The principles of these tools are based in the National Flood Insurance Program (NFIP) which requires minimum standards of floodplain regulation. For communities where future growth and expansion has been identified, restrictive land use regulations may be a deterrent to life loss and property damage (USACE 2019b).

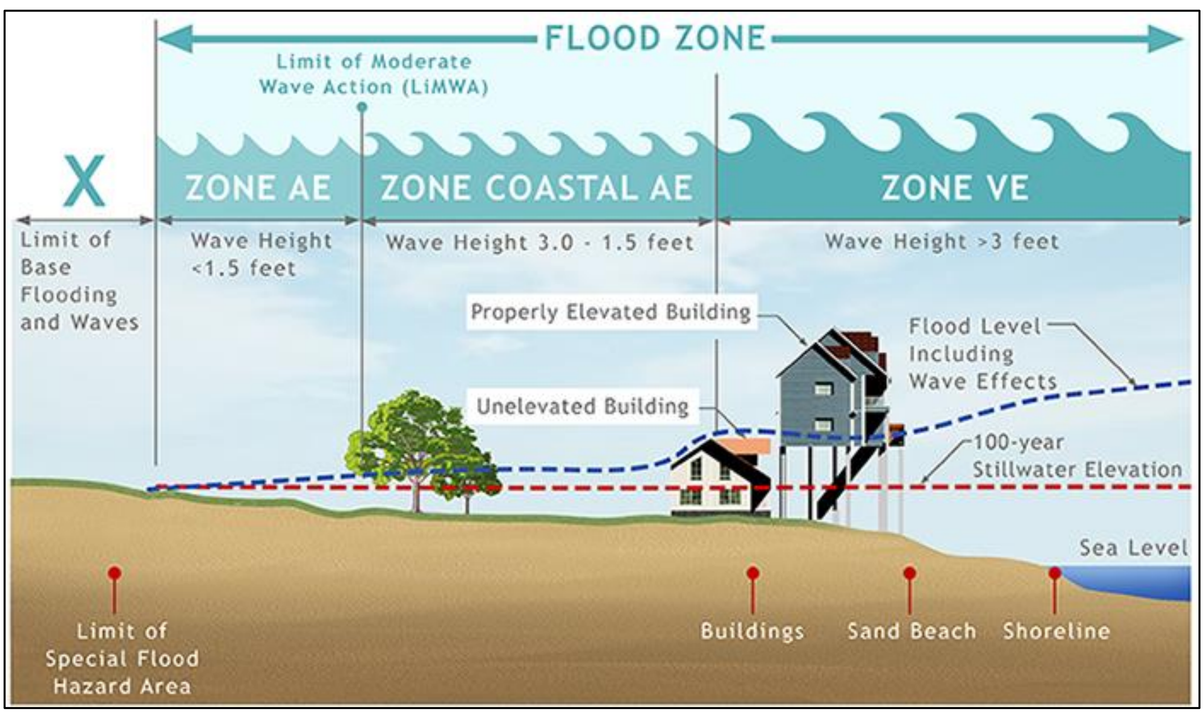

Figure 7-5: Conceptual Land Use Regulation (USACE 2015a)

7.2.7 NS-12: Evacuation Plans

Evacuation Plans require detailed hydrologic analyses for determining the rate of rise of floodwaters for various rainfall or snowmelt events. When used in conjunction with flood warning systems, this measure can provide significant loss of life avoidance and flood damage reduction benefits. Evacuation planning should consider vertical evacuation as well as the traditional horizontal evacuation. This measure should only be implemented when there is significant response and action time available for floodplain occupants to evacuate. Rally points and evacuation routes should be thoughtfully planned and communicated to the public.

7.2.8 NS-13: Risk Communication

Risk communication involves the development and use of educational tools, such as presentations, workshops, hand-outs, and pamphlets, to communicate flood risk and flood risk management measures to government entities and floodplain occupants to reduce the consequences associated with flooding.

7.2.9 NS-14: Risk Analysis

Risk analysis includes studies undertaken for the purposes of risk assessment, risk management, and/or risk communication. USACE technical assistance programs that could potentially be used to provide technical analysis include Floodplain Management Services (FPMS), Planning Assistance to States (PAS), or to inform risk management investment decisions such as the CAP and General Investigations (GI).

7.2.9.1 Floodplain Management Services

Floodplain Management Services (FPMS) – "All Things Flood" from
https://www.sad.usace.army.mil/Missions/Assistance-Programs/Floodplain-Management-Services/

"The Floodplain Management Services (FPMS) program is authorized by Section 206 of the 1960 Flood Control Act, as amended, and provides information on flood hazards to guide floodplain development by advising, recommending, educating, informing, and providing technical support. FPMS efforts might include a variety of data development, public outreach, planning guidance, information dissemination in the form of guides, pamphlets, or supporting studies, or national flood insurance program support (on a reimbursable basis). The purposes are to foster public understanding of the options available to address flood hazards and promote prudent use and management of the Nation's floodplains. The FPMS program addresses the needs of people who live in floodplains by helping them understand flood hazards and actions they can take to reduce property damage and prevent the loss of life.

Technical services and planning guidance under the FPMS program are provided to state, regional, and local governments without charge, within program funding limits, and generally last 12-24 months. FPMS services are conducted completely at the federal expense, however, FPMS services for federal agencies and private persons are on a cost-recovery or fee basis.

Study Cost

FPMS assistance is 100% federally funded for state, regional, or local government, or Native American Indian Tribes.

Other Federal agencies and private parties must pay 100% of the costs of all FPMS efforts.

Final Design/Construction Cost

The program does not give USACE the authority to complete detailed final designs or construction activities."

7.2.9.2 Planning Assistance to States

Planning Assistance to States (PAS) Program – "All Things Water" from https://www.sad.usace.army.mil/Missions/Assistance-Programs/Planning-Assistance-to-States/

"Water, an essential resource to the Nation, represents complexities that encompass environmental, social, cultural, legal, and economic concerns. As such, water resources often require varying degrees of planning solutions. The PAS program facilitates the US Army Corps of Engineers' (USACE) mission in assisting States on an array of water resource planning. Authorized by Section 22 of WRDA 1974, as amended (42 U.S.C. &1962d-16), the PAS program helps states, local government, non-Federal entities, and federally recognized Native American Indian Tribes to plan for the use, development, and conservation of water and related land resources. Flexible in scope, PAS studies can build on existing data to develop the basis for local planning decisions. In other study scopes, PAS efforts address information gaps related to a site-specific water resource to better identify problems and opportunities. The length of PAS studies depends on the scope. Some studies can be completed in a few months from receipt of funds, while others may take a full 12 months. In some cases, multi-phased studies can be completed over the course of 2 years, subject to the availability of Federal funds.

Because USACE is not authorized to design or construct under this program, plan implementation may be carried out by the partner. PAS programs are funded annually by Congress and are cost shared (50%/50%) with the study partner. The process for PAS investigations begins after a state, regional, local government, or Native American Indian tribe requests Corps of Engineers assistance under the program.

There are two types of efforts available through the PAS program: Comprehensive Plans and Technical Assistance Programs.

Comprehensive Plans

Comprehensive Planning is a type of water resource planning available through the PAS program to plan for the development, use, and conservation of water and related resource, for example, through a state water plan. Comprehensive plans can also extend across state boundaries if the States or partners agree. Comprehensive Planning opportunities include flood risk management, water supply and conservation, environmental restoration, water quality, hydropower, erosion, navigation, fish and wildlife, cultural resources, and environmental resources.

Comprehensive planning activities are cost shared (50%/50%) with the study partner, and funds in excess of the cost share may be voluntarily contributed by the non-Federal partner. The non-Federal cost share for preparing a state comprehensive water resource plan may be provided by funds through the provision of services, materials, supplies, or other in-kind services.

Technical Assistance Program

The purpose of Technical Assistance (TA) programs is to leverage resources in a constrained environment to address diverse water resource issues. Technical Assistance offers a variety of hydrologic, economic, or environmental data and analysis, state hazard mitigation, preparedness, response, and recovery related to changing hydrologic conditions, climate change, long-term sustainability, and resilience.

TA activities are cost shared (50%/50%) with the study partner, and funds in excess of cost share may be voluntarily contributed by the non-Federal partner. The cost share for TA must be provided by funds (not in-kind). This allows USACE to provide deliverables to sponsors, empowering them to make risk-informed decisions for their communities."

7.2.9.3 Continuing Authorities Program

Continuing Authorities Program (CAP) from https://www.saj.usace.army.mil/CAP/

"The Continuing Authorities Program (CAP) authorizes USACE to plan, design and construct small scale projects under existing program authority from Congress. Local governments and agencies seeking assistance may request USACE to investigate potential water resource issues that may fit a particular authority. A CAP project is conducted in two phases: a feasibility phase and a design and implementation phase. Both phases of a CAP project are cost-shared between the federal government and the non-federal sponsor. Certain territories of the United States (including Puerto Rico and the U.S. Virgin Islands) as well as Tribal organizations, are eligible for a reduction of the CAP Program non-federal cost-sharing requirement (based on the Water Resources Reform Development Acts of 2014 and 2016, applicable CAP projects with feasibility phase agreements or construction contracts executed on or after June 10, 2014, are eligible for waivers up to $455,000)."

The feasibility phase of a CAP project is cost shared 50/50 between the Federal government and the non-Federal sponsor. The design and implementation phase has a differing cost share depending on the authority of the project. CAP feasibility study phase can last up to 18 months and cost between $100,000 and $800,000. **Table 7-16** provides additional detail on the different CAP authorities as well as study and implementation costs.

Table 7-16: Continuing Authorities Program Authorities

Purpose	Authority	Feasibility Study Cost Share Federal / Non-Federal	Implementation Cost Share Federal / Non-Federal	Federal Project Limit
Emergency Stream Bank and Shoreline Protection	Section 14, 1946 Flood Control Act, as amended	100% / 0% for initial $100,000; 50% / 50% remaining cost	65% / 35%*	$ 5,000,000
Hurricane and Storm Risk Management (Beach Erosion)	Section 103, 1962 River and Harbor Act, as amended	100% / 0% for initial $100,000; 50% / 50% remaining cost	65% / 35%	$ 10,000,000
Navigation Improvements	Section 107, 1960 River and Harbor Act, as amended	100% / 0% for initial $100,000; 50% / 50% remaining cost	Varies, based on depth	$ 10,000,000
Mitigation to Shore Damage Attributable to Navigation Works	Section 111, 1968 River and Harbor Act, as amended	100% / 0% for initial $100,000; 50% / 50% remaining cost	Shared in same proportion as project causing damage	$ 10,000,000
Regional Sediment Management Beneficial Use of Dredged Material (CSRM, Eco, FRM)	Section 204, 1992 Water Resources Development Act, as amended	100% / 0%	65% / 35%**	$ 10,000,000
Flood Damage Reduction	Section 205, 1948 Flood Control Act, as amended	100% / 0% for initial $100,000; 50% / 50% remaining cost	65% / 35%**	$ 12,000,000
Aquatic Ecosystem Restoration	Section 206, 1996 Water Resources Development Act, as amended	100% / 0% for initial $100,000; 50% / 50% remaining cost	65% / 35%	$ 10,000,000
Snagging and Clearing for Flood Damage Reduction	Section 208, 1954 Flood Control Act, as amended	100% / 0% for initial $100,000; 50% / 50% remaining cost	65% / 35%*	$ 500,000

Purpose	Authority	Feasibility Study Cost Share Federal / Non-Federal	Implementation Cost Share Federal / Non-Federal	Federal Project Limit
Project Modifications for Improvements to the Environment	Section 1135, 1986 Water Resources Development Act, as amended	100% / 0% for initial $100,000; 50% / 50% remaining cost	75% / 25%	$ 10,000,000

* For structural flood damage reduction purpose, Non-Fed share is 35% up to 50% (based on cost of LERRDs), plus 5% must be in cash.

** For structural flood damage reduction purpose, Non-Fed share is 35% up to 50% (based on cost of LERRDs), plus 5% must be in cash. For nonstructural flood damage reduction purpose, Non-Fed share limited to 35%, with no 5% cash requirement.

7.2.9.4 General Investigations

GI studies play a vital role in supporting the USACE Civil Works water resources development mission. A Civil Works feasibility study is the initial step in the U.S. Army Corps of Engineers process for addressing many of the nation's significant water resources needs and typically focuses on one or more of USACE's key mission areas: flood risk management (inland and coastal), navigation (inland and deep draft), or ecosystem restoration.

After Congress has both authorized and appropriated funds to begin a study, USACE planners work with a non-Federal sponsor and multidisciplinary project delivery team to conduct a feasibility study.

A feasibility study establishes the Federal interest, engineering feasibility, economic justification, and environmental acceptability of a water resources project recommended for congressional authorization and construction. Specifically, USACE and the sponsor work together to identify water resources problems, formulate and evaluate solutions, resolve conflicting interests and prepare recommendations. Feasibility studies are cost shared equally between the sponsor and Federal government. Typically, the feasibility study and resulting recommendation for project authorization in the form of a Chief's Report should be completed at a total cost of $3 million and within 3 years, although exemptions will be made if the study's scope and complexity justifies a larger investment.

7.2.10 NS-15: Land Conservation

Land conservation is the process of returning developed land to a more natural, pre-developed state. Retaining open space in the floodplain can reduce future flood damages by removing buildings from areas subject to flooding and by creating a less impervious surface area which can impede the progression of flooding (Kousky, et al. 2013). Preservation, restoration, remediation, and mitigation are some land conservation methods and techniques.

SECTION 8

Conclusions/Summary/Key Points

8.1 Review of the Measures and Cost Library

The MCL is a detailed and standardized repository of risk management measures developed to assist USACE PDT and stakeholders in CSRM planning efforts. The general purpose of the MCL is to reduce time and effort needed to develop an array of risk management measures and ROM cost ranges that can be used to address the identified problem for a CSRM study.

The MCL encompasses a range of unit costs for each measure based on shoreline type and location for the entire South Atlantic and portions of the Gulf Coast coastline (Mississippi to North Carolina), Puerto Rico and the U.S. Virgin Islands. When using this tool, the user will need to apply additional information such as the location, length, and/or size of the measure to estimate the range of total project costs or annualized life cycle costs.

The MCL is intended for use at the start of a coastal storm risk management study by identifying applicable measures and costs that can be developed into alternatives. However, owing to the regional nature of the data being developed, it is impossible to address the scope and site specificity issues prevalent in all CSRM projects. Items such as environmental and real estate impacts as well as their influence on the cost of measure implementation is not addressed in the SACS MCL.

8.2 Use of the MCL to Develop an Array of Measures

- **Step 1** – Clearly identify problem in terms of the hazard (inundation, wave attack or erosion), the subject of risk management (public and private property, critical infrastructure, population at risk, environmental resources, cultural resources), and location. Information on the physical setting is also useful in describing the problem.

- **Step 2** – Identify spatial extent of the problem. Using the SACS Tier 2 Economic Risk Assessment Dashboard, select the census blocks that define the extent of the problem. Record the existing and future economic risk (EADs). These become the upper and lower bounds for a risk management measure cost estimate to justify Federal interest.

- **Step 3** – Select the planning reach and range of measures that are effective at addressing the identified problem. Consider risk management function (inundation, wave attack, erosion) and measure applicability by wave characteristic relative to the stated problem when choosing measures. Then enter appropriate unit parameters for each selected measure to estimate the ROM cost range.

- **Step 4** – Observe the annualized range of costs and compare to the range of risk. If the lower bound of the measure cost (EAC) exceeds the upper bound of the damages (EAD), there is a high likelihood that the measures cost will exceed its risk management benefits.

- **Step 5** – Describe the uncertainties associated with each of the preceding steps and the risk of making decisions without reducing those uncertainties.

The importance of properly understanding the problem cannot be overstated. Depending on the degree of uncertainty about the problem or its spatial dimensions (Step 1 or Step 2), the wisest course of action may be to recommend future study (NS-14) prior to delving into management measure formulation/recommendations.

Table 8-1: Use of Coastal Storm Risk Management (CSRM) Approaches and Methods

CSRM Approach	CSRM Method	CSRM Measures	Usage
Performance-Based	Coastline Armoring	S-2, S-3, S-4, S-6, S-7, S-8, S-9, S-12	Narrow area between hazard and exposure; densely developed areas with established economies
Performance-Based	Coastline Stabilization	S-1, S-5, NNBF-7, NNBF-8, NNBF-9, NNBF-10, NNBF-11, NNBF-12	Narrow area between hazard and exposure; densely developed areas with established economies with high shoreline change rates
Performance-Based	Coastline Restoration	S-10, S-11, NNBF-1, NNBF-2, NNBF-3, NNBF-4, NNBF-5, NNBF-6	Use to rebuild natural barrier between hazard and exposure
Exposure-Based	Temporary Retreat	NS-7, NS-10, NS-13	Use to evacuate the population at risk prior to an event
Exposure-Based	Permanent Retreat	NS-1, NS-6	Permanent evacuation when structural measures are less practical; wave action; deepwater/compound flooding
Vulnerability-Based	Retrofit (Elevation)	S-12, NS-2	High frequency, low magnitude flooding; may be able to retrofit foundation to manage erosion risk; increase resiliency of critical infrastructure
Vulnerability-Based	Retrofit (Floodproofing)	NS-3, NS-4, NS-5	High frequency, low magnitude flooding
Decision-Based	Informational	NS-7, NS-9 NS-14, NS-15	Inform evacuation decisions; inform future risk management actions; inform decisions about the character and composition of future exposure
Decision-Based	Future Exposure	NS-8, NS-11, NS-12, NS-15, NS-16	

8.3 Use of the Measures and Cost Library to Develop Strategies

Ultimately, the goal of USACE CSRM efforts is to build community resiliency with respect to coastal storms and sea level change. The MCL can be used to build resiliency by incorporating PARA principles into the development of USACE CSRM strategy. **Table 8-2** provides details on the distribution of MCL measure codes by PARA principle. See **Table 4-1** for description of measure codes. A good CSRM community resiliency strategy should include measures from each PARA principle.

- **Prepare:** Measures that build resiliency through preparedness focus on advance actions that immediately limit the impact of the storm event. These include measures that facilitate temporary retreat and/or temporary retreat decision-making.

- **Absorb:** Measures that build resiliency by withstanding the storm and limiting the damage are the primary focus of all performance and vulnerability-based CSRM approaches.
- **Recover:** MCL measure that addresses the recovery component of resiliency is flood insurance.
- **Adapt:** Measures that facilitate resiliency by adapting to future coastal storm risk include permanent retreat, as well as methods designed to alter the composition of future exposure to avoid the risk in the future.

Table 8-2: PARA Principles and Coastal Storm Risk Management (CSRM) Approaches, Methods, and Measures

CSRM Approach	CSRM Method	Prepare (Measures that enhance readiness to take the hit)	Absorb (Measures that enhance ability to take the hit)	Recover (Measures that enhance ability to bounce back)	Adapt (Measures that reduce susceptibility to future hits)
Performance-Based	Coastline Armoring	–	S-2, S-3, S-4, S-6, S-7, S-8, S-9, S-12	–	–
Performance-Based	Coastline Stabilization	–	S-1, S-5, NNBF-7, NNBF-8, NNBF-9, NNBF-10, NNBF-11, NNBF-12	–	–
Performance-Based	Coastline Restoration	–	S-10, S-11, NNBF-1, NNBF-2, NNBF-3, NNBF-4, NNBF-5, NNBF-6	–	–
Exposure-Based	Temporary Retreat	NS-7, NS-10, NS-13	–	–	–
Exposure-Based	Permanent Retreat	–	–	–	NS-1, NS-6
Vulnerability-Based	Retrofit (Elevation)	–	S-12, NS-2	–	–
Vulnerability-Based	Retrofit (Floodproofing)	–	NS-3, NS-4, NS-5	–	–
Decision-Based	Informational	NS-7, NS-14, NS-15	–	–	NS-9
Decision-Based	Future Exposure	–	–	NS-8	NS-11, NS-12, NS-15, NS-16

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SECTION 9
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