ENHANCING BENEFITS EVALUATION FOR WATER RESOURCES PROJECTS: TOWARDS A MORE COMPREHENSIVE APPROACH FOR NATURE-BASED SOLUTIONS

Case Study Analysis Results and Recommendations

JORDAN R. FISCHBACH, SOUPY DALYANDER, TIM CARRUTHERS, COLLEEN MCHUGH, ALLISON DEJONG, BRETT MCMANN, ABBY LITTMAN, ALLISON HAERTLING, PATRICK KANE, AND CRAIG A. BOND

Produced for and funded by U.S. Army Corps of Engineers' Engineering With Nature Program

June 2023

SUGGESTED CITATION

Fischbach, Jordan R., Soupy Dalyander, Tim Carruthers, Colleen McHugh, Allison DeJong, Brett McMann, Abby Littman, Allison Haertling, Patrick Kane, and Craig A. Bond (2023). Case Study Analysis Results and Recommendations. The Water Institute of the Gulf. Funded by the U.S. Army Corps of Engineers Engineer Research and Development Center, Vicksburg, MS.

PREFACE

To accelerate progress and delivery of new and enhanced infrastructure projects for navigation, flood risk management, water operations, and ecosystem restoration consistent with its Engineering With Nature® (EWN) Program, the U.S. Army Corps of Engineers (USACE) has engaged in a collaborative effort with The Water Institute of the Gulf (the Institute) to conduct policy research for fully evaluating the benefits of EWN strategies and projects, to include Natural Infrastructure, Natural and Nature Based Features, and other Nature-Based Solutions (NBS).

This document is the fourth and final report produced as part of this collaborative effort. Previous reports developed during this project describe the evolution of USACE evaluation approaches from prior eras of planning to the present day (Ehrenwerth et al., 2022), investigate where and how NBS were considered in planning studies from 2005–2020 (Windhoffer et al., 2023), and review relevant planning and valuation methods that could be applied by USACE to improve NBS evaluation and were considered to inform the subsequent case study analysis (Fischbach et al., 2023).

This report builds on these earlier efforts and presents the results from six retrospective case studies developed by the collaborative study team based on completed USACE planning studies. The goal is to demonstrate how USACE could apply new or augmented methods to consider a wider range of social, environmental, and economic benefits and costs when evaluating NBS alongside traditional infrastructure solutions.

Questions about this research should be directed to the project lead and Director of Planning and Policy Research at the Institute, Jordan Fischbach (jfischbach@thewaterinstitute.org).

ACKNOWLEDGEMENTS

This report represents the culmination of a multi-year research effort conducted by a broad study team. Many individuals contributed at various stages of research and writing, and the authors gratefully acknowledge the input and support provided by contributors across the multi-institution collaborative.

This report was reviewed by Alyssa Dausman and edited and formatted by Charley Cameron of the Institute. Dexter Ellis developed and improved figures throughout the document. Eva Windhoffer and Hoonshin Jung assisted with the case study analysis and contributed to the supporting technical material. Sue Hughes and Tom Hughes contributed to early phases of the research and ensured it was well-grounded in USACE planning practices. Other key Institute contributors include Justin Ehrenwerth, who provided guidance and input throughout the research effort, and Beaux Jones. The authors are grateful to Jean Cowan, Senior Project Manager at the Institute, for supporting the final stages of report development and overseeing report review and revisions. Partners outside of the Institute including Scott Pippin, Matthew Shudtz, and Shana Jones also supported this research effort, and the authors gratefully acknowledge the contributions of the University of Georgia's Institute for Resilient Infrastructure Systems.

Todd Bridges and Jeff King (USACE Engineering With Nature Program) provided oversight, guidance, and feedback throughout the research effort.

Development of this report was funded by the USACE Engineering With Nature Program under contract number W912HZ22C0026.

EXECUTIVE SUMMARY

BACKGROUND

The U.S. Army Corps of Engineers (USACE) Civil Works program is tasked with development and management of the Nation's water resources, including maintaining navigable waterways, managing flood risk, and restoring aquatic ecosystems. Projects to advance these objectives must be selected based on weighing the overall benefits and costs to the public, which is conducted within USACE using benefit-cost analysis (BCA). Currently, BCA as applied by USACE to evaluate water resources projects is focused on the economic benefits and impacts (expressed in monetary terms) produced by the project (e.g., avoided flood damage to properties, commerce generated by navigation infrastructure).

The Water Resources Development Act of 2020 §110 directs USACE to implement the Principles, Requirements and Guidelines for Water and Land Related Resources Implementation Studies (PR&G), which govern how federal agencies evaluate proposed water resource development projects. With the updated PR&G, studies will need to consider a broader suite of variables that lead to sustainable, resilient, and enduring investments, including economic, social, and environmental factors.

STUDY APPROACH

To accelerate progress and delivery of new and enhanced infrastructure projects for navigation, flood risk management, water operations, and ecosystem restoration consistent with its Engineering With Nature® (EWN) Program, USACE engaged in a collaborative effort with The Water Institute of the Gulf (collectively referred to as the *study team*). The study team analyzed how to best quantify—and potentially monetize—a more comprehensive range of economic, environmental, and social costs and benefits that nature-based solutions (NBS) can provide. In earlier stages, the study team reviewed the evolution of USACE evaluation approaches from prior eras of planning to the present day, investigated where and how NBS were considered in 150 feasibility studies conducted from 2005–2020, and reviewed relevant planning and valuation methods that could be applied by USACE to improve NBS evaluation.

Incorporating knowledge gained from these earlier tasks, the study team worked with USACE to identify and conduct case studies on six of the 150 feasibility studies (Figure ES 1). The purpose of reviewing these studies was to investigate opportunities for USACE to apply new or augmented evaluation methods to a wider range of social, environmental, and economic benefits and costs when evaluating NBS with traditional infrastructure solutions. The analysis included 1) applying approaches that simultaneously assess multiple objectives measured with different performance metrics, and 2) considering how USACE might apply ecosystem service valuation methods to integrate additional categories into the formal BCA currently applied to evaluate and prioritize alternatives within a USACE planning study.

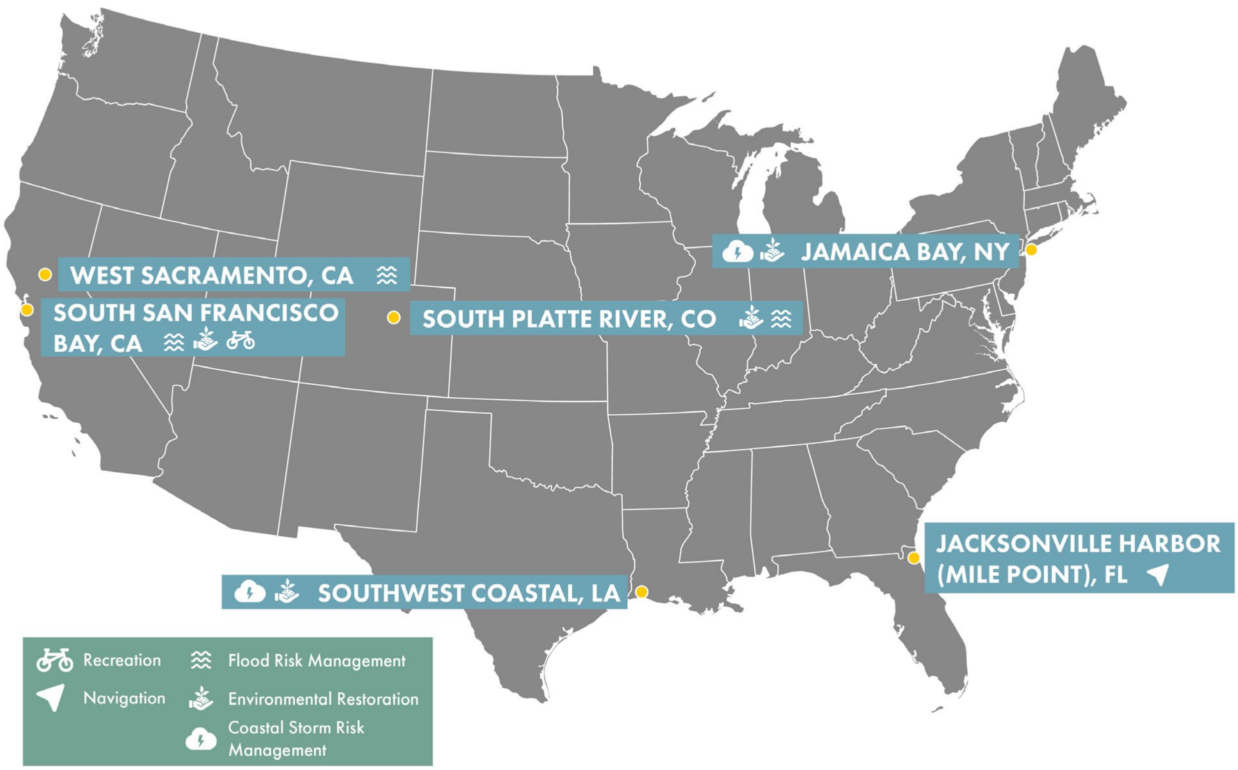


Figure ES 1. Six case studies were selected for further evaluation based on mission area, local interest, and available data.

SUMMARY OF FINDINGS

The study team identified several key findings and opportunities for USACE to enhance its planning and evaluation process to include a wider range of social, environmental, and economic benefits and costs. These opportunities may support USACE in developing and applying forward-looking and practical approaches for formulating, evaluating, and developing water resources projects in a way that integrates and considers the multiple benefits NBS may provide, as required by the updated PR&G.

The key findings and opportunities are organized around the stages of a typical planning analysis (Table ES 1) and are discussed in more detail below, along with supporting examples from the six case studies.

Table ES 1. Summary of key findings and opportunities, organized by planning stage.

Planning stage	Key finding	Opportunity
Study Scope	Scoping within separate mission areas limits NBS opportunities.	Use an integrated, multi-objective approach to scope planning studies.
Alternative Formulation	NBS options are often excluded during alternative formulation.	Formulate integrated alternatives designed to provide benefits or co-benefits across all PR&G guiding principles and to different communities of interest.
Evaluation of Non-Monetized Outcomes	Existing tools can support non-monetary benefit estimation.	Evaluate alternatives using metrics for all PR&G guiding principles and communities of interest.
Ecosystem Service Valuation	A range of existing methods may be applied to enable more comprehensive valuation.	Develop USACE guidance, resources, and tools for monetizing a broader range of benefits.
Prioritization and Alternative Selection	Monetizing ecosystem service benefits improved BCA analysis but was generally insufficient to change alternative rankings due to decisions made during scoping, screening, and alternative formulation. Multi-objective analysis is necessary to capture all benefits.	Apply transparent multi-criteria decision analysis as the primary approach for alternative ranking and selection.

STUDY SCOPING

Key Finding: Scoping Within Separate Mission Areas Limits NBS Opportunities

Scoring by USACE subject matter experts indicated that approximately 85% of the planning studies included in the initial inventory for this research began with some consideration of NBS. However, only about half of the studies evaluated NBS in the final array of alternatives. Many of these remaining studies were focused solely on environmental restoration, leaving less than a third of the studies that considered NBS options and evaluated them across multiple objectives together (for example, both flood risk management and ecosystem restoration).

Although all but one of the six evaluated planning studies identified multiple goals that could be addressed through integrated NBS, most studies formulated and evaluated these goals separately by mission area rather than holistically.

As a result, the first key finding is that the process of study scoping within specific mission areas can limit the ability to capture synergistic and cross-mission area benefit and, therefore, limit consideration of NBS. In many cases, NBS options are excluded early in the planning process, in large part due to study scoping that emphasizes a single or limited set of study objectives.

Example Case Study: Jamaica Bay, New York

Jamaica Bay, New York presents a useful example of the impacts of study scoping within mission areas on consideration of NBS. Low-lying elevation, dense population, and development put this area at high risk for storm surge inundation. Further, this urbanization has degraded coastal ecosystems and processes that historically provided a buffer against tidal flooding.

The study team looked at two separate studies that included Jamaica Bay and were completed around the same time: the *Hurricane Sandy General Reevaluation Report*, which focused on coastal storm risk management and was completed in 2019, and the *Hudson Raritan Estuary Study*, which focused on environmental restoration and was completed in 2020.

The combined ecosystem service benefits from large-scale interventions in Jamaica Bay could be significant given the bay's size and location, potentially serving millions of New York City residents and visitors. The coastal storm risk management study did ultimately include NBS to help manage tidal flooding, but only for a small number of sites along Rockaway Peninsula. The restoration study separately identified promising ecosystem restoration opportunities for Jamaica Bay, but through an entirely separate process from the risk study. Ultimately, scoping under separate mission areas produced a segregated set of alternatives and projects rather than identifying solutions that integrated NBS and simultaneously advanced ecosystem restoration and flood risk reduction objectives.

Opportunity: Use Integrated, Multi-Objective Approach to Scope Planning Studies

A scoping approach that could broaden consideration of NBS is to use an integrated, multi-objective study scope as the default to begin future studies. Under this approach, beneficial outcomes and associated objectives identified by USACE and stakeholders would be considered at the start of the study, and would consider benefits that span mission areas and the co-equal principles established in the PR&G.

Implementation of this opportunity could be supported by:

- Eliciting and incorporating input from non-federal sponsor(s) and stakeholders to inform the objectives that the study will address,
- Considering the potential for benefits across all PR&G guiding principles, and
- Ensuring that all alternatives would address the authorized project purpose(s), and otherwise consider all PR&G principles when ranking alternatives.

ALTERNATIVE FORMULATION

Key Finding: NBS Options Are Often Excluded During Alternative Formulation

The process and assumptions that undergird alternative formulation play an essential role in considering or excluding integrated NBS. Most of the case studies reviewed excluded or did not identify integrated alternatives with NBS that could support primary study objectives or that could provide ancillary benefits.

The lack of NBS in the formulated alternatives resulted from:

- Separate formulation of alternatives for each mission area,
- Use of fundamentally different approaches (e.g., structural vs. nonstructural risk reduction) in alternative formulation, and/or
- Preliminary analysis screening out integrated approaches in favor of more narrowly tailored options that are economically justifiable in isolation.

Example Case Study: South Platte River and Tributaries

An example supporting this finding can be found in the South Platte River and Tributaries study, which focused on a 6.5-mile stretch of the South Platte River in Denver and Adams counties in Colorado. This study included ecosystem restoration, connectivity, and flood risk management goals in an integrated and highly urbanized watershed, but risk reduction alternatives were formulated separately from the restoration options. The study was also considered in isolation from other major interventions occurring in this watershed, including private investments.

The resulting plan may have missed opportunities for greater benefit from NBS, both in support of flood risk reduction and trail and habitat connectivity. Overall, delineating the baseline restoration outcomes USACE wanted to achieve and then designing a project intended to meet those outcomes while maximizing other categories of benefit could allow for a more holistic project analysis.

Opportunity: Formulate Alternatives to Meet Multiple Objectives

An approach to alternative formulation that can support more widespread consideration of NBS is for studies to deliberately identify integrated alternatives designed to meet multiple objectives.

Implementation of this opportunity could be supported by:

- Formulating integrated alternatives designed to provide benefits or co-benefits across all PR&G mission areas and to different communities of interest,
- Explicitly considering NBS in alternative formulation for all relevant studies, and

- Focusing initial screening on feasibility and cost rather than economic performance, reserving BCA as a minimum threshold for economic performance as part of a multi-criteria analysis of complete, integrated alternatives.

NON-MONETIZED OUTCOME EVALUATION

Key Finding: Existing Tools Can Support Non-Monetary Benefit Estimation

Full consideration of the co-equal principles established by the updated PR&G requires consideration of a wide suite of benefits and costs, including those that cannot be effectively monetized through BCA (e.g., environmental justice considerations and environmental benefits that may not be directly associated with ecosystem services).

The study team found that some environmental/social/non-economic metrics may be estimated with existing USACE tools, while others will require additional modeling or analysis not typically incorporated into a planning study. However, NBS evaluation across multiple objectives could be augmented with relevant science developed independently of the study, expert knowledge, and local and community knowledge.

Example Case Study: Southwest Coastal Louisiana

An example of leveraging outside science to better estimate benefits is in the Southwest Coastal Louisiana case study. This large-scale study, encompassing three parishes in coastal Louisiana and intended to address both coastal storm risk management and environmental restoration goals, was conducted in parallel to the State of Louisiana's coastal master planning process.

Many of the proposed wetland restoration, shoreline protection, and other measures considered in the USACE study were also evaluated through an integrated modeling process that projected coastal change over 50 years with or without new projects in place to support Louisiana's 2017 Coastal Master Plan.

Given the overlap in geography and scope, the study team was able to leverage simulation results from the Coastal Master Plan process to estimate several new categories of benefit:

- The monetized ecosystem service value of wetland creation or preservation, which also used benefit transfer values from a literature review focused specifically on coastal Louisiana, and
- The benefits from carbon sequestration in these wetland ecosystems, which present another potentially important factor in future studies.

In this case study, the monetized ecosystem and carbon sequestration benefits exceeded restoration costs under some assumptions, but not others. However, the combined benefits from risk reduction and restoration exceeded the combined project costs by at least a 2:1 ratio across all study assumptions.

Opportunity: Evaluate Alternatives with Metrics from Across All PR&G Guiding Principles

There is an opportunity to broaden the benefits and costs included in alternative evaluation by using metrics from all relevant PR&G guiding principles and communities of interest with a stake in study outcomes. There are challenges to this approach, however, given that it is likely unfamiliar to many USACE practitioners and because identifying and utilizing available tools from other USACE Districts and/or that can be found in the literature may be beyond the scope of most feasibility studies.

Implementation of this opportunity could therefore be supported by:

- Expanding the USACE-certified modeling toolkit to support alternatives evaluation for multiple outcomes, and
- Developing updated guidance for using multiple lines of evidence regarding project benefits and costs including benefit-relevant indicators or metrics for each PR&G principle, and use of peer-reviewed science, expert input, and traditional and community knowledge to augment study analysis.

MONETIZED VALUATION

Key Finding: Existing Methods Can Enable More Comprehensive Valuation

Although there are ecosystem services benefits that cannot be monetized, analysis of the case studies indicates that there are opportunities to make BCA more comprehensive through ecosystem service valuation. The study team identified a variety of existing methods that could be used to improve estimation of monetized benefits, thereby valuing outcomes that are often excluded and (inaccurately) assumed to be zero.

Methods are available to estimate monetized benefits from ecosystem services, including some already in use by USACE or that rely exclusively on USACE data and methods. In addition, methods such as benefit transfer, which rely on using appropriate valuation parameters established outside of the case study, would allow for broader valuation of NBS in BCA analysis.

The study team also considered how incorporation of ecosystem service benefits and associated costs impacted the benefit cost ratio (BCR). Although the ratio of benefits to costs increased in some studies, the inclusion of ecosystem services decreased the ratio in others due to increased costs associated with NBS implementation. Additionally, incorporating additional ecosystem service benefits did not change alternatives ranking in most cases based on BCA alone. This finding is tempered by the fact that decisions made during study scoping, screening, and alternative formulation limited the number and diversity of NBS and alternatives that integrated NBS with traditional infrastructure that could be evaluated in the reanalysis. However, the change in BCR identified for some of the case studies suggests that incremental improvements can be made by reducing the uncounted costs and benefits of BCA by building on existing methods and new tools and providing guidance on use to USACE practitioners.

Example Case Studies

Jacksonville Harbor Mile Point, FL

The study team performed a reanalysis of the Jacksonville Harbor Mile Point study, which focused on reducing crosscurrents and shoreline erosion for a portion of the St. John's River and thereby mitigating safety risks and threats to surrounding development. The study team used existing and publicly available data to estimate monetized benefits from water quality, access to waterways, and the avoided cost of additional sediment disposal. A hedonics study of home prices in the area was leveraged for the first two categories, while a cost comparison of disposal sites provided a new estimate of the reduced dredging cost.

The original suite of alternatives identified for Mile Point did not include any of the NBS that were ultimately included in the Recommended Plan, which were added later in the study because of targeted Value Engineering studies. Results showed that the Recommended Plan BCR increased from 1.4 to 2.3 when including these additional categories of benefit. This result did not change the rankings of alternatives, in part because the beneficial use of dredge material site was closer—and therefore cheaper—than the alternate dredge disposal area.

This case study does, however, demonstrate how ecosystem service valuation could augment study analyses and potentially tip the balance from a net negative to a net positive result, as well as the benefit of including NBS and holistic solutions within the alternative suite.

West Sacramento, CA

The West Sacramento, CA case study illustrated the incremental results of incorporating additional ecosystem services benefits into BCA. This study was focused on flood risk management improvements for a portion of the Sacramento levee system, where outdated levees and external threats led to increasing flood hazards for adjacent communities.

Although the study primarily focused on reducing flood risk and potential impacts to critical infrastructure, the study team considered how the proposed setback levee and subsequent land use change might increase or decrease the ecosystem service value associated with the project footprint. As was used at multiple sites, the study team used benefit transfer values from a synthesis of more than 300 case studies to calculate and monetize the change in acres under pre- and post-project conditions for wetlands and other land use categories.

Overall, the additional benefits of land use/land cover change were negligible when compared to the overall benefits in this study (and in the context of the BCA), but these sources of benefit may still represent millions of dollars' worth of benefit each year that were previously uncounted.

Opportunity: Develop USACE Resources to Help Monetize a Broader Range of Benefits

The case study analysis indicates there are additional ecosystem services that can be included within BCA beyond those in widespread use in USACE. However, methods to monetize these services typically rely on data and models that may be beyond the scope of a feasibility study to generate and/or for Districts to have in-house expertise in application. An opportunity therefore exists to support more comprehensive BCA through development of additional guidance and resources for monetizing environmental and social benefits.

Implementation of this opportunity could be supported by:

- Updated guidance to raise awareness and capacity across Districts to use existing USACE methods, such as recreational Unit Day Values or dredge disposal cost estimation, and
- Development of a benefit transfer database and/or decision support tool(s) to support ecosystem valuation in BCA analysis. This could build on similar efforts by other agencies, such as the U.S. Environmental Protection Agency and the National Oceanic and Atmospheric Administration.

PRIORITIZATION AND ALTERNATIVE SELECTION

Key Finding: Multi-Objective Analysis is Necessary to Capture All Benefits

One of the key determinations of the case study reanalysis is that NBS alternatives tend to provide benefits that are difficult to robustly monetize. There are multiple reasons driving this outcome. First, there is still the challenge of lack of data and/or appropriate methods for some key sources of benefit. More broadly, though, even with improved approaches monetized valuation alone cannot fully represent the PR&G principles, values, and associated benefits from the water resources case studies considered.

The study team did determine, however, that multi-objective decision analysis provides an opportunity to consider a broader range of benefits and costs consistent with the PR&G principles, including those where ecosystem service valuation is limited by data availability or impossible due to the inherently non-monetary nature of a desired outcome.

Example Case Study: South San Francisco Bay, CA Shoreline

Among the case studies, the best example of a multi-mission study designed to address multiple goals with NBS is the South San Francisco Bay, CA Shoreline study. This area is prone to tidal flooding, which is anticipated to increase due to sea level rise. Further, historical commercial salt pond development has led to loss of tidal marsh habitat, and what remains is fragmented.

This study was scoped to reduce risks from tidal flooding, restore ecological function to the tidal marsh habitat, and improve public access, education, and recreation. Flood risk reduction and recreation were valued in dollar terms, while improved ecological function was measured in other units. To address these goals, the San Francisco District formulated and evaluated multipurpose NBS alternatives that included a combination of levee building, tidal marsh restoration, and recreational features.

The San Francisco District also considered an "ecotone" transitional habitat for the foreshore of the levee and accelerated marsh restoration techniques, but these improvements were not included in the Recommended Plan because the BCR was slightly lower than an alternative without these additional features (though benefits still exceeded costs at more than a 5:1 ratio). However, these additional NBS elements were ultimately included in the project as part of the Locally Preferred Plan[1], with the local sponsor responsible for the additional costs.

This project is a strong exemplar for future studies, especially with respect to the scoping and alternative formulation. However, it also helps to illustrate the pitfalls of prioritization using the BCR as a primary criterion. Although some potential NBS benefits were difficult to value in dollar terms, a multi-criteria prioritization approach might have led to the conclusion that a slight reduction in the cost efficiency of the project is worth the tradeoff for the additional non-monetized benefits from the ecotone levee and accelerated restoration approach.

Opportunity: Apply Multi-Criteria Decision Analysis for Alternative Ranking and Selection

The opportunity identified by the study team that is likely to have the most widespread impact on feasibility study outcomes is to adopt transparent, multi-objective decision analysis as the primary approach for alternative ranking and selection. Under this approach, BCA can be used as an initial screening criterion to address cost-efficiency considerations, such as by excluding those alternatives that do not achieve a breakeven threshold of 1.0 even with the inclusion of ecosystem services benefits of the types identified in the case study review.

Multi-objective decision analysis techniques that rely on monetized and non-monetized benefits, and which can be augmented by expert judgement in cases where insufficient data exist to robustly characterize outcomes, can then support final prioritization of alternatives. This approach also allows for explicit tradeoffs to be considered directly in the alternative evaluation process; for example, using approaches taken in Value Engineering studies where the benefit per unit cost is considered in addition to the total values. Use of BCA as a screening rather than prioritization tool is similar to what is used for

[1] A Locally Preferred Plan is one that includes alternative actions to those identified in the Federal Plan and includes components that address local interests.

FEMA grant programs and allows incremental improvement to valuation to incorporate where appropriate while still removing other impediments to the broader consideration of NBS.

Implementation of this opportunity could be supported by:

- Guidance for practitioners on use of multi-objective decision analysis to consider economic and non-economic quantitative outputs,
- Augmenting quantitative assessment with qualitative information, such as local knowledge and values, along with expert input, and
- Prioritizing alternatives that provide balanced benefits across all PR&G guiding principles rather than optimizing for a single mission.

NEXT STEPS

The initial phase of this effort identified multi-objective decision analysis, supported in part by BCA that incorporates a wider range of ecosystem services than is traditionally included, as a method for greater consideration of NBS and the co-equal principles of the PR&G. The study also determined, however, that there are non-monetized (and non-monetizable) social outcomes and equity considerations that could potentially be quantified through additional study. Going forward, the same set of six case studies presented in this report will be analyzed to specifically consider social outcomes and equity as part of the overall study process and BCA analysis. In addition, updated guidance and tools can support USACE in implementation of multi-objective analysis and expanded BCA in future planning studies.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS

Acronym	Term
AAEQ	Average Annual Equivalent
AAHU	Average Annual Habitat Unit
AEP	Annual Exceedance Probability
ARIES	Artificial Intelligence for Ecosystem Services
BCA	Benefit Cost Analysis
BCR	Benefit Cost Ratio
BRI	Benefit-Relevant Indicator
BUD	Beneficial Use of Dredge Material
CE	Cost Effectiveness
CEQ	Council on Environmental Quality
CHAP	Combined Habitat Assessment Protocols
CMP	Coastal Master Plan
CPRA	Coastal Protection and Restoration Authority
CSRM	Coastal Storm Risk Management
CSU	Concrete Structural Units
DMDU	Decision Making under Deep Uncertainty
DWSC	Deep Water Ship Channel
EAB	Environmental Advisory Board
EEIRP	Evaluation of Environmental Investments Research Program
EIS	Environmental Impact Statement
EMRRP	Ecosystem Management and Restoration Research Program
ENR	Environmental Restoration
EQ	Environmental Quality
ERDC	Engineer Research and Development Center
ESV	Ecosystem Services Valuation
EWN	Engineering with Nature
FEMA	Federal Emergency Management Agency
FIC	Flood Improvement Channel
FRM	Flood Risk Management
FRR	Flood Risk Reduction
FWA	Future With Action

Acronym	Term
FWOA	Future Without Action
GAO	Government Accountability Office
GIS	Geographic Information Systems
GIWW	Gulf Intracoastal Water Way
GMI	Great Marsh Island
GRR	General Reevaluation Report
HCFP	Helen Cooper Floyd Park
HEC-FDA	Hydrologic Engineering Center-Flood Damage Reduction Analysis
HFF	High Frequency Flooding
HFFRRF	High Frequency Flood Risk Reduction Features
HQ	Headquarters
HRE	Hudson-Raritan Estuary
HSDRR	Hurricane and Storm Damage Risk Reduction
HSGRR	Hurricane Sandy General Reevaluation Report
ICA	Incremental Cost Assessment
ICM	Integrated Compartment Model
IIJA	Infrastructure Investment and Jobs Act
InVest	Integrated Valuation of Ecosystem Services and Tradeoffs
IPBES	Intergovernmental Science Policy Platform on Biodiversity and Ecosystem Services
IWG	Interagency Working Group
IWR	Institute for Water Resources
IWW	Intracoastal Waterway
LDWF	Louisiana Department of Wildlife and Fisheries
LF	Linear Feet
LPP	Locally Preferred Plan
LSU	Louisiana State University
LULC	Land Use Land Cover
MCDA	Multi-Criteria Decision Analysis
MEA	Millennium Ecosystem Assessment
MODA	Multi-Objective Decision Analysis
MORDM	Many Objective Robust Decision Making
MVD	Mississippi Valley Division
MVN	New Orleans District

Acronym	Term
NAD	North Atlantic Division
NAN	New York District
NASEM	National Academies of Science, Engineering, and Medicine
NAV	Navigation
NBS	Nature Based Solutions
NED	National Economic Development
NER	National Ecosystem Restoration
NNBF	Natural and Nature Based Features
NOAA	National Oceanic and Atmospheric Administration
NPS	National Park Service
NWD	Northwestern Division
NWO	Omaha District
O&M	Operations & Maintenance
OMB	Office of Management and Budget
OMRR&R	Operation, Maintenance, Repair, Replacement, & Rehabilitation
OSE	Other Social Effects
OWPR	USACE Office of Water Project Review
P&G	Principles and Guidelines
PDT	Project Development Team
PR&G	Principles, Requirements and Guidelines
ProACT	Problem, Objectives, Alternatives, Consequence analysis, Tradeoffs
RED	Regional Economic Development
RIRA	Ridgway's Rail
RP	Recommended Plan
SAD	South Atlantic Division
SAJ	Jacksonville District
SBSP	South Bay Salt Pond
SC-GHG	Social Cost of Greenhouse Gases
SDD	Secchi Disk Depth
SDM	Structured Decision Making
SJR	St Johns River
SLC	Sea Level Change
S.M.A.R.T.	Specific, Measurable, Achievable, Relevant, Timeline realistic

Acronym	Term
SMHM	Salt Marsh Harvest Mouse
SPD	South Pacific Division
SPK	Sacramento District
SPN	San Francisco District
SROI	Social Return on Investment
SWCLA	Southwest Coastal Louisiana
TEEB	The Economics of Ecosystems and Biodiversity
TNEHP	Timucuan Ecological and Historic Preserve
TSP	Tentatively Selected Plan
TSS	Total Suspended Solids
UDV	Unit Day Value
UPRR	Union Pacific Railroad
USACE	United States Army Corps of Engineers
USEPA	United States Environmental Protection Agency
USFS	United States Fish and Wildlife Service
USGS	United States Geological Survey
VE	Value Engineering
WRDA	Water Resources Development Act
WUI	Wildland-Urban Interface

1.0 INTRODUCTION

To accelerate progress and delivery of new and enhanced infrastructure projects for navigation, flood risk management, water operations, and ecosystem restoration consistent with its Engineering With Nature® (EWN) Program, the U.S. Army Corps of Engineers (USACE) has engaged in a collaborative effort with The Water Institute of the Gulf (the Institute) to conduct policy research for fully evaluating the benefits of EWN strategies and projects, to include Natural Infrastructure, Natural[2] and Nature Based Features (USACE, 2021c), and other Nature-Based Solutions (NBS). Throughout this document, these techniques are referred to using the umbrella term "NBS".

This document is the fourth and final report produced as part of this collaborative effort. Previous reports developed during this project describe the evolution of USACE evaluation approaches from prior eras of planning to the present day (Ehrenwerth et al., 2022), investigate where and how NBS were considered in planning studies from 2005–2020 (Windhoffer et al., 2023), and review relevant planning and valuation methods that could be applied by USACE to improve NBS evaluation (Fischbach et al., 2023) and that were considered to inform the subsequent case study analysis described here.

This report builds on these earlier efforts and presents the results from six retrospective case studies developed by the collaborative study team based on completed USACE planning studies. The goal is to demonstrate how USACE could apply new or augmented methods to consider a wider range of social, environmental, and economic benefits and costs when evaluating NBS alongside traditional infrastructure solutions. Expanding USACE's evaluation toolkit in this way would be an important step towards an integrated water resources planning approach and a more balanced consideration of the multiple benefits NBS can provide. The analysis described here includes approaches that prioritize multiple objectives—measured with different performance metrics—at once, and specifically considers how USACE might apply new methods to integrate additional categories into the formal benefit-cost analysis (BCA) currently applied for the evaluation and prioritization of alternatives within a USACE planning study.

1.1 ECOSYSTEM SERVICE VALUATION OPPORTUNITIES AND CHALLENGES

Natural ecosystems provide value to people as ecosystem services with both economic and socio-cultural benefits. These services can be difficult to measure or estimate with precision, however, given significant variation in type, function, quality, and associated human value that can occur across different geographies, ecosystem types, and human communities. Methods for placing economic value on ecosystem goods and services have proliferated in recent decades, but the practice continues to evolve and

[2] "[N]atural features are created and evolve over time through the actions of physical, biological, geologic, and chemical processes operating in nature… [c]onversely, nature-based features are those that may mimic characteristics of natural features, but are created by human design, engineering, and construction to provide specific services such as coastal risk reduction" (Bridges et al., 2015).

there may be greater uncertainty in estimating ecosystem benefits and costs when compared to approaches to value traditional water resources infrastructure (e.g., asset damage reduction from flood defenses).

As a result, environmental benefits and costs are often excluded from traditional BCA approaches, including USACE analyses intended to estimate the national economic development (NED) or regional economic development (RED) benefits from water resources projects under consideration. These traditional approaches focus on more precise estimates of a subset of benefits and costs rather than less precise estimates of the total picture, and implicitly treat the excluded categories as having zero benefit and cost. As Ehrenwerth et al. (2022) notes, this can lead to choices that do not necessarily provide the greatest public welfare and tends to deprioritize NBS approaches.

BCA also has other inherent limitations. The approach weights disparate effects according to estimated social value, masking tradeoffs within a "black box" summary valuation that does not necessarily speak to the distribution of benefits across different populations or other social objectives. Furthermore, BCA approaches typically use post-hoc sensitivity analysis to consider uncertainty rather than incorporating uncertainty from the outset, as with scenario-based methods.

BCA is only one of many potential approaches to support water resources decision analysis, and in this report the study team also pilots the application of additional methods of potential interest for USACE that are designed to support decision making across multiple objectives. These approaches can incorporate both monetary and non-monetary metrics for assessing project impacts and necessitate developing meaningful and interpretable non-monetary metrics to capture other types of benefits and costs.

1.2 PAST AND PRESENT USACE PLANNING PRACTICE

The USACE Civil Works Program is responsible for implementing a water resources mission that includes flood risk reduction, navigation, recreation, infrastructure, ecosystem restoration, and emergency response.[3] USACE is tasked with developing and executing water resources projects in such a way as to ensure that the expenditure of federal funds is reasonable and yields appropriate benefits, consistent with national policy and its legislated authorities.

Over its more than 200-year history, USACE has evolved from a limited role in enhancing navigation for military and commercial purposes to a more expansive and complex role at the intersection of commerce, transportation, recreation, environmental protection and restoration, protection of human life, and promotion of ecological and social resilience. A summary of the major steps in USACE evolution is shown in Figure 1-1.

[3] This section is adapted from Ehrenwerth et al. (2022).

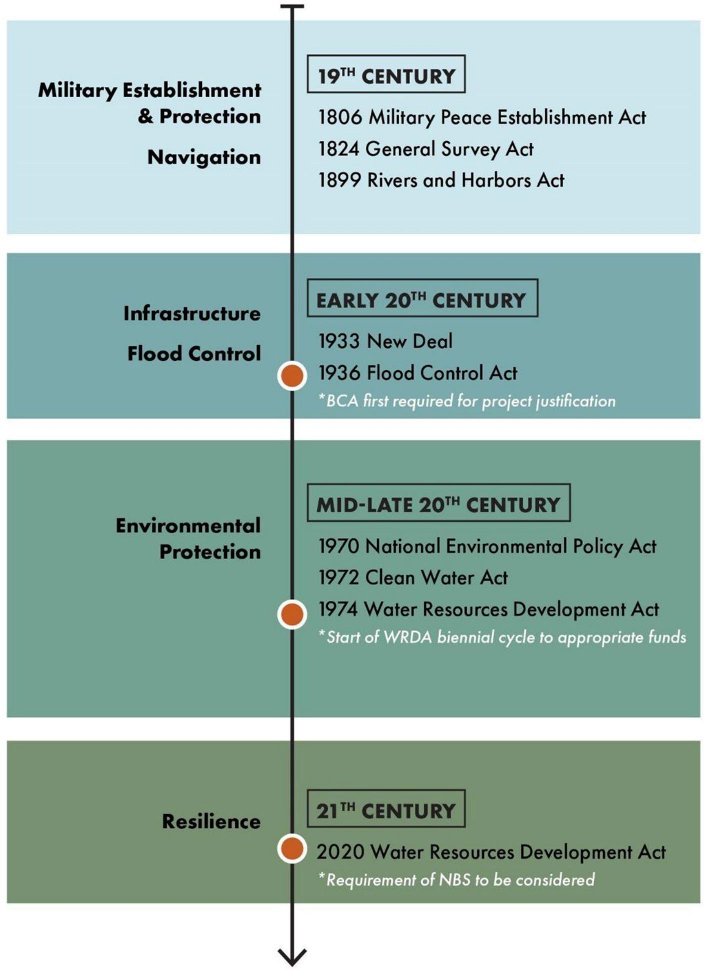


Figure 1-1. Timeline of USACE mission evolution and selected events. Source: Ehrenwerth et al. (2022).

The USACE approach to project evaluation has evolved in tandem with broader public expectations about the role of the federal government in managing water resources for public safety, ecosystem protection, and economic development. USACE project valuation strategies were originally designed to responsibly guide federal investment to projects that provide benefits to the nation. These valuation methods have been refined through multiple iterations over the course of time to incorporate additional scientific information and consider a more diverse array of benefits and costs.

Since 1983, USACE review and prioritization of water resources projects have been driven by BCA. Specifically, the *Principles and Guidelines for Water and Related Land Use Implementation Studies* (colloquially known as the "P&G") has guided project evaluation since 1983 (Water Resources Council, 1982; Water Resources Council, 1983). The P&G established NED as the primary purpose for water resources management while also establishing three other "accounts" that could be considered as part of project formulation and prioritization. A summary of the key features and objectives of the 1983 P&G is shown in Table 1-1. Additional detail on the P&G, as well as other past phases of USACE evaluation practice, can be found in Ehrenwerth et al. (2022).

Table 1-1. Key features of the 1983 Principles and Guidelines for Water and Related Land Use Implementation Studies*. Source: Ehrenwerth et al. (2022)*

1983 P&G: FOUR OBJECTIVES FOR WATER RESOURCES PLANNING AND EVALUATION			
System of Accounts			
REQUIRED	**National Economic Development (NED)** The NED account covers "changes in the economic value of the national output of goods and services" and is generally expressed in monetary units. NED benefits relevant to flood-control projects include quantifiable benefits such as protecting crops and other developed land, enhancing recreational opportunities, and protecting commercial fisheries (1983, p. 9).		
OPTIONAL	**Environmental Quality (EQ)** The EQ account covers "non-monetary effects on significant natural and cultural resources." Examples include functional aspects of the environment such as nutrient cycling and erosion, structural aspects of the environment such as plant or animal populations and chemical/physical properties of water or air, and cultural attributes that provide evidence of human lifeways (1983, p. 103).	**Regional Economic Development (RED)** The RED account "registers changes in the distribution of regional economic activity that result from each alternative plan" (1983, p. 11). It reflects an interest among policymakers in understanding how public works projects can provide sizeable income and employment benefits to local communities.	**Other Social Effects (OSE)** The OSE account "registers plan effects from perspectives that are relevant to the planning process but are not reflected in the other three accounts." It includes "urban and community impacts; life, health, and safety factors; displacement; long-term productivity; and energy requirements and energy conservation" (1983, p. 12).

The past and current use of BCA has contributed to undervaluing the environmental and social benefits of potential water resource alternatives and projects. Consequently, this practice has adversely impacted the evaluation of NBS intended to reduce risk and support public safety while also providing environmental and social co-benefits.

1.3 RECENT DEVELOPMENTS IN PROJECT EVALUATION

In 2007, Congress instructed the Secretary of the Army to revise the P&G consistent with a new set of priorities, which included sustainable economic development, minimizing "unwise" land use in floodplains, and protecting and restoring "the functions of natural systems" (WRDA, 2007).[4] A multi-year process of drafting, feedback, and iteration during the Obama Administration eventually led to a new policy in two parts: first, reframing and revising the *Principles and Requirements* in March 2013, and separately developing *Interagency Guidelines* in December 2014 (78 Fed. Reg. 18562, 2013; 79 Fed. Reg. 77460, 2014). Collectively, the *Principles, Requirements, and Interagency Guidelines* are colloquially known as the updated "PR&G".

The PR&G encourages agencies to return to multi-objective analysis and establishes a new model for project evaluation based on an ecosystem services model. It presents the ecosystem services approach as "a way to organize all the potential effects of an action (economic, environmental, and social) within a framework that explicitly recognizes their interconnected nature" (Council on Environmental Quality [CEQ], 2013b). It also calls for the more flexible application of BCA, acknowledging the challenge in quantifying all relevant benefits and costs and recognizing that subjective judgement is often required.

The PR&G also establishes a new set of accounts in identifying six co-equal principles for water resources planning, putting environmental and social effects on the same level as economic considerations. The six principles (accounts) are:

1. **Healthy and resilient ecosystems**: Includes an explicit objective of protecting and restoring ecosystem function.
2. **Sustainable economic development**: Emphasizes "the creation and maintenance of conditions under which humans and nature can coexist in the present and into the future."
3. **Floodplain management**: Avoiding unwise uses that have "an unreasonable adverse effect on public health and safety, or … [are] incompatible with or adversely affects one or more floodplain functions that leads to a floodplain that is no longer self-sustaining."
4. **Public safety**: Avoiding, reducing, and mitigating risks of death and injury.
5. **Environmental justice**: Includes both fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies.
6. **Watershed approach**: Promotes policies that "facilitate evaluation of a more complete range of potential solutions and is more likely to identify the best means to achieve multiple goals over the entire watershed" (CEQ, 2013, pp. 4–6).

---

[4] This section is adapted from Ehrenwerth et al. (2022).

After publication, however, some members of Congress objected to the way the PR&G placed all three objectives listed in the Water Resources Development Act (WRDA) of 2007 on co-equal footing. These objections led to annual riders in USACE's appropriations that prevented USACE from implementing the new guidelines (U.S. Government Accountability Office [GAO], 2019, p. 24). Congress recently dropped this rider, however, and in WRDA 2020 directed USACE to issue final agency-specific procedures to implement the PR&G.

The research in this report is intended to support USACE in developing future procedures in considering the full suite of economic, environmental, and social costs and benefits in water resources projects, and builds on the ecosystem services model and new principles outlined above.

1.4 ORGANIZATION OF THIS REPORT

This report proceeds in 10 chapters. Chapter 2 provides an overview of the planning study inventory, case study selection, and case study analysis process. Chapters3–8 present the results from each of the six retrospective case studies in turn, with one chapter per case study. Chapter 9 includes emerging themes and other cross-cutting analysis developed by the study team when synthesizing results across the case studies. Chapter 10 concludes with a summary of key analysis findings and opportunities for USACE to help inform improved NBS evaluation as part of PR&G implementation. The report also includes appendices with additional technical detail supporting the case studies (Appendix A) and acknowledging the USACE and non-USACE stakeholders who contributed to this effort (Appendix B).

2.0 CASE STUDY SELECTION AND ANALYSIS APPROACH

In the first phase of this effort, the study team collaborated with USACE to develop an inventory of recent, completed planning studies, gather expert input on the suitability of these studies for reanalysis, and identify a subset of planning studies that included NBS in both plan formulation and evaluation and solicited interest in NBS from non-federal sponsors. The team then worked with USACE stakeholders to identify a subset of six planning studies suitable for case study evaluation. The inventory development and case study selection process is described in detail in Windhoffer et al. (2023). Figure 2-1 provides a summary of the inventory development and study selection process.

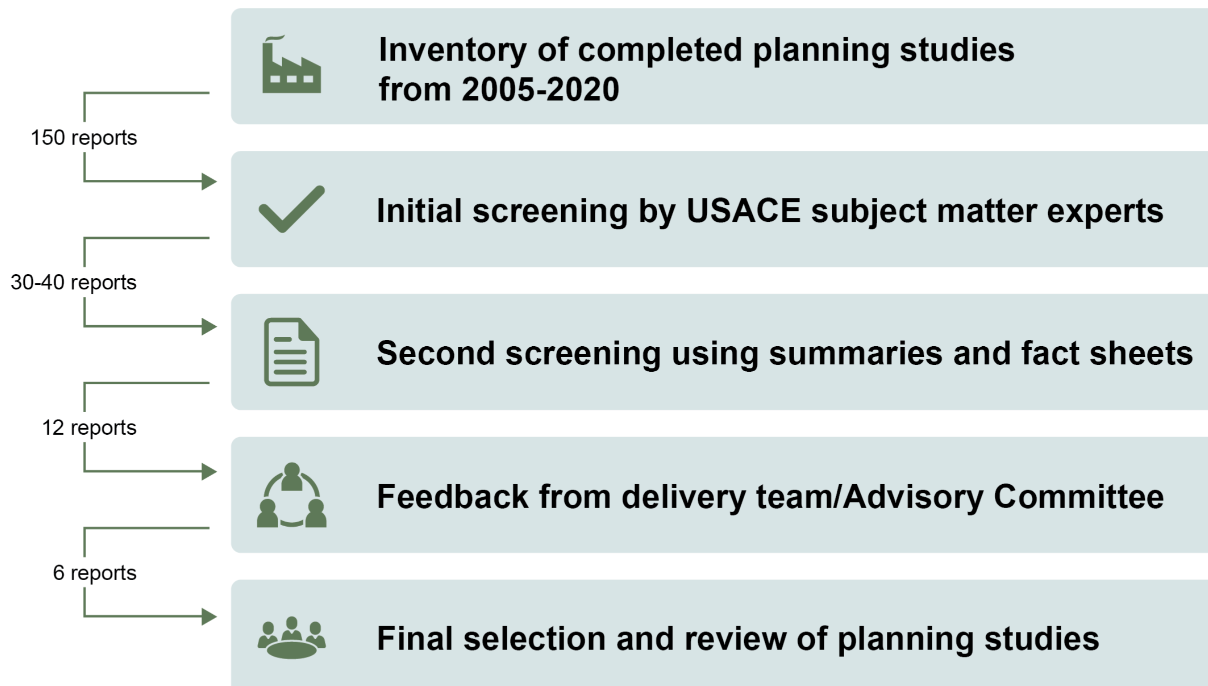


Figure 2-1. Overview of study selection process. Source: Windhoffer et al. (2023)

2.1 IDENTIFYING PLANNING STUDIES THAT CONSIDERED NBS

The study team developed an inventory from a convenience sample of recent USACE planning studies finalized between 2005–2020.[5] The planning studies spanned a range of mission areas[6], including Coastal Storm Risk Management (CSRM), Flood Risk Management (FRM), Navigation (NAV), Environmental

---

[5] This section was adapted from Windhoffer et al. (2023).

[6] The term “mission area” is used to denote which business line and/or program a USACE project was authorized under. Projects are typically authorized to occur under a single mission area.

Restoration (ENR), and Water Supply. The initial screening process relied on input from Division and District Planning Chiefs and USACE Headquarters via a scoring process (see Sections 2.2 and 2.3).

The study team reviewed each planning study to identify the project purpose, geographic area, project complexity, and benefit-cost ratio (BCR). In general, the team found that the number of studies conducted in any given year, and the purpose of those studies, was influenced by major disaster events (e.g., hurricanes) and the passage of legislation by Congress (e.g., WRDA bills).

2.2 USACE AND STAKEHOLDER ENGAGEMENT

The study team subsequently initiated a two-round scoring process designed to elicit feedback on the suitability of identified planning studies for case study analysis from the Division and District Planning Chiefs and USACE Headquarters (HQ) Office of Water Project Review (OWPR), respectively.[7] This process served to provide different perspectives on the utilization of NBS alternatives and thus inform case study selection. Although the study team did not receive feedback from all Divisions and Districts, the broad knowledge and familiarity of the planning studies provided by HQ staff were adequate to address data and knowledge gaps.

In addition, a USACE Advisory Committee was formed to provide expertise and input during the study. Advisory Committee members were selected by USACE Planning and Policy Division and USACE EWN to include different organizational perspectives, functional areas, expertise, and geographic distribution. The Advisory Committee members included District, Division, and HQ personnel from planning and engineering organizations with experience and familiarity with USACE planning policies and NBS practices. Advisory Committee members were briefed several times through the course of the study, and specifically provided feedback to inform final case study selection (see Section 2.3). The study team also met with a smaller group from this committee several times for additional feedback related to valuation methodologies.

The study team also engaged a group of stakeholders outside of USACE, largely composed of representatives from environmental non-governmental organizations, to provide additional feedback at key study milestones. The study team briefed these stakeholders in virtual sessions three times through the course of the study: in early stages to discuss the overall research approach, then during case study selection, and finally with a draft of complete results from the case study analysis. Feedback from this group helped to identify key questions from stakeholders interested in encouraging additional consideration of NBS, supported final case study selection, and informed the communication of study results for USACE audiences.

A list of selected USACE and non-USACE participants who provided feedback and contributed to the study in these convenings can be found in Appendix B of this report.

---

[7] This section was adapted from Windhoffer et al. (2023).

Finally, in partnership with the National Academies of Science, Engineering, and Medicine (NASEM), the study team hosted a one-day hybrid in-person and virtual summit in Washington, DC on November 30, 2022 to present preliminary research results and bring together a diverse range of stakeholders interested in improving federal evaluation and planning processes.[8] Participants included federal personnel working with BCA in water resources planning, grantmaking, and regulatory contexts; academic, non-government organization, and other applied researchers working at the nexus of ecosystem services and applied valuation; and interested industry and private sector partners. Questions, discussion, and feedback gathered during the summit improved the final stages of this work and will help to guide next steps for research and implementation.

2.3 CASE STUDY SELECTION

In the first round of scoring, the Division and District Planning Chiefs were asked to assess each planning study along two dimensions: 1) the level of consideration given to NBS during the formulation and evaluation process and 2) the non-Federal sponsor's interest in formulating and implementing NBS. Of the 150 planning studies identified in the 2005–2020 inventory, the Division and District Planning Chiefs provided responses for 108 planning studies.[9] The scoring results showed that comparatively few planning studies carried NBS forward throughout the entire evaluation process. Eighty-five planning studies (79% of the 108 scored reports) considered NBS at some level, and of these 67 (62%) were formally considered during plan formulation and evaluation.

Approximately 57 of 108 studies scored (53%) considered NBS during formulation and carried NBS alternatives through to the final array. Twenty-six of these 57 studies (46%) specifically focused on the ENR mission, where NBS alternatives would be the primary or sole focus, leaving 31 studies with other primary missions (or considered multi-mission) that formulated NBS alternatives and carried them through all phases of the analysis.

In the second round of scoring, experts from OWPR were asked to rate the suitability of planning studies from the inventory for case study analysis in this effort, taking into account both the level of NBS consideration and the current availability of documentation and data after planning study completion. Of the studies OWPR was able to score, 31 were rated highly in terms of their suitability for retrospective NBS case study analysis. Twenty of the studies scored highly by OWPR also scored high on level of NBS consideration and non-federal interest, while an additional 11 studies were scored highly by OWPR that either scored lower in the initial screening (3 studies) or were not previously scored (8 studies). The study

---

[8] For more information on the summit, including meeting materials and recorded sessions, please see: https://www.nationalacademies.org/event/11-30-2022/measuring-what-matters-towards-a-more-comprehensive-and-equitable-evaluation-of-benefits.

[9] This section was adapted from Windhoffer et al. (2023). See Figure 1 in Ehrenwerth et al. (2022) for a visual representation of the USACE planning study evaluation process.

team used this input to carry forward 28 planning studies from the overall inventory for further consideration.

The study team next conducted further screening based on diversity of geographic location, business lines, scale and complexity, preliminary data availability, and alternative formulation information. This led to a final list of 12 case studies. The study team developed summary fact sheets for each of these final options, drawing on available documentation, and presented the final options to the Advisory Committee. Drawing on their feedback and additional input from the stakeholder group, the study team selected a list of six final case studies for analysis in the second phase of the project.

Overall, this effort was successful in selecting six studies that represent diversity across geographic regions, purposes, and various levels of complexity. The selected case studies are mapped in Figure 2-2 and listed in Table 2-1 along with their key characteristics.

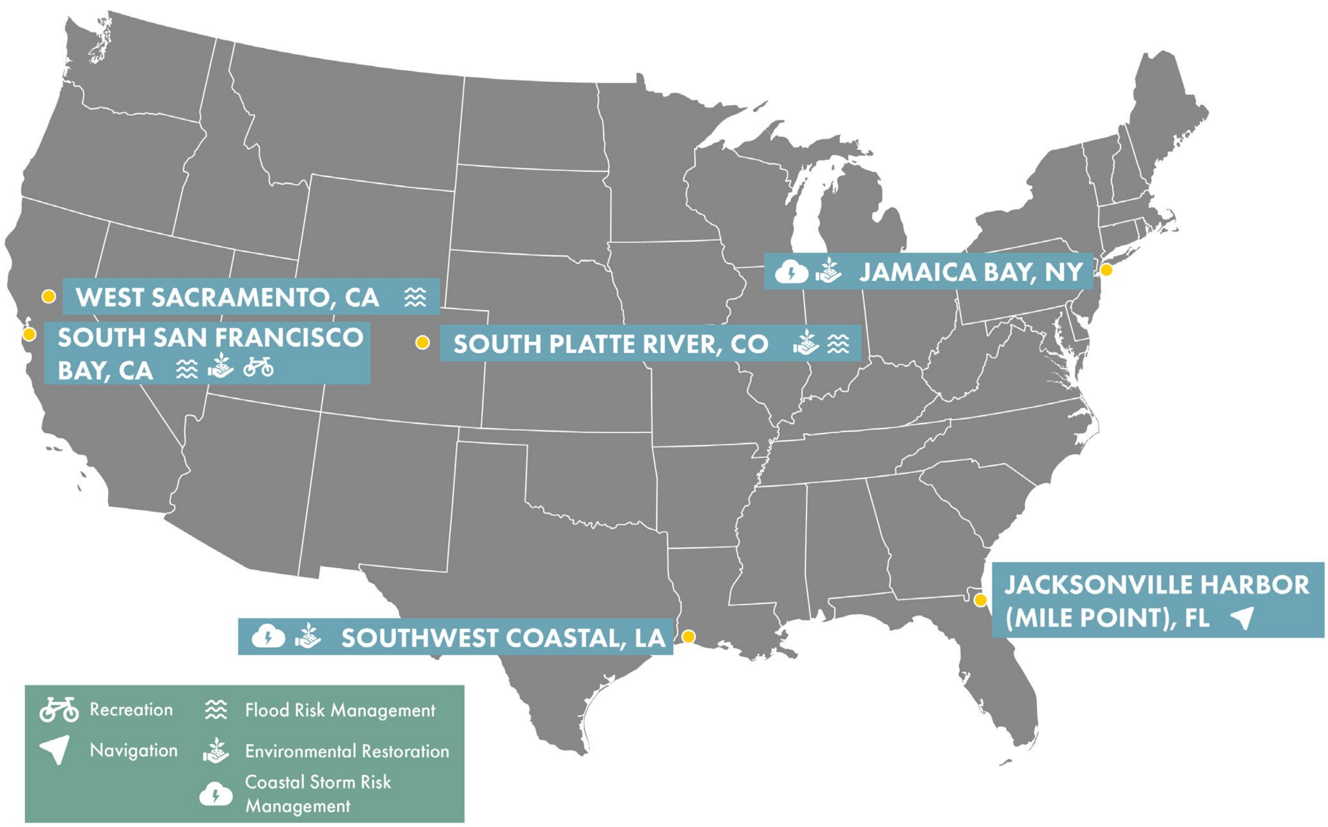


Figure 2-2. Six case studies selected for further evaluation based on mission area, local interest, and available data.

Table 2-1. The final six planning studies selected as case studies for the policy research.

Project name	Purpose	Level of NBS rating	Non-Federal Interest	OWPR Scoring	Division	District	Year	Cost (in billions)
Jacksonville Harbor, Mile Point, FL	NAV	5	3	5	SAD	SAJ	2012	$0.04
Southwest Coastal, LA	CSRM/ ENR	5	5	5	MVD	MVN	2016	$3.16
South San Francisco Bay Shoreline, CA	FRM/ ENR	-	-	5	SPD	SPN	2015	$0.17
West Sacramento, CA	FRM	4	5	5	SPD	SPK	2016	$1.19
South Platte River and Tributaries, Adams and Denver Counties, CO	FRM/ ENR	5	3	4	NWD	NWO	2019	$0.51
East Rockaway Inlet to Rockaway Inlet and Jamaica Bay Reformulation, Atlantic Coast of NY	CSRM	5	3	5	NAD	NAN	2019	$0.96

Note: scoring is based on a 5-point scale, with 5 representing the highest score from each source. Purpose: NAV = Navigation, CSRM = Coastal Storm Risk Management , ENR = Environmental Restoration, FRM = Flood Risk Management. USACE Divisions: SAD = South Atlantic Disvision , MVD = Mississippi Valley Division, SPD = South Pacific Division , NWD = Northwestern Division , NAD = North Atlantic Division. USACE Districts: SAJ = Jacksonville District , MVN = New Orleans District , SPN = San Francisco District , SPK = Sacramento District , NWO= Omaha District , NAN = New York District.

2.4 REVIEW OF DECISION AND VALUATION METHODOLOGIES

The study team reviewed and considered decision analysis and valuation methodologies relevant for the case study analysis.[10] This task included 1) the development of an overview of recent and relevant decision analysis designed to inform decision makers when considering or trading off among multiple objectives when prioritizing water resources projects and 2) a review of relevant valuation methodologies in recent economics and ecological management literature. The study team then used this overall review to develop a blueprint and guide for the case study analyses that followed. This investigation is documented in detail in a separate report (Fischbach et al., 2023). A summary is included here to support the case study analysis described in Chapters 3.0–8.0.

2.4.1 Multi-Criteria and Multi-Objective Decision Analysis

Monetized valuation of ecosystem goods and services cannot capture the full range of benefits and costs from a given project that incorporates NBS. Technical limitations, time and resource constraints, and the

[10] This section was adapted from Fischbach et al. (2023).

inherent challenges in monetizing some desired outcomes (e.g., environmental resiliency) suggest the need for a broader decision framework that can consider project consequences in non-monetized terms and use these outputs to help prioritize different approaches or consider key tradeoffs. The need for alternate frameworks is further reinforced when including the social impacts of proposed alternatives, as the benefits and costs can vary significantly across different communities and traditional BCA methods can exacerbate historical inequities. Finally, uncertainty about future benefits and costs is another challenge that traditional BCA comparisons alone may not address. The assumptions required for valuation may lead to underestimating or ignoring uncertainties essential to a long-term infrastructure decision.

To support USACE in addressing these challenges, the study team reviewed decision analysis approaches designed to address multiple objectives measured in different units, consider tradeoffs across these multiple objectives, and use scenario analysis to incorporate future uncertainty explicitly and build towards alternatives that are more robust to uncertainty related to project performance or cost. A brief overview of methods considered is provided here; for more information and supporting literature, see Fischbach et al. (2023).

- *Multi-criteria or Multi-objective Decision Analysis* (MCDA/MODA) is a broad term that describes a suite of different approaches for systematically evaluating the performance of alternatives towards multiple objectives, assessing tradeoffs, and considering the robustness of a decision to uncertainty (Fischbach et al., 2023). USACE has a long history of developing and applying MCDA/MODA to inform planning (Ehrenwerth et al., 2022) and as part of IWR management (Linkov, Satterstrom, Kiker, Batchelor, et al., 2006; Linkov, Satterstrom, Kiker, Seager, et al., 2006), but many USACE planning studies are primarily weighted towards a single objective and may not consider other objectives on a co-equal basis or capture key tradeoffs between objectives. For simplicity, throughout the remainder of the report these methods are referred to by the umbrella term "MODA."
- *Structured Decision Making* (SDM) is an extension of MODA that includes both tradeoff analysis and optimization. SDM features a rigorous and structured approach to problem definition and decomposition, and the structure and transparency introduced throughout the process makes it well-suited for applications with multiple decision-makers or stakeholders. Iterative SDM can also help support the implementation of adaptive management at the project or strategy scale.
- Methods for *Decision Making Under Deep Uncertainty (DMDU)* are designed to inform decisions where the decision-maker(s) and key stakeholders do not know, or do not agree on, projections of future conditions that directly affect the success or failure of a project or plan. In these cases, DMDU methods are designed to help identify alternatives that are more robust to future conditions, meaning that they will perform reasonably well across a range of diverging future conditions. Robustness often entails including adaptive elements or multiple pathways that are pre-defined in response to observed conditions over time. Methods included in this toolkit include Robust Decision Making, Multi-Objective Robust Decision Making, Dynamic Adaptive Policy Pathways, and InfoGap.

- *Social Return on Investment* (SROI) and other *participatory planning* methods seek to more fully represent the spectrum of social, environmental, and economic benefits and costs that may not be captured through traditional economic analysis. Building on the concept of social accounting, SROI analysis is a conceptual and quantitative approach that incorporates social and environmental values into a traditional economic-only BCA. It can be considered a complementary method that adds local context, richness, and narrative to standard valuation studies. Other related participatory approaches are designed to bring together qualitative local knowledge systems with technical scientific knowledge and formal mathematical models to inform community planning and ecosystem management decisions.

The majority of the methods reviewed in this section proved infeasible to fully implement within the scope of a retrospective case study analysis reliant on secondary data. However, the study team applied selected tools where possible—for example, a *stoplight chart* for implementing MODA that aligns metrics across multiple objectives and illustrates potential tradeoffs between different approaches. In addition, each case study includes a qualitative discussion of alternative performance across multiple criteria and environmental and social outcomes not otherwise captured in the quantitative analysis that are relevant for decision making.

2.4.2 Economic Valuation of Ecosystem Services

Methods for placing economic value on ecosystem goods and services have proliferated in recent decades, but different approaches have relative strengths and weaknesses and may introduce additional dimensions of uncertainty into a decision analysis. The study team reviewed a range of currently employed methods, considering the suitability of each method for estimating different types of benefits, the data, and assumptions necessary to implement the methods, and their relative advantages and disadvantages.

Ecosystem service methods include *primary methods* designed to estimate willingness to pay for ecosystem services using alternative techniques and *secondary methods* that draw usable information from studies developed in one or a range of context and develop generalized values suitable for application elsewhere. Primary methods reviewed for this study are briefly summarized in Table 2-2; for a more detailed discussion see Fischbach et al. (2023).

Table 2-2. Primary ecosystem service valuation methods reviewed for this study. Source: Adapted from Fischbach et al. (2023).

Name	Category	Description	Key assumptions	Limitations
Averting Behavior / Cost Based Methods	Revealed preference	Infer the use value of a good or service from expenditures, avoided costs, mitigation and restoration costs, or replacement costs.	Known cost of providing a nonmarket good or service provides a minimum estimate of its value.	Cannot distinguish between willingness to pay and actual cost of a good or service.
Hedonic Property Method	Revealed preference	Use statistical models to estimate the marginal use value of an amenity based on observed property values, sales, or rents.	Property markets are competitive; individual perceptions match objective reality.	Marginal estimate may be insufficient to capture large changes; potential for bias from multiple sources.
Travel Cost Method	Revealed preference	Use statistical models, travel time, and measures of the value of time to estimate the value of a recreational trip to a participant.	Demand for recreation inversely related to costs to travel to a site.	Single site models may not apply to substitute sites and cannot consider key changes; multiple site models more complex and difficult to estimate.
Contingent Valuation / Choice Experiments	Stated preference	Use survey data and/or an experimental design to estimate willingness-to-pay for use and/or non-use (existence) values.	Well-designed survey and incentives will lead to accurate and consistent participant responses.	Estimates are not based on revealed behavior; experiment incentives or other challenges may lead to bias.

The study team also considered secondary methods, which rely on one or more studies conducted outside the area of interest or bounds of a particular decision analysis. In these approaches, estimates of ecosystem service values developed in one context are used to estimate their value in another context with similar characteristics. These approaches can be less time intensive and expensive to implement, but with the tradeoff that values developed for one location may be biased when applied in another site with different characteristics (e.g., biophysical system, neighboring community characteristics). For this reason, secondary methods may be more likely to be feasible to incorporate into ecosystem service valuation for USACE planning studies moving forward.

Benefit transfer methods, which use estimates from previous valuation research and apply them in a new context, are the most common form of secondary valuation. These methods can range from simply adopting values from one study and using them in another, up to more complex meta-analysis or meta-regression models that estimate values across a range of studies. Benefit transfer has been recognized as an appropriate tool for BCA in the U.S. and other peer countries. Specifically, USACE and other federal agencies have developed databases of transfer values for use in BCA and regulatory analysis (see Table 2-3).

Table 2-3. Benefit transfer tools and data sources from U.S. government agencies

Name	Agency	Description	Source
Benefit Transfer Toolkit	USGS	Nonmarket valuation database, statistical forecasting models, and recreation activities map	https://sciencebase.usgs.gov/benefit-transfer/
Recreation Use Values	USFS	Estimated recreation use values for 14 recreational categories using the Recreation Use Values Database	https://www.fs.fed.us/pnw/pubs/pnw_gtr957.pdf
Recreation Unit Day Values	USACE	Estimated day use values for recreation by quality tier	https://planning.erdc.dren.mil
Ecosystem Service Benefits	FEMA	Allowable ecosystem service values for Hazard Mitigation Assistance programs by land use type	https://www.fema.gov/sites/default/files/documents/fema_innovative-drought-flood-mitigation-projects.pdf (Table 2-2)
EcoService Models Library	USEPA	Library of ecological production models	https://www.epa.gov/eco-research/ecoservice-models-library
Value of water quality changes meta-analysis	USEPA	Meta-analysis for improvements in water quality based on 51 original studies	https://www.epa.gov/sites/default/files/2015-10/documents/steam-electric_benefit-cost-analysis_09-29-2015.pdf (Appendix H)
BlueValue	NOAA	Database of ecosystem service values focused on coastal areas	https://imagery2.coast.noaa.gov/digitalcoast/tools/gecoserv.html

Source:Fischbach et al. (2023). USGS = U.S. Geological Survey; USFS = U.S. Forestry Service, FEMA = Federal Emergency Management Agency, USEPA = U.S. Environmental Protection Agency, NOAA = National Oceanic and Atmospheric Administration.

Finally, researchers have developed integrated decision support tools that combine transferred values with ecological production models (e.g., the Integrated Valuation of Ecosystem Services and Tradeoffs [InVEST] and Artificial Intelligence for Ecosystem Services [ARIES] models [Tallis et al., 2009; Villa et al., 2014]). These and similar tools include pre-programmed functions that allow for local or regional customization, and generally take spatial data such as land cover as key model inputs. Such tools can provide a transparent and replicable analysis at relatively low cost and effort but face similar challenges to other benefit transfer approaches (e.g., model complexity when capturing multiple ecosystem services;

potential for bias when applied in new settings). Model validation is also a concern; at present, these models have not yet been widely adopted or certified for use in decision analysis for USACE investments.

2.5 CASE STUDY REANALYSIS PROCESS

The case studies presented in the chapters that follow each used a common structure to help inform comparisons and cross-cutting analysis (Figure 2-3). After reviewing the background and context of each case study, the study team followed an approach to alternative analysis that could potentially be adopted by USACE in feasibility studies for more comprehensive analysis of NBS that is consistent with the co-equal principles of the PR&G: study scoping, alternative formation, non-monetized outcome evaluation, monetized valuation, and Prioritization and Alternative Selection. Each case study team was composed of 2–3 team members, and the teams worked in parallel through the steps below. Case study leads met regularly to coordinate and share progress.

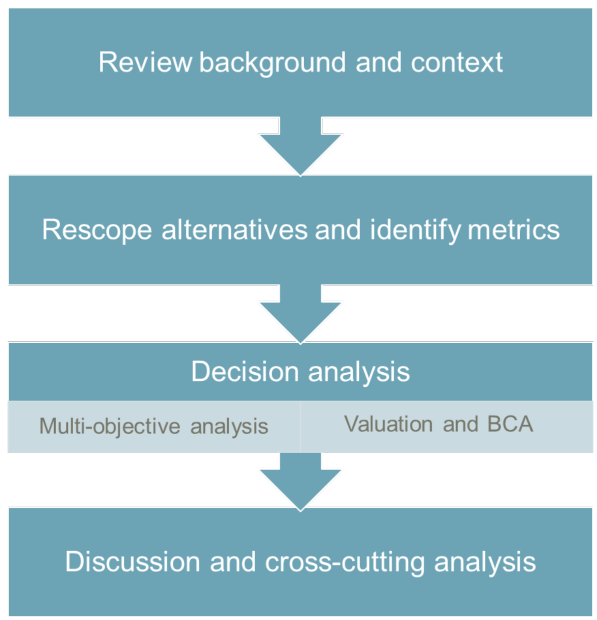


Figure 2-3. Overview of case study analysis process.

2.5.1 Overview of Background and Context

Each case study began with a review of key background and context for the original USACE feasibility study. This review included a summary of the motivation for the study, including problem(s) to be addressed, geography of interest, congressional authorization, and USACE mission areas and goals for each study. The study teams then summarized the process for identifying options, screening, and formulating specific alternatives to be competed in the final decision analysis. This summary particularly highlighted how and at which steps NBS options were either included or excluded as part of the formulation process. Finally, the study team summarized the comparison of alternatives, identification of a final array of alternatives and recommended plan (RP), and the final results and outcome of the study as documented in the Chief’s Report. The team concluded by noting the current project status and discussing other information relevant for case study reanalysis (e.g., local sponsor actions after study finalization, additional local context, and such).

2.5.2 Case Study Reanalysis: Study Scope

After reviewing the case study background and context, the study team conducted a study scoping exercise to identify NBS that would be considered as part of case study reanalysis. The study team considered NBS that were part of the original USACE feasibility study or value engineering (VE) studies conducted as part of developing the Chief's Report and collocated USACE feasibility studies. Because of the reliance of the reanalysis on existing data and the desire to benchmark the reanalysis against the outcomes of the original feasibility studies, the study team did not formulate any new NBS as part of study scoping.

2.5.3 Alternative Formulation

The study team next identified the alternatives that would be evaluated in case study reanalysis. The focus of alternative selection was to identify a select set of alternatives that (1) could potentially provide benefits (or costs) that were not fully accounted for in the original BCA; and (2) would address the stated objectives of the feasibility study as well as achieve potential ecosystem service co-benefits. For most case studies, 3–5 alternatives were selected that drew from measures identified in the original feasibility study, associated VE studies, and/or collocated studies executed under separate authorizations. However, this approach was adapted to reevaluate a single alternative for Southwest Coastal Louisiana, where underlying data could not provide the site-specific information needed to robustly reevaluate multiple alternatives.

2.5.4 Non-Monetized Outcome Evaluation

After alternatives were formulated for the case study, the study team then considered the range of ecosystem services and other benefits and costs that the alternatives and associated NBS could provide. This process followed a *funnel* approach (Fischbach et al., 2023), wherein potential socioeconomic and environmental benefits and costs are first broadly identified before considering metrics for quantifying those impacts and, ultimately, the potential to monetize a subset of those impacts, where impacts constrained at any point within the funnel can still be considered as part of MODA. Figure 2-4 summarizes this conceptual approach.

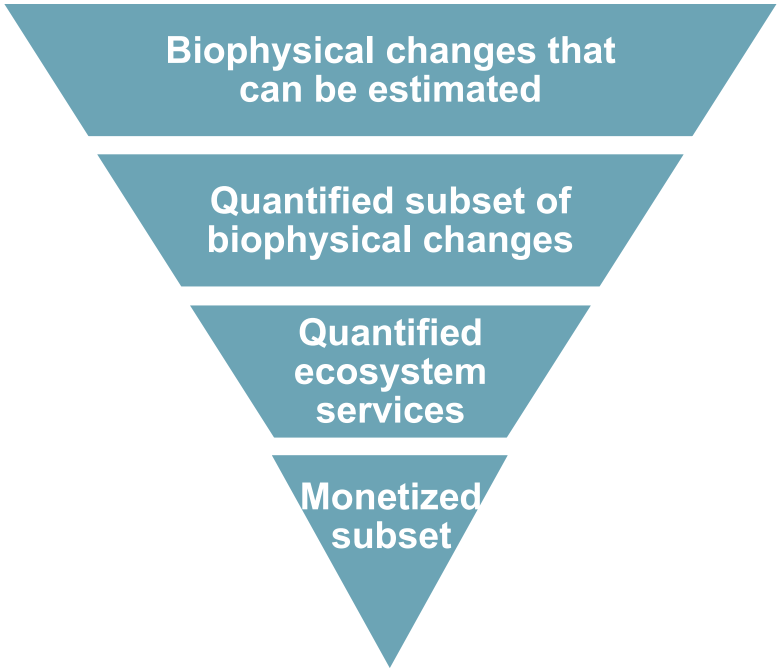


Figure 2-4. Flowchart showing analysis funnel concept. Source: Fischbach et al. (2023).

For ecosystem services, this process aligned with a causal chain model and consisted of identifying ecological indicators and benefit relevant indictors (BRIs; Figure 2-5). A benefits table was developed for each case study that captured NBS actions, metrics, sensitivity of the ecosystem to the action, links to beneficial use, and valuation methods associated with each potential action proposed in the re-scoping. Through this process, information and data constraints became more apparent, and a smaller subset of monetizable outcomes suitable for quantification was identified. In addition to utilizing analysis conducted as part of the USACE feasibility study, each case study team identified and applied data and methods found through a literature review of studies that included the case study locations.

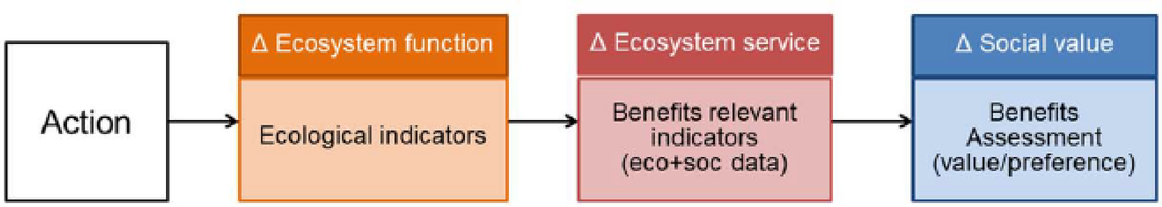


Figure 2-5. Ecosystem service causal chain with benefit-relevant indicators. Adapted from Olander et al. (2018).

2.5.5 Monetized Valuation

During the next phase of reanalysis, the study team identified the subset of costs and benefits identified for each case study (Section 2.5.4) that could be valued through monetized metrics. The study team began this process by broadly considering all the potential ecosystem service benefits and factors contributing to potential value, then identified metrics and valuation approaches. As in the case of non-monetized outcomes, this process included a literature review of co-located studies that could provide relevant information and transferable methodologies. After an updated suite of benefits and costs were identified, the study team conducted an updated BCA using both planning study and Office of Management and Budget (OMB) discount rates to determine the impacts of incorporating these factors on the BCR and alternative ranking. Each planning study applied a different federal water resources discount rate depending on the year of the analysis, so these discount rates varied by study. The OMB discount rate, however, was fixed at 7 percent for this case study effort (see Ehrenwerth et al., 2022, p. 4).

2.5.6 Prioritization and Alternative Selection

For the last phase of reanalysis, the study team conducted a MODA to determine how inclusion of non-monetized benefits and costs would impact the ranking of the reformulated alternatives. MODA provides a mechanism through which tradeoffs between objectives can be quantified and explicitly considered; there are multiple mechanisms through which MODA can be conducted, as reviewed in Fischbach et al. (2022). The development of an alternative ranking using MODA typically relies on developing a set of quantified metrics capturing impacts to targeted objectives, which can then be combined in a weighted sum based on the relative importance of those objectives for a study. Metrics can either be directly calculated based on available data or models, or expert elicitation can be used to identify a value on a relative scale (e.g., in a defined impact scale, benchmarks are used to provide consistency within a numerical ranking scheme, such as the *Fujita Scale* used to rank tornados based on their expected damage).

For the case study reanalysis, the study team was limited by data and model output availability for calculating quantified metrics as well as a lack of USACE and local input to weight the relative importance of multiple objectives. For this reason, this phase of reanalysis focused on identifying tradeoffs between alternatives and on developing stoplight charts to characterize the positive and negative outcomes of alternatives on a scale of 2 to -2, informed by relevant data, information, and expert judgement.

2.6 CONCLUSION

The steps described in Sections 2.5.1–2.5.6 were conducted concurrently for each case study, with the study team personnel assigned to each case study meeting regularly to cross-reference identified costs and benefits, potential metrics and calculation methods, and valuation approaches. The results of this process are presented for each case study in the next six chapters.

3.0 JACKSONVILLE HARBOR MILE POINT

The Jacksonville Harbor Mile Point feasibility study was authorized under the navigation Mission Area to reduce safety risks associated with strong currents at a bend of the St. Johns River (SJR). In the following sections, an overview of the planning study is provided along with the results of a reanalysis of alternatives using MODA and an updated BCA that considers benefits including improvements to water quality and access, as well as the value of space preserved at an upload disposal site through beneficial use of dredge material.

3.1 OVERVIEW

Jacksonville Harbor's Mile Point shoreline is located west of the Atlantic Ocean along the SJR between river miles four and five in Duval County, Florida (Figure 3-1). Located to the north and south of the SJR in the vicinity of Mile Point is the Timucuan National Ecological Historic Preserve (TNEHP), a 46,000-acre National Park Service (NPS) unit that protects one of the largest remaining salt marsh estuaries in the southeastern United States (NPS, 2016). The preserve also encompasses Great Marsh Island (GMI) and Chicopit Bay, which border Mile Point to the south and provide high-quality habitat for oysters, fish, and other wildlife. Along the north shore of the SJR at Mile Point there is a community of private homes and businesses on Fanning Island, while along the south shore are Naval Station Mayport and Helen Cooper Floyd Park (HCFP; formerly known as "Little Jetties Park"), which is a public park popular for fishing (USACE, 2012a). The SJR near Mile Point is also a popular location for fishing from small boats and several recreational charters use the area (Hackney, 2011).

In addition to its ecosystem and recreational benefits, Mile Point is a critical thoroughfare for shipping between the Atlantic Ocean and Jacksonville Harbor's marine terminals further inland (USACE, 2014a). However, the Intracoastal Waterway (IWW) and SJR converge within Mile Point, historically producing crosscurrents that are difficult to navigate during ebb tide (USACE, 2012a). The north bank of the river has experienced significant erosion that threatens surrounding development, while multiple sections of the Mile Point training wall on the southern portion of the river were submerged as of 2012 (USACE, 2012a). These dangerous conditions produced over 500 casualties between 1982 and 2004 and contributed to the St. Johns Bar Pilot Association restricting vessels with drafts greater than 33 feet inbound and 36 feet outbound to transiting only on or near a flood tide (USACE, 2012a). As a result, a plan to address concerns at Mile Point was warranted for both safety and economic reasons. Improving navigation at Mile Point also facilitates execution of a regional plan, evaluated as part of a separate USACE study, to deepen Jacksonville Harbor and the SJR navigation channel to enable access by deeper draft ships (USACE, 2014a).

3.1.1 Project Goals

In 1998, Congress authorized a feasibility study to investigate and recommend solutions to water resources issues at Mile Point that would reduce crosscurrents. Reduction of crosscurrents is expected to reduce erosion of the shoreline and allow larger vessels to pass with less risk, leading to removal of navigation restrictions for vessels transiting Jacksonville Harbor (USACE, 2012a). The objectives of the planning study were (USACE, 2012a):

1. Eliminating the navigation restrictions on the ebb tide due to the crosscurrents and Mile Point; and
2. Reducing the effects of crosscurrents on the erosion of the Mile Point shoreline.

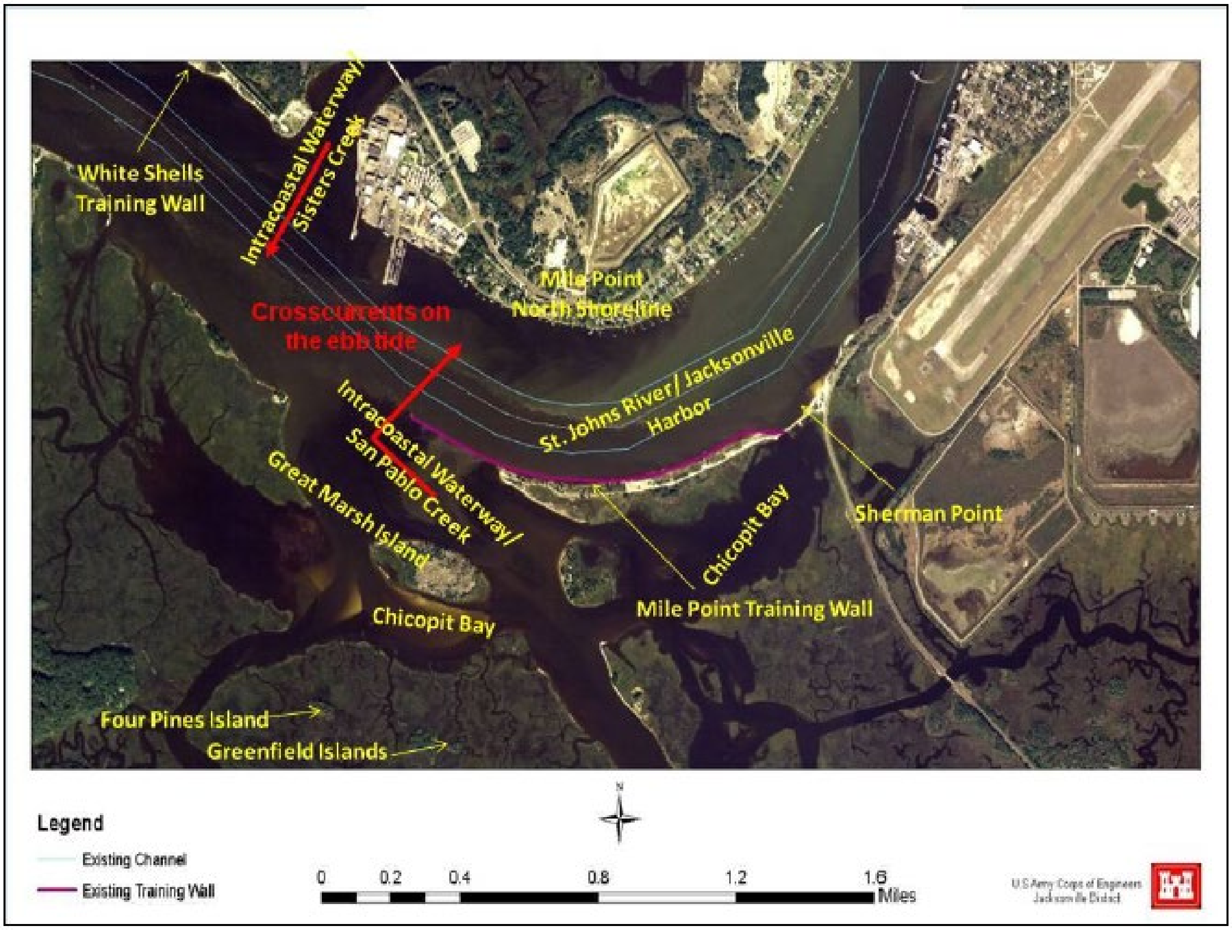


Figure 3-1. Shoreline erosion and crosscurrents in the Jacksonville Harbor Mile Point study area prior to project implementation and restoration of Grand Marsh Island. Source: USACE (2012a).

3.1.2 Alternative Formulation Process

The initial measures formulated for the USACE study aimed to reduce the effects of crosscurrents at Mile Point to eliminate the St. Johns Bar Pilot Association navigation restrictions and reduce shoreline erosion. These measures included additional tugs, light loading, structural erosion protection measures (bulkhead, groins, or beach fill), crosscurrent reduction measures (submerged weir, training wall, a diversion/bypass channel), and reconfiguration of an existing training wall (USACE, 2012a). Together with the St. Johns Bar Pilot Association and local homeowners, USACE developed five alternative plans to address erosion on the Mile Point shoreline and reduce ebb tide navigation restrictions. The measures outlined in these plans featured combinations of structural and nonstructural alternatives; however, only one plan—Alternative 3B—achieved the primary project objective of crosscurrent reduction.

The measures put forward in Alternative 3B reconfigured the Mile Point training wall, and this alternative was selected for further review and refinement in a VE study. Although initial plans included disposing of dredged material at Buck Island, the VE study identified a lower cost disposal option to place dredged sediment at nearby GMI (USACE, 2012a). This alternative provided an opportunity to reduce transit distance and associated costs while also restoring wetlands lost at GMI through decades of erosion. Additionally, the inclusion of marsh restoration would support navigation improvement and potentially reduce shoreline erosion along Mile Point. GMI restoration also includes incidental environmental benefits and mitigates for 8.15 acres of marsh that would be lost through relocation of the training wall (USACE, 2012a). This revised alternative was denoted Alternative VE-3B. Because this alternative was also cheaper than dredge disposal at Buck Island, it was also the NED Plan.

Restoration of GMI would, however reduce flushing of Chicopit Bay and potentially lead to habitat and water quality degradation (USACE, 2012a). This outcome was of concern to natural resource management entities including the Florida Department of Environmental Protection, Florida Fish and Wildlife Conservation Commission, and the U.S. Fish and Wildlife Service (USFWS). USACE modified the alternative to include construction of a flow improvement channel (FIC) to maintain water quality in Chicopit Bay (Alternative VE-3B + FIC), which ultimately became the RP. Dredged sediment from the FIC would be placed at GMI to contribute to its restoration.

3.1.3 Consideration of Nature-Based Solutions

Several variations of the GMI restoration alternative (Table 3-1) were evaluated with an incremental cost analysis (ICA) prior to finalization (USACE, 2012a).[11] These alternatives varied the extent of marsh restoration across:

- 1:1 mitigation of the 8.15 acres of marsh that would be lost due to relocation of the training wall (included for benchmark purposes only);
- “required restoration” of the 18.84 acres of marsh calculated as the minimum to mitigate for relocation of the training wall;
- “optimal restoration” of 45 acres of marsh created by placing all sediment dredged for Alternative 3B at GMI; and
- “expanded restoration” of 53 acres of marsh that utilized additional sediment dredged to create the FIC.

VE alternatives also varied the amount of vegetation planted from 8.15 acres to 53 acres, with marsh vegetation expected to colonize naturally on any remaining acreage created by the alternative. The restoration option with the largest acreage of marsh creation and planting (53 acres) was selected because the incremental cost of this alternative was as low or lower than the other alternatives considered while maximizing the habitat units created and accelerating the development and stabilization of the marsh (USACE, 2012a).

[11] Incremental cost analysis is the determination of the greatest increase in output (acres restored) for the least increase in cost.

The FIC in Chicopit Bay was also incorporated in the RP as a vital counterpart to the GMI restoration to prevent water quality issues that would arise from the inability to flush out non-point source pollution and silt if GMI was restored. The FIC would also restore the historical channel which had silted in from GMI's erosion (USACE, 2012a) and provide boating access to the SJR for homes along the inland waterways to the south of the TNEHP, specifically those that access the river through Mt. Pleasant Creek.

Table 3-1. Restoration alternatives considered in Alternative VE-3B and VE-3B + FIC.

Mitigation Plan restoration alternatives	Project phase		
	Total project acreage	Quantified Habitat Units (HUs)	Incremental cost (millions) / HUs
Alternative 1: 1:1 Mitigation + 8.15 acres of planting	8.15	4.89	$0.0047
Alternative 2: Required Mitigation + 18.84 acres of planting	18.2	10.92	$0.0049
Alternative 3: Optimal Restoration + 18.84 acres of planting	45	16.28	$0.055
Alternative 4: Optimal Restoration + 45 acres of planting	45	27	$0.0047
Alternative 5: Expanded Restoration + 18.84 acres of planting	53	17.88	$0.056
Alternative 6: Expanded Restoration + 45 acres of planting	53	28.6	$0.0048
Alternative 7: Expanded Restoration + 53 acres of planting	**53**	**31.8**	**$0.0047**

Note: The range of marsh restoration acreages include: 1:1 mitigation, restore 8.15 acres that would be lost due to relocation of the training wall (included for benchmark purposes only); "required restoration," restore 18.84 acres calculated as the minimum to mitigate relocation of the training wall; "optimal restoration," restore 45 acres of marsh using all sediment dredged for Alternative 3B; and "expanded restoration," restore 53 acres utilizing additional sediment dredged to create the FIC. Alternative 7, in bold, denotes the RP.

3.1.4 Outcome of Chief's Report

On April 30, 2012, the Chief's Report submitted the NED Plan, Alternative VE-3B + FIC, as the RP. The report recommended relocating and reconfiguring the existing Mile Point training wall, as well as restoring the breakthrough in GMI using excavated material from project construction (USACE, 2012a). The GMI restoration was designed to create up to 53 acres of salt marsh, exceeding the 18.84 acres required to mitigate 8.15 acres of marsh lost due to reconfiguration of the training wall. The report also recommended construction of the FIC to mitigate water quality issues arising from closing off the recently formed channel that flushes Chicopit Bay. The RP's BCR was 1.4, with a project first cost estimated at $36 million (OMB, 2012). The average annual costs were estimated at $1.7 million based on a 4% discount rate at October 2011 price levels. The same analysis was performed for approval by OMB with a discount rate of 7%. This resulted in average annual costs of $2.9 million and a BCR of 0.84; OMB did not object to the submission of the Chief's Report despite the BCR falling below the threshold of 1.0 typically used for approval. The reasons why OMB did not object despite the low BCR were not articulated in the OMB recommendation (OMB, 2012), but may have been related to the crosscurrents posing a threat to human lives and safety; OMB did note that "the project would need to compete with other proposed investments for funding in future budgets."

Congress authorized the Mile Point project through Section 7002(1) of the Water Resources Reform and Development Act of 2014 and USACE entered into a project partnership agreement with the Jacksonville Port Authority, the project's nonfederal sponsor, in January 2015 (USACE, 2015a). Construction began in November 2015 ("Jacksonville Harbor Begins Mile Point Project Ahead of Port Deepening," 2015), and was completed in 2017, though the project's benefits and improvements to navigation were noticeable before finalization (Robinson, 2017).

3.1.5 Other Key Considerations

In addition to the Environmental Impact Study (EIS) and marsh restoration ICA conducted for Mile Point, a VE study was developed to evaluate the use of Concrete Structural Units (CSUs) as part of the relocated West Training Wall (Figure 3-2; USACE, 2012b). This study evaluated the costs and benefits of using CSUs, which provide hard bottom habitat for oysters and fish, rather than a stone training wall. An overall cost savings of approximately $20,120,000 was identified for use of CSUs, with enhancement of habitat benefits and no impacts to project durability or Life Cycle Costs (i.e., the complete cost of maintaining the structure over its planned lifespan). Although not specified explicitly as part of the original RP, CSUs were ultimately incorporated into the project (Manson Construction Co., 2022).

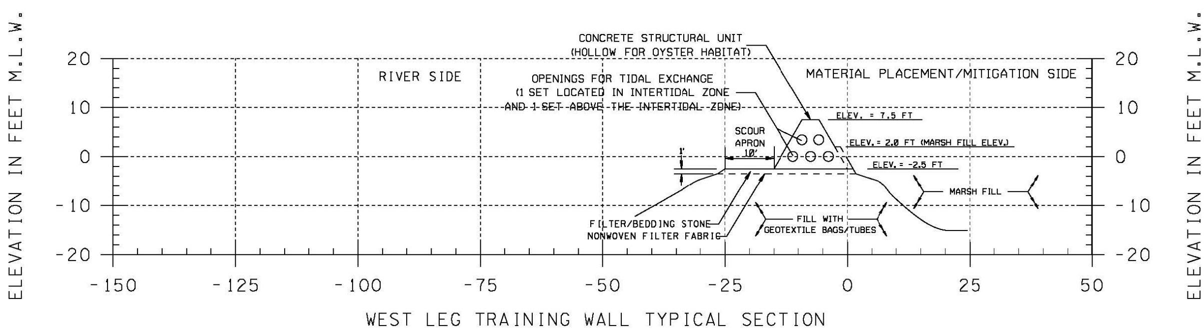


Figure 3-2. Schematic showing the configuration of Concrete Structural Units (CSUs), an EWN approach that provides hard bottom habitat for oysters and other species, used in the Mile Point feasibility study. From USACE (2012b).

3.2 CASE STUDY REANALYSIS: STUDY SCOPE

Three NBS were identified in the feasibility and VE studies (USACE, 2012a, 2012b) that were conducted for Mile Point, all of which were ultimately incorporated into the final project:

1. Beneficial use of dredge (BUD) at GMI with varying acreages considered (see Section 3.1.3);
2. Construction of a FIC to maintain and improve water quality in Chicopit Bay and restore boating access to the SJR from the south through Mt. Pleasant Creek; and
3. Use of CSUs rather than stone for a portion of the relocated training wall, which would create hard bottom habitat for oysters and fin fish.

No additional NBS were identified in a literature review of studies conducted in this region.

3.3 ALTERNATIVE FORMULATION

The study team considered a set of four alternatives in reviewing the Mile Point project (Table 3-2). The first alternative, relocation of the stone training wall with dredge disposal at Buck Island, does not incorporate NBS. For Alternative 1, dredge material is used to create 53 acres of GMI, whereas Alternatives 2 and 3 add a FIC and use of CSUs, respectively. In addition, the team benchmarked the alternatives against a future without action (FWOA).

Table 3-2. Alternatives considered in the reanalysis of the Mile Point case study, which included beneficial use of dredge (BUD) at Great Marsh Island (GMI), creation of a flow improvement channel (FIC), and use of concrete structural units (CSUs) in place of stone for a relocated training wall. The bolded alternative is the RP.

Feature	USACE Alternative Name	Alternative measures			
		Relocate Training Wall	GMI Restoration	FIC	CSUs
0. Future without Action (FWOA)	FWOA	-	-	-	-
1. Relocate the Stone Training Wall, Dredge Disposal at Buck Island	"Alternative 3B – Relocation of the Training Wall"	X	-	-	-
2. Relocate the Stone Training Wall, BUD to restore and plant 53 acres of GMI	"Final Alternative 3B – Relocation of the Training Wall"	X	X	-	-
3. Alternative (2), adding a FIC to improve water quality	"Alternative VE-3B+FIC"	X	X	X	-
4. Alternative (4), with CSUs replacing a portion of the relocated stone training wall	**N/A. Although CSUs were included in the final RP, this measure was not re-evaluated separately from Alternative VE-3B+FIC**	**X**	**X**	**X**	**X**

3.4 NON-MONETIZED OUTCOME EVALUATION

A suite of ecosystem service metrics (Table 3-3) were identified for the NBS alternative measures considered in this case study. These included a variety of recreational uses of GMI and the SJR (birding, fishing, hiking, etc.), as well as reduced dredging of the SJR and the preservation of volume at the Buck Island disposal site for future use.

3.4.1 Biophysical Outcomes

All four alternatives considered in this case study produce desirable biophysical outcomes for the river and estuarine ecosystem in the vicinity of Mile Point when benchmarked against FWOA. The restoration of 53 acres of salt marsh at GMI creates essential fish habitat and mitigates loss of oyster habitat associated with the relocation of the stone training wall (USACE, 2012a, 2012b); this restoration helps offset historic trends of marsh loss within the TNEHP (NPS, 2016). The disposal of sediment at GMI also preserves volume at the Buck Island upland disposal site, which is one of the primary locations used to dispose of material dredged from Jacksonville Harbor and the SJR as part of routine maintenance of the navigation channel (USACE, 2014a).

Lastly, marshes have been shown to attenuate waves and flow, thereby reducing shoreline erosion and promoting trapping of sediment. Both of these effects can reduce navigation channel shoaling and the need for maintenance dredging (Baptist et al., 2019; Suedel et al., 2021). The addition of the FIC increases flushing of water and silt from Chicopit Bay, thereby improving water quality in the system, and also restores access to the SJR through Mt. Pleasant Creek (USACE, 2012b). Replacing a portion of the relocated stone training wall with CSUs creates hard bottom habitat that can be utilized by fish and oysters (USACE, 2012b, 2012a). CSUs have also been shown to attenuate wave energy and inhibit shoreline erosion, thereby also potentially reducing shoaling of the main navigation channel (Townsend et al., 2014).

3.4.2 Benefit-Relevant Indicators

The potential for BUD to restore GMI was quantified in this case study through the volume of sediment storage capacity, in cubic yards (cy), preserved at the Buck Island disposal area. This site is an active disposal site for placement of material removed from the SJR during routine maintenance. A dredge disposal plan created for the Jacksonville Harbor Deepening Study determined that Buck Island has insufficient capacity for placement of material associated with the channel deepening and that alternate, more expensive disposal alternatives would be needed once Buck Island reaches capacity (USACE, 2014a). BUD at GMI would result in 900,000 cy of capacity preserved at this site (USACE, 2012a).

The creation of the FIC increases access to the SJR through Mt. Pleasant Creek for homes that have waterfront access in the tributaries connected to this waterway (USACE, 2012a). The addition of the FIC also increases flushing of the system, which can improve water clarity (transparency) and water quality by removing suspended sediment, nutrients, and undesirable biomass (e.g., harmful algal blooms) from the system.

Both water access and water quality improvement have a demonstrable positive impact on home value. Waterway access enhances water-based recreational opportunities such as kayaking and fishing for homeowners, whereas improved water clarity and quality improves property aesthetics and increases desirability (Seidel et al., 2016). Tributary fronting properties that gained boating access to the SJR through the FIC were identified using publicly available parcel data from the City of Jacksonville (JaxGIS Duval Maps, n.d.), then verified through visual inspection of Google Earth Pro using 2018 imaging to more closely match conditions at project completion. Properties included in the valuation border Mt. Pleasant Creek or one of its tributaries, Mud Flats Creek, and Greenfield Creek. Parcels with extensive marsh between the property line and one of the aforementioned waterways were assumed to be too far from the shoreline to appreciate significant benefits from boating access and were excluded unless Google Earth Pro imaging indicated that the property contained a dock, pier, or boat launch that granted tributary access. There were 180 properties that fit these criteria and were included for analysis.

Table 3-3. Ecosystem services and associated benefit-relevant indicators considered in the Jacksonville Harbor case study.

Action / approach	Primary metric	Quantifiable (units and method)	Sensitivity of change relative to project	Direct links to Beneficial Use	Quantification metric of Beneficial Use	Example of approach to monetize this change	PR&G Goal(s)
Marsh Creation	Marsh extent	Area (acres)	53 acres of marsh created. Acreage is relatively limited in comparison to the 46,000 acres that comprise the entirety of Timucuan National Ecological Preserve (TNEHP).	Recreation: hiking	Change in day use - number of people visiting TNEHP and Helen Cooper Flood Park (HCFP) for hiking	Monetary value of day use recreation	Healthy and Resilient Ecosystems
				Recreation: viewshed from shoreline	Change in day use - number of people visiting TNEHP and HCFP for relaxation	Monetary value of day use recreation	Healthy and Resilient Ecosystems
				Recreation: kayaking	Change in number of people kayaking (e.g., people kayaking per year)	Revenue raised from tour operators for kayak tours or kayak rental	Healthy and Resilient Ecosystems
				Recreation: camping	Change in use of campground (sites rented) for campgrounds near the Preserve	Campground fees	Healthy and Resilient Ecosystems
	Marsh habitat value for fauna	Marsh edge distance	Project creates 53 acres of marsh. However, extent is limited in comparison to the 46,000 acres that comprise TNEHP.	Recreation: fishing	Change in day use - number of people fishing from the shoreline of HCFP and from small boats in the SJR	Monetary value of day use recreation; kayak rental revenue; sport fishing charters	Healthy and Resilient Ecosystems
		Area (acres)	53 acres of marsh created. Acreage is relatively limited in comparison to the 46,000 acres that comprise the entirety of Timucuan National Ecological Preserve (TNEHP).	Recreation: bird watching	Change in day use - number of people visiting TNEHP and HCFP for bird watching	Monetary value of day use recreation	Healthy and Resilient Ecosystems
	Sediment disposal	Cubic yards (cy)	Approximately 889,000 cy of sediment that would have been placed at Buck Island was part of BUD at Great Marsh.	Long-term cost savings: Reduces need for identification of new disposal areas	Cy of future placement volume preserved at the Buck Island disposal area.	Cost of establishing a new dredge disposal area and/or use of more distal (nearshore/offshore) dredge disposal after Buck Island disposal site has filled	Sustainable Economic Development
	Sediment trapping	Cubic yards of sediment per year (cy/year)	53 acres of marsh created, providing localized benefit at Mile Point.	Reduced dredging: marshes reduce wave attenuation/shoreline erosion and entrap sediment that would otherwise deposit in the navigation channel	Annual reduction in cy of sediment dredged from the SJR navigation channel at Mile Point	Cost savings of reduced need for navigation channel dredging at Mile Point	Sustainable Economic Development
Flow Improvement Channel (FIC)	Access to St. John's River (SJR) from Mt. Pleasant Creek	Number of residential homes with access to SJR (count)	Access to the SJR for 180 waterfront households on Mt. Pleasant Creek and its distributaries.	Recreation: boating	Waterfront households with access to SJR enabled by FIC	Hedonics-based evaluation of the increase in home value with improved access to SJR	Healthy and Resilient Ecosystems Watershed Approach
	Water quality in Chicopit Bay for fauna	Total suspended solids (TSS)	Water quality in 164 acres of Chicopit Bay would be adversely affected if FIC not built, as well as 3 stream miles at Greenfield Creek and 3.4 stream miles at Mt. Pleasant Creek.	Recreation: fishing; Quality of life: improves water quality for homes along Chicopit Bay	Total suspended solids (TSS) Chicopit Bay	Hedonics-based evaluation of the increase in home value with improved water quality	Healthy and Resilient Ecosystems Watershed Approach
Concrete Structural Units (CSU) for West Training Wall	Hard bottom habitat	Linear feet (LF) of CSU construction	504 CSUs placed for a total of 4000 LF.	Recreation: fishing	Change in day use – number of people fishing from the shoreline of HCFP and from small boats in the SJR	Sport fishing charter revenue (both in-water and off the Little Jetties)	Healthy and Resilient Ecosystems Watershed Approach
	Wave attenuation and erosion control	Shoreline erosion rate (feet/year)	504 CSUs placed for a total of 4000 LF of shoreline protected.	Dredging frequency: reduction of shoreline erosion reduces sediment deposition in the channel	Change in volume of sediment eroded from the shoreline and deposited in the navigation channel	Change in cost of navigational channel maintenance	Sustainable Economic Development

3.4.3 Additional Quantitative or Qualitative Outcomes of Interest

3.4.3.1 Economic

Based on studies conducted elsewhere (Baptist et al., 2019; Suedel et al., 2021), the creation of additional salt marsh area at GMI along the edge of the SJR is likely to attenuate wave energy and trap sediment, thereby reducing shoreline erosion and shoaling in the main navigation channel. The use of CSUs for the training wall would be expected to have a similar impact on wave attenuation, shoreline erosion, and the navigation channel (Townsend et al., 2014). This would ultimately reduce the need for maintenance dredging of the SJR, which could be quantified in terms of the frequency of dredging, volume of sediment removed, and associated annual cost. However, there were insufficient data available to quantify this benefit for the case study alternatives.

3.4.3.2 Environmental

The restoration of GMI increases the acreage of salt marsh habitat and the length of marsh edge (Table 3-3). There are numerous species within the TNEHP that are likely to utilize the newly created habitat, including oysters and migratory birds (NPS, 2016). The creation of the FIC and associated improvement of water quality will increase quality of habitat within Chicopit Bay (USACE, 2012b). Replacing part of the relocated training wall with CSUs provides nesting habitat and refuge from predators for some fish species, and can further result in up to 20 oysters per square foot of structure (USACE, 2012b). However, sufficient data and model output on species usage of these habitats were not available to quantify their benefit.

3.4.3.3 Social

The increase in GMI acreage may promote recreational use of TNEHP, HCFP, and SJR for consumptive (recreational and charter fishing) and non-consumptive (hiking, birdwatching, kayaking, enjoying nature) purposes. BRIs associated with these usages include change in day usage on an annual basis. In addition, there are several campgrounds within or adjacent to TNEHP which could see increased use. Although it is straightforward to quantify the acreage of marsh creation, it is difficult to project the associated increase in recreational use, particularly given that recreational users have ready access to locations with similar environmental characteristics throughout the TNEHP.

The use of CSUs and associated increase in hard bottom habitat are likely to locally attract fish species, potentially including those that are of interest to recreational and charter fishermen.[12] The region of the SJR along Mile Point is popular with charter fishermen and the HCFP is historically popular for shoreline fishing (Spicer, 2015), therefore a local increase in fin fish may draw additional use to the area. However, models could not be identified to project that impact of CSUs on quality of fishing in the area.

[12] The southern shore of the SJR at Mile Point is not within a designated oyster fishing area, therefore oyster population will not provide direct social or economic benefit.

3.5 MONETIZED VALUATION

3.5.1 Valuation Methods and Key Assumptions

Of the additional sources of costs and benefits identified in this case study, three were selected by the study team for full quantification into an updated cost benefit calculation: the benefit of improved water quality due to the Mile Point project, the benefit of improved access to the SJR, and the reduced long-term cost associated with preserving disposal capacity at Buck Island through BUD at GMI.

The benefits of improved water quality and increased access to the SJR were derived from a hedonics study of property values that included homes that could potentially benefit from the inclusion of a FIC in the Mile Point project (Palmquist & Smith, 2003). This approach uses a regression analysis of home values and various covariates to statistically estimate the premium paid by home buyers for certain features a house might have, in this case the quality of the water and river access. In addition to the various statistical assumptions required to conclude that the premium estimates are correct, the core assumption of this approach is that these premiums accurately reflect the value of these features. As with other “willingness to pay” approaches, these numbers likely underestimate the value of these features to other community members, for example renters or visitors, who may get some value out of improved water quality that is not reflected in housing prices. Importantly, these metrics depend on the number of affected homes, and any benefit calculated here would grow or shrink linearly with any changes in the number of the affected homes.

The analysis of water quality’s effect on prices assumes that a particular level of water quality is achieved in the study area, which may or may not occur with project implementation. The improvement in home value associated with an increase in water quality for the SJR is described as a function of water clarity or transparency (Seidel et al., 2016), which varies depending on the amount of suspended sediment and solids within the water column (Davies-Colley & Smith, 2001). In the hedonics study used here, a generic water quality parameter of Trophic State Index as a function of water clarity was used. Water clarity for this study is measured in Secchi disk depth (SD), a measurement that is determined by lowering a circular disk with alternating white and black quadrants (a Secchi disk) into a body of water until it disappears from view at the surface (Preisendorfer, 1986). The SD is given in meters (m) and is greater in water that is more transparent (i.e., where water clarity is higher). The study determined that an improvement in water clarity to 1.5 m SD in the Duval County area of the SJR would result in a rise in total home value over Duval County of $171,000 per affected home (Seidel et al., 2016). Throughout the Duval County area clarity was as low as 0.5 m SD as of the time of the hedonics study. In terms of homeowner experience, therefore, a 1.5 m SD would reflect a noticeable increase in water clarity, with areas that were previously murky or loaded with sediment being perceptibly clearer.

The reduced costs associated with preserving capacity at Buck Island were derived from internal USACE numbers on the costs of disposing of sediment at new sites (USACE, 2014a). The Buck Island disposal site has limited capacity and the proposed deepening of Jacksonville Harbor is projected to result in exceedance of this capacity over time (USACE, 2021b). For these calculations, it was assumed that the available capacity will be exceeded sooner if sediment placed at GMI under the BUD alternative is instead disposed of at Buck Island. In this case, USACE would need to seek an alternate disposal location, such as the creation of a new upland dredge disposal area or the use of offshore disposal sites.

For the calculations conducted here, the creation of a new upland site was chosen as the alternate disposal area because it represents the closest analog to placement at Buck Island. Disposal at nearshore or offshore disposal sites, for example, might be limited or prohibited for some sources of sediment due to the presence of contaminants, whereas upland disposal sites have fewer constraints. The value of preserving capacity at Buck Island through BUD at GMI would vary if USACE decided to dispose of the excess sediment in some other way, though estimates of the unit cost to dispose at other sites are comparable.

3.5.2 Updated Benefits

3.5.2.1 Improved Water Quality in the SJR

Duval County parcel data was used to identify tributary fronting properties, and these were cross-referenced using Google Earth imaging as described in Section 3.4.2. Through this method, it was determined that an estimated 180 homes along tributaries of the SJR would have improved water quality due to the Mile Point project. This results in a total benefit of $31 million ($26 million in 2011 constant dollars). The study team assumed that the improvement to 1.5 m SD water clarity is not achieved immediately upon the completion of construction, but rather accrues linearly over the course of the project lifespan. The equation for the annual cash flow is:

$$C_{WQ,t} = \frac{B_{WQ} * H}{T}$$

Where $C_{WQ,t}$ is the annual benefit cashflow, B_{WQ} is the total benefit from improved water quality per house, H is the number of houses, and T is the total project lifetime. This string of cashflows corresponds to an Average Annual Equivalent (AAEQ) of $520,000.

3.5.2.2 Improved Access to the St. Johns River

The authors of the hedonic study estimate that providing a home with access to a tributary of the SJR increases its value by approximately $123,000 (Seidel et al., 2016). Using Duval County parcel data to identify tributary fronting properties and cross-referencing these using Google Earth Pro imaging as described above, an estimated 180 homes gained access to a tributary to the SJR due to the Mile Point project. This results in a total of $23 million in benefits ($19 million in 2011 dollars). The study team assumed that this benefit accrues immediately in 2014, which was the planned year of construction (note, the beginning of construction was delayed until 2015). The equation for the annual cash flows is:

$$C_{WA,\boldsymbol{1}} = B_{WA} * H$$

$$C_{WA,t\neq 1} = 0$$

Where $C_{WA,t}$ is the annual benefit cashflow, B_{WA} is the total benefit from improved water access per house, and H is the number of houses. Using the USACE Planning Analysis discount rate this translates to an AAEQ of $887,000.

3.5.3 Updated Costs

Approximately 900,000 cy of sediment that would have had to go Buck Island were instead used to create GMI. If this material had been placed at Buck Island, the reported capacity for disposal of sediment from other projects would be exceeded as early as 2015 and would necessitate sending dredge material from these projects elsewhere (USACE, 2012a). Applying the methods described in the previous section, the disposal of sediment at a new site rather than at Buck Island would constitute an increase in cost of $7.83/cy. The total overflow from Buck Island in 2015 would have been 371,000 cy of sediment for a total avoided cost of $3 million. Adjusting for inflation, this becomes $2 million. The calculations used in this analysis were:

$$C_{S,1} = R_S * S$$

$$C_{S,t \neq 1} = 0$$

Where $C_{S,t}$ is the annual cost reduction cashflow at year t, R_S is the difference in cost between Buck Island disposal and a new location and S is the total amount of new sediment. Annualizing this cost reduction using the water resources discount rate of the project results in an AAEQ of $98,000 dollars.

3.5.4 Benefit-Cost Comparisons

3.5.4.1 Planning Analysis

Excluding the NBS costs and benefits considered in the reanalysis and using the USACE Planning Analysis discount rate of 4.125%, resulted in a BCR of 1.4 (Table 3-4). By including the value of water quality improvement, waterway access, and preservation of capacity at Buck Island the BCR improves to 2.3. Thus, the original analysis suggested a project that was mildly beneficial with benefits that were approximately 40% higher than costs, while the new calculation performed by the study team suggests that benefits may in fact have been more than 200% greater than costs. Including the reduction in cost attributable to preserving capacity at Buck Island is enough to raise the BCR to 1.5.

3.5.4.2 OMB Process Analysis

Using a 7% discount rate, the original OMB analysis resulted in a BCR of 0.84 (Table 3-5). However, when the NBS benefits identified by the study team are incorporated the BCR is improved to 1.6, enough for the project to pay for itself. When only the reduction in cost due to preserving space at Buck Island is considered, the BCR raises to 0.95—approaching the threshold of 1.0.

Table 3-4. AAEQ of the benefits and costs of the Mile Point project using the USACE Planning Analysis assumptions.

Plan 3B	
Benefit/cost source	**AAEQ (millions of dollars)**
Original Benefit	$2.44
Original Cost	$1.74
Original BCR	1.4
Reduced Cost, Buck Island Capacity	$0.10
Water Quality Benefit	$0.52
Water Access Benefit	$0.89
Reanalysis BCR	2.3

Shown are the benefit, cost, and BCR values calculated at the time of the Mile Point study ("original") using the USACE Planning Analysis discount rate of 4.125%. The study team updated these values as shown to include cost savings associated with preserving disposal capacity at Buck Island and the benefit provided by improving water quality and water access for homeowners. AAEQs are in millions of dollars.

Table 3-5. AAEQ of the benefits and costs of the Mile Point project using OMB assumptions.

Plan 3B	
Benefit/cost source	**AAEQ (millions of dollars)**
Original Benefit	$2.44
Original Cost	$2.73
Original BCR	0.84
Reduced Cost, Buck Island Capacity	$0.15
Water Quality Benefit	$0.52
Water Access Benefit	$1.36
Reanalysis BCR	1.6

Shown are the benefit, cost, and BCR values calculated at the time of the Mile Point study ("original") using the OMB discount rate of 7%. The study team updated these values as shown to include cost savings associated with preserving disposal capacity at Buck Island and the benefit provided by improving water quality and water access for homeowners. AAEQs are in millions of dollars.

3.6 PRIORITIZATION AND ALTERNATIVE SELECTION

The value of preserving sediment disposal capacity at Buck Island and the increase in property values associated with improved access to the SJR and enhanced water quality can be monetized using available data; these benefits are described in more detail in Section 3.5. Additional benefits that are likely to be significant for the NBS considered are the reduction of maintenance navigation channel dredging due to reduced shoaling resulting from the creation of GMI and/or the inclusion of CSUs, and the improved quality of local fish habitat that may enhance the quality of shoreline and boat-based fishing in the Mile Point area.

Additional modeling studies, or expert elicitation of projected outcomes, would be required to project the likely outcomes of these actions to quantify their benefit. Although there are environmental benefits associated with the creation of GMI and the habitat that it provides to salt marsh species, the relative value of the GMI restoration on a regional scale is small when considering the size of the created marsh (53 acres) in relation to the extent of TNEHP (46,000 acres). Species and recreational users of the region have ready access to similar habitat and locations, making the likely increase in value for the NBS solutions included here relatively small.

Because there is insufficient data to fully quantify the benefits associated with the alternatives, a stoplight chart has been developed (Table 3-6). In the case of sediment dredge disposal capacity preserved at Buck Island, alternatives have a binary ranking of 2 or 0 to denote BUD preserving (or not preserving) 900,000 cy of capacity. Similarly, alternatives that preserve SJR access and water quality for the 180 waterfront properties along Mt. Pleasant Creek and alternatives that enhance local fishing are given a ranking of 2 for those metrics, whereas alternatives that do not are given a 0. In the case of reduced maintenance of the navigational channel, alternatives that include the FIC are given a 1, the alternative that includes both the FIC and CSUs is given a 2, and the alternative with no likely impact on shoaling is given a 0. The primary objective of this navigation study, removal of dangerous cross currents at Mile Point, is scored as a 2 for the alternatives that achieve this objective and as a 0 for the FWOA. The five alternatives were ranked by project construction cost on a scale of -2 (most expensive) to 2 (least expensive, the FWOA). Cost models completed as part of VE studies for Mile Point (USACE, 2012b) estimated the project cost at $76.388 million for relocation of the stone training wall and dredge disposal at Buck Island, which was ranked a -2 as the most expensive alternative. The project cost estimate for BUD to create 53 acres of marsh at GMI was $46.888 million for BUD to create 53 acres of marsh at GMI. Although the costs of the FIC were not independently analyzed by USACE, the study team construction would increase costs but not exceed the ~$30 million in difference between disposal at GMI and Buck Island. Therefore, the alternative for BUD at GMI with the FIC was ranked a -1 and the alternative without the FIC was ranked a 0. The VE study estimated $20.12 million in additional savings from use of CSUs for part of the training wall; therefore, the alternative that includes this option is ranked as a 1.

Table 3-6. Benefits and costs associated with alternatives considered in the Mile Point case study.

Alternative	Sediment disposal capacity preserved at Buck Island	Properties with increased access and improved water quality	Reduced maintenance of navigation channel	Enhance recreational and charter fishing	Navigation safety	Project construction cost
0. Future without Action (FWOA)	2	0	0	0	0	2
1. Relocate the Stone Training Wall, Dredge Disposal at Buck Island	0	0	0	0	2	-2
2. Relocate the Stone Training Wall, BUD to restore and plant 53 acres of GMI	2	0	1	0	2	0
3. Alternative (2), adding a FIC to improve water quality	2	2	1	0	2	-1
4. Alternative (4), with CSUs replacing a portion of the relocated stone training wall	**<u>2</u>**	**<u>2</u>**	**<u>2</u>**	**<u>2</u>**	**<u>2</u>**	**<u>1</u>**

Benefits included beneficial use of dredge (BUD) at Great Marsh Island (GMI), creation of a flow improvement channel (FIC), and use of concrete structural units (CSUs) in place of stone for a relocated training wall. For each benefit, a numerical value is provided indicating the benefit provided by that alternative relative to the others on a scale of 0 (no benefit) to 2 (maximum benefit). Bold underlines indicates the alternative selected as the Recommended Plan.

The BUD to create GMI, addition of a FIC, and use of CSUs all result in increased benefit, and the only tradeoff to consider is project cost. USACE analysis determined that BUD at GMI is cheaper than disposal at Buck Island and CSUs have a lower project Life Cycle Cost than the use of a stone training wall (USACE, 2012b), therefore these alternatives will always be ranked higher than alternatives that do not include them. The only alternative for which a cost tradeoff might be considered is the incorporation of the FIC. However, USFWS and the National Marine Fisheries Service (NMFS) support for GMI restoration was contingent upon the inclusion of the FIC due to the degradation of water quality that would occur if the FIC was not also constructed.

Alternative 4—which includes BUD at GMI, creation of a FIC, and use of CSUs—was ultimately chosen as the RP for the Mile Point site. This selection was based on VE studies that determined that the included measures were cheaper than the non-NBS solutions, thereby resulting in a higher BCR. Therefore, the additional benefits from CSUs, the BUD at GMI, and the FIC that were quantified in this study would not change the ranking of the alternatives: Alternative 4 (least cost and highest benefits), followed by Alternatives 3, 2, and 1. However, the incorporation of additional benefits would improve the BCR for the RP and increase the differential between these alternatives.

3.7 DISCUSSION

NBS in the Mile Point study were less expensive to implement than other options, and also provided ancillary benefits. As a result, the additional benefits quantified in this case study would increase the BCR for these alternatives rather than changing alternative ranking or RP selection. The methodologies developed here are applicable to other USACE navigation projects, however, where the change in the BCR could alter the choice of RP.

Dredge disposal sites throughout the country are approaching capacity and forcing the creation and permitting of alternate sites (Frittelli, 2019; Talton, 2018). Similarly, NBS such as marsh creation and use of CSUs can be incorporated into navigable waterways in a variety of locations to provide benefits of wave attenuation, reduced shoreline erosion and navigation channel shoaling, and reduction in need for navigation channel dredging. The cumulative value of these benefits is likely to be significant on a nationwide scale. Although the incorporation of a FIC at Mile Point is site specific, the hedonics approach used here is applicable to any project alternative that improves water quality and/or waterway access.

Several limitations and areas of future improvement were identified during this case study. First, there were limitations in the available data and numerical model output that could be used to quantify some NBS benefits. Although water quality is projected to improve for Chicopit Bay under alternatives that include the FIC, modeling studies would be needed to quantify this improvement through, for example, estimates of total suspended sediment loads for different alternatives. Similarly, additional site-specific data or model projects would be needed to quantify the benefits that CSUs might provide to oysters and fish, as well as the subsequent benefits to the quality of local fishing areas. In addition, methodologies for quantifying the benefits which marshes and CSUs provide for wave attenuation, shoreline erosion, and reduced navigation channel shoaling are limited and/or site specific. Future work to either quantify those outcomes for Mile Point, or to create generalized approaches for estimating these benefits that could provide an estimate of outcomes without developing site-specific hydrodynamic and sediment transport models, would enable more robust quantification of associated benefits.

The recreational use benefit associated with GMI was excluded from this analysis because it was estimated to create a small differential increase relative to existing habitat associated with TNEHP. Approaches that rely on differential increases applied to individual project footprints, however, may undervalue the cumulative effects that multiple projects may have when taken in combination (i.e., any 53-acre area of TNEHP has equal value relative to the whole, but if a significant portion of TNEHP was lost in 53-acres increments there would be a large overall impact). It is also difficult to capture recreational use benefit without additional perspective from the users themselves; although the area of the GMI restoration is relatively small compared to TNEHP, it is unknown how highly users value this specific location relative to other areas of the preserve, and if their use of the area would increase with enhancements at the Mile Point location specifically.

Lastly, the hedonics approaches used here are explicitly tied to property values. This type of approach is inherently biased toward quantifying the value provided to affluent communities with high property values and will therefore undervalue quality-of-life benefits provided to less affluent communities.

4.0 SOUTHWEST COASTAL LOUISIANA

4.1 OVERVIEW

Louisiana's Cameron, Calcasieu, and Vermilion parishes are located in the southwest corner of the state and include approximately 80 miles of coastline from the Texas-Louisiana border in the west to Vermilion Bay in the east. This southern portion of the Louisiana Chenier Plain consists of a system of estuarine lakes and coastal marshes interspersed with chenier ridges[13] and isolated high ground gradually transitioning to coastal prairie terraces to the north. This includes the Rockefeller National Wildlife Refuge, which has been described as one of the "most biologically diverse wildlife areas in the nation" (LDWF, n.d.). Due to their high elevation relative to the surrounding landscape, the chenier ridges have historically served as the site of human settlement in the southern portion of the region. Although sparsely populated, communities in this area are essential to the state's industries, its unique cultural composition, and its working coast (USACE, 2016a; The Water Institute of the Gulf, 2022). This southern portion of the Louisiana Chenier Plain contributes to regional and national economies through oil and gas production and export, and through support to navigation industries. The area is also important in both commercial and recreational fisheries.

The northern portion of the Louisiana Chenier Plain, beyond the marshes and estuarine lakes, transitions to a coastal prairie landscape. Much of the development in the north is in the coastal prairie and includes a combination of urban, suburban, and rural/agricultural development. This includes the Lake Charles Metropolitan Area in the north of the Calcasieu-Sabine Basin, with a combined population of just over 210,000 persons, and many smaller communities to the east, including Jennings, Lake Arthur, Gueydan, and Kaplan. According to the 2020 Decennial Census, the combined population of Cameron, Calcasieu, and Vermilion parishes is approximately 280,000, with nearly 78% of this population (216,785) residing in Calcasieu Parish (U.S. Census Bureau, 2020).

Southwest Coastal Louisiana is, however, vulnerable to multiple well-documented threats. The state is currently experiencing the highest rates of coastal wetland loss in the U.S., and the accumulated land loss between 1932 and 2016 was nearly 2,000 square miles (Couvillion et al., 2017). The Louisiana Chenier Plain alone accounts for almost 20% of the approximately 1,883 square miles of wetlands lost in Louisiana from1932 to 2010 (USACE, 2016b). Coastal Cameron, Calcasieu, and Vermilion parishes are, as with much of the state's coastline, low lying and subject to the effects of both sea-level change (SLC) and subsidence. Due to these compounding threats, this area is increasingly vulnerable to coastal flooding, shoreline erosion, saltwater intrusion, tropical cyclone impacts, and loss of wetlands and chenier habitats into the future.

[13] Chenier ridges are sandy and/or shelly beach ridges that are part of a strand plain. Otherwise referred to as "chenier plains," these features consist of ridges colonized by woody vegetation separated by mud-flats with marsh vegetation. Cheniers/strand plains are associated with shorelines characterized by generally low wave energy and low gradients with abundant sediment supply.

To adapt to these coastal changes and minimize impacts to habitats, communities, and the economy, comprehensive regional and coastwide restoration and risk reduction planning studies have been undertaken by state and federal authorities, namely the *Southwest Coastal Louisiana: Integrated Final Feasibility Report and Environmental Impact Statement* (EIS; USACE, 2016a) and Louisiana's *Comprehensive Master Plan for a Sustainable Coast* (Louisiana Coastal Protection and Restoration Authority [CPRA], 2017a). In 2009, USACE New Orleans District (MVN) and the local sponsor, CPRA, initiated an *Integrated Feasibility Study and EIS for Southwest Coastal Louisiana* (the SWCLA study herein), which encompasses an area of 4,700 square miles within Cameron, Calcasieu, and Vermilion parishes (Figure 4-1).

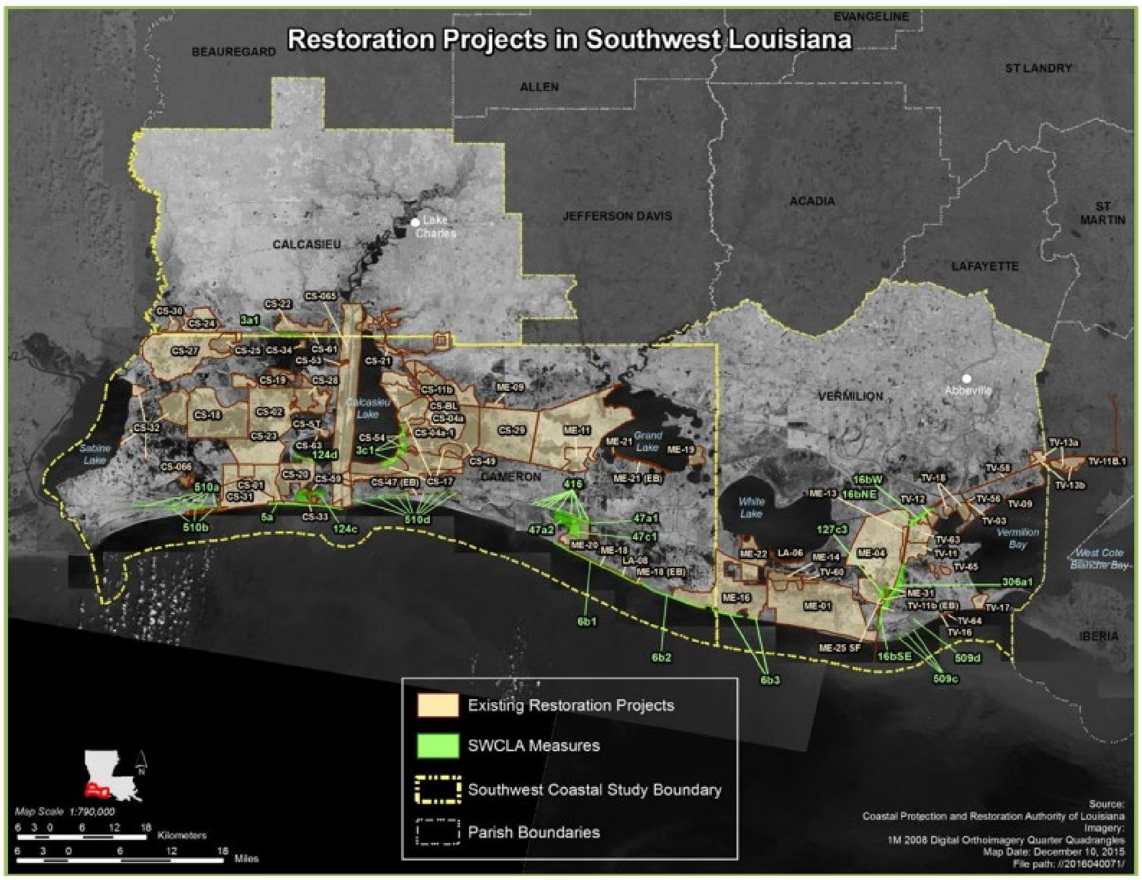


Figure 4-1. Southwest Coastal Louisiana Tentatively Selected Plan measures (in green). Source: Figure 3-1 of the Integrated Feasibility Study and Environmental Impact Statement for Southwest Coastal Louisiana *(USACE, 2016b).*

4.1.1 Project Goals

In 2005, Congress authorized the SWCLA study to investigate alternatives to restore environmental conditions and reduce risks and damage from hurricanes (USACE, 2016b). A feasibility study was conducted by USACE MVN to investigate possible restoration and risk reduction features to avoid further ecosystem degradation and reduce storm damage. This study specifically addresses the impacts of hurricanes that occurred in the area prior to 2016: Audrey (1957), Lili (2002), Rita (2005), Gustav (2008), and Ike (2008), as well as offers a path forward for mitigating impacts from future storms.

Objectives outlined for the SWCLA study included five planning objectives to apply to the entire study area for the 50-year period of analysis (2025–2075):

- Reduce the risk of damages and losses from hurricane storm surge flooding.
- Manage tidal flows to improve drainage and prevent salinity from exceeding 2 parts per thousand (ppt) for fresh marsh and 6 ppt for intermediate marsh.
- Increase wetland productivity in fresh and intermediate marshes to maintain function by reducing the time which water levels exceed marsh surfaces.
- Reduce shoreline erosion and stabilize canal banks to protect adjacent wetlands.
- Restore landscapes, including marsh, shoreline, and cheniers to maintain their function as wildlife habitat and improve their ability to serve as protective barriers.

The integrated feasibility study developed both a NED Plan consisting of risk reduction measures and a National Ecosystem Restoration (NER) Plan consisting of ecosystem restoration measures.

Although the NED and NER plans covered the same geographic area and are included within a single report, the two plans were formulated separately and had no analytical interaction or overlap of costs or benefits considered. This resulted in risk reduction and ecosystem services benefits being formulated, screened, and analyzed from a cost-benefit perspective independently, even though the NED and NERs are acknowledged as co-beneficial in the feasibility study report.

4.1.2 Alternative Formulation Process

USACE MVN evaluated approximately 300 ecosystem restoration and risk reduction project concepts to arrive at the initial array of NED alternative plans. Of these, 15 Hurricane and Storm Damage Risk Reduction (HSDRR) alternatives consisting of an armored 12-foot levee along the Gulf Intracoastal Waterway (GIWW), highway armoring, levee alignments, and nonstructural measures were considered for further analysis. However, none of the structural solutions had a BCR greater than 1.0 and were therefore excluded from further study, leading to the proposal of only nonstructural solutions in the NED Tentatively Selected Plan (TSP).

Two nonstructural plans (Alternative 7 and 8) made the Final Array of Alternatives, with Alternative 7 (the Nonstructural Justified Reaches Plan) selected as the initial TSP. However, controversy arose during the 2013–2014 public comment period over the plan's eminent domain procedures, which led to the development of a new NED TSP—a modified version of Alternative 8 (Nonstructural 0–25 Year Floodplain Plan)—in 2015. Alternative 8 consists of nonstructural measures for 3,961 residential structures, including voluntary acquisition or elevation of residential structures located in the 25-year (4% annual exceedance probability [AEP]) floodplain (USACE, 2016b).

The alternative formulation for the NER Plan (CM-4 Small Integrated Restoration) included 49 ecosystem restoration features in the final plan from a total of 173 possible concept features considered. To address land loss and ecosystem degradation, the plan focused on stabilizing wetlands through marsh creation, chenier reforestation, and shoreline protection features. Although USACE considered measures throughout the study area, those selected for the final NER Plan are all located in Cameron and Vermilion parishes.

4.1.3 Consideration of Nature-Based Solutions

The NER Plan was formulated separately from the NED Plan, and prioritized NBS from the outset. USACE's SWCLA study team analyzed NBS for engineering and economic feasibility, maximum benefits provided over the 50-year analysis period (2025–2075), and capacity to meet the project's objectives. The process for selecting the NER TSP consisted of several rounds of qualitative and semi-quantitative screening and plan iterations before arriving at the final combination of measures that most effectively offered net environmental benefits that contribute to regional and coastal ecosystem functions. Considering the difficulty in quantifying benefits for such a wide array of NBS, cost effectiveness and incremental cost analysis (CE/ICA)[14] was utilized to best inform environmental investment decisions. Ultimately, the Comprehensive Small Integrated Restoration Plan (CM-4) was determined to be the most cost-effective and economically justified option to achieve project goals.

4.1.4 Outcome of Chief's Reports

The Chief's Report was signed on July 29, 2016, and submitted for Congressional approval. The project first cost for the NER Plan was $2.19 billion and the NED Plan was $906 million based on October 2015 price levels and a 3.125% discount rate (USACE, personal communication, July 29, 2016). The Water Infrastructure Improvements for the Nation Act of 2016 (WIIN Act of 2016) authorized the SWCLA project; in 2018, federal funding of $1.2 million initiated identification and preparation of 50–100 residential structures eligible for elevation (CPRA, 2020). The 2022 Infrastructure Investment and Jobs Act (IIJA) allocated $120 million in construction funding for elevation of approximately 600–700 residential structures as part of the storm damage risk reduction features identified in the NED Plan (USACE, n.d.). However, the NER Plan had not received funding as of October 2022, and it is unclear whether the remaining features of the SWCLA project will be fully funded.

4.1.5 Other Key Considerations

During the period of development of the SWCLA study, CPRA, a Louisiana state agency charged with coastal restoration and risk reduction, initiated development of the *Comprehensive Master Plan for a Sustainable Coast* (Louisiana Coastal Master Plan; CPRA, 2012, 2017a). The Louisiana Coastal Master Plan (hereafter referred to as "CMP") is used as a blueprint to prioritize $50 billion of integrated risk reduction and ecosystem restoration projects over a 50-year planning horizon. The CMP is updated every 5–6 years as required by the state legislature, and at the time of writing, the 2007, 2012, and 2017 CMPs have been published, with the 2023 CMP forthcoming. The CMP prioritizes projects based on their

[14] Cost effectiveness is determined based upon a finding that no other plan provides a higher output level of acres restored for the same or less cost. Incremental cost analysis is the determination of the greatest increase in output (acres restored) for the least increase in cost.

projected performance, which is evaluated through an integrated series of morphologic, hydrodynamic, and risk computational models.

The 2017 CMP update evaluated a broad suite of restoration projects for marsh creation, ridge restoration, and shoreline protection project types in CPRA's morphologic model, named the Integrated Compartment Model (ICM), for a near-identical planning period to the SWCLA study (White et al., 2017). As the CMP project alternatives largely covered more expansive footprints than the SWCLA TSP features, the case study team was able to extract CPRA analysis results using geographic information systems (GIS) software and the SWCLA TSP project alternative footprints. Figure 4-2 displays the project alternatives considered from the SWCLA TSP and CMP, respectively.

The CMP modeling results prove useful to this case study in that they afford high-resolution predictions of future bathymetric, topographic, and vegetation changes of Louisiana's coastal landscape for Future With- and Without Action conditions (FWA and FWOA, respectively). The only NER TSP measure from the SWCLA study not captured in the 2017 CMP analysis was Measure 3a1: "Beneficial use of dredged material from the Calcasieu Ship Channel adjacent to the south shore of the GIWW west of the ship channel near Black Lake." Due to the alignment in the two studies' planning horizons and project analysis, the 2017 CMP can be considered a useful, in-depth, and parallel scientific analysis of the SWCLA NER TSP features, and thus results from the CMP could be incorporated into this case study analysis.

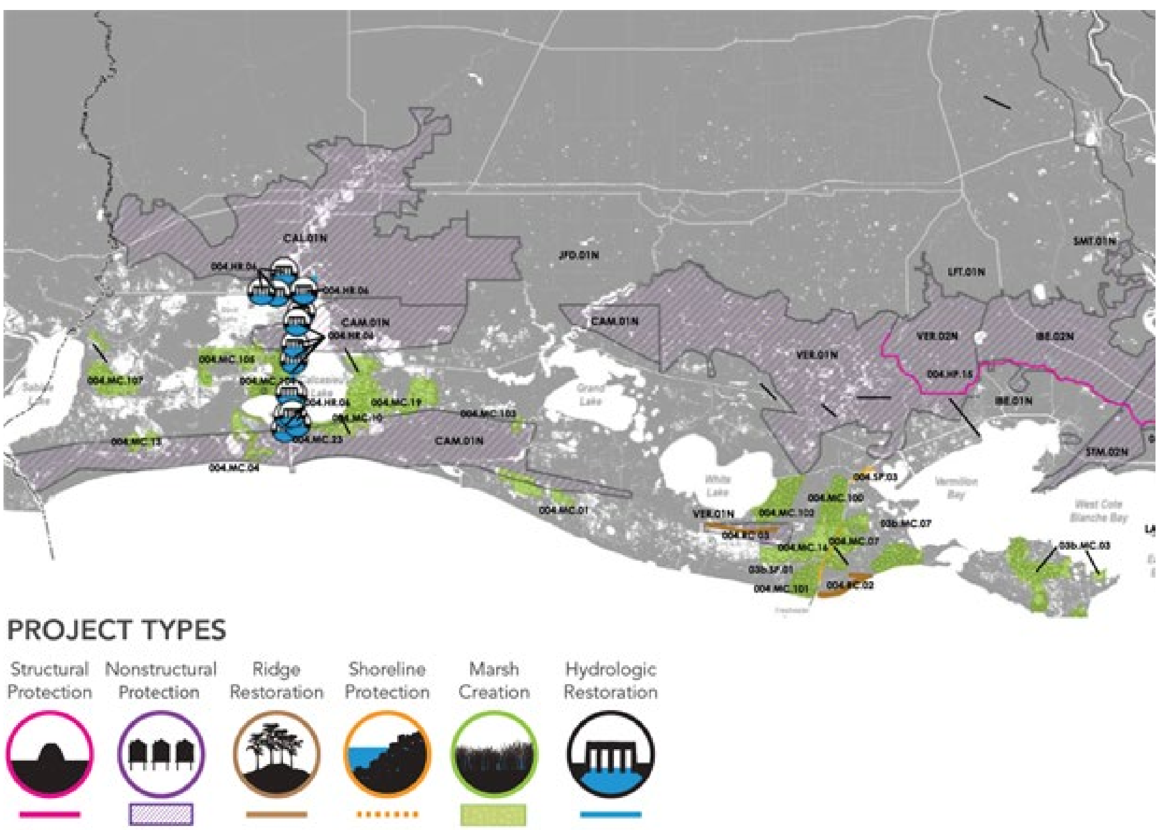


Figure 4-2. 2017 Coastal Master Plan projects used to support ecosystem outcome analysis for the Southwest Coastal Louisiana Tentatively Selected Plan. Adapted from Figure ES.5 of CPRA (2017a).

4.2 CASE STUDY REANALYSIS: STUDY SCOPE

Multiple NBS were identified in the SWCLA study, all of which were incorporated into the final TSP. No additional NBS were identified in a literature review of studies conducted in this region.

The SWCLA study considered 173 distinct NER measures of six NBS project types, four of which were carried into the TSP:

- 40 marsh creation projects via hydraulic dredged fill,
- 1 oyster reef restoration via placement of culch and hard bottom (all measures dropped from final NER),
- 64 hydrologic restoration projects via construction of channels and water control structures (all measures dropped from final NER),
- 6 terracing projects via mechanical dredge and creation of linear marsh terraces,[15]
- 19 chenier ridge restorations via tree planting, and
- 43 shoreline protection projects via placement of stone aggregate.

4.3 ALTERNATIVE FORMULATION

The various alternatives presented in the NER Plan include a large amount of overlap: of the 173 total measures, 154 appear in the TSP. Due to this overlap, the study team focused the remainder of this analysis only on the NER TSP and not the various competing alternatives, since there was little differentiation among the projects comprising the various alternatives found within the plan.

4.4 NON-MONETIZED OUTCOME EVALUATION

The SWCLA case study benefited from the extensive existing research and related literature on the biophysical change and ecosystem services of Louisiana's coastal ecosystems. This literature includes the quantification of a broad suite of monetary wetland[16] benefits per unit area (e.g., dollars per acre benefit). Specifically, a synthesis of coastal Louisiana wetland valuation by Louisiana State University (LSU) and the RAND Corporation considered several meta analyses of aggregated ecosystem services supported by wetlands and estuaries in Louisiana (S. R. Barnes et al., 2017). Rather than use individual valuation methods for each ecosystem service, these multi-faceted ecosystem service metrics are considered in aggregate for the monetized valuation as a single range of wetland valuation per acre for all ecosystem

---

[15] A marsh terrace is a linear, artificially created berm using in-situ sediment. Terraces are built in wetland environments to reduce wind fetch and wave energy and to prevent erosion.

[16] For the purposes of this case study, wetlands are a subcomponent of the landscape morphology formed by both natural and artificial processes tracked within the ICM (White et al., 2017). Acreage within the study domain was delineated as wetland, open water, or upland within the ICM framework. Only wetland acreages (areas unpopulated by humans and colonized by wetland species as categorized and predicted by the ICM) were considered for the monetization analysis.

services listed. The aggregated suite of ecosystem service metrics was identified for the NBS alternative measures considered in this case study.

The list of ecosystem services assembled by Barnes et al. (2017) is shown in Table 4-1 The list of potential ecosystem services provided by Louisiana wetlands is extensive and diverse; a few key services are highlighted here by way of example:

- Serve as the historical home to several Native American groups, whose traditions are intrinsic to the greater culture of the area.
- Regulate the nutrient cycling of various estuaries; without the filtration wetlands provide, the nutrient-rich discharge of the Mississippi River could cause even larger hypoxic zones in the Gulf of Mexico.
- Play an important role in the regulation of the tidal prism as well as storm tides, limiting the surge carrying capacity of coastal estuaries and limiting damage to ecosystems and properties.

In addition, the characteristic chenier ridges that make up an important part of the southwest Louisiana ecosystem provide additional services:

- Critical habitat for neotropical migratory avian species.
- Elevated features help to limit inundation from storm surge and waves.
- Spiritual and historic benefits to native populations, as chenier ridges were often the oldest-inhabited locations within wetlands (e.g., relative high ground).

Table 4-1. Partial list of ecosystem services supported by wetlands and estuaries in Louisiana, adopted from Table 5.1 (S. Barnes et al., 2015).

Provisioning goods	Regulating services	Cultural goods and services	Supporting services
Water Supply (consumption and transport)	Storm Protection Services	Recreation	Nutrient Cycling
Food (e.g., fish)	Gas Regulation	Aesthetic	Soil Formation
Raw Materials	Climate Regulation	Science and Education	Biological Regulation and Biodiversity
Genetic Resources	Disturbance Regulation	Spiritual and Historic	Marine, Avian, and Vegetative Species Habitat
Medicinal and Plant Resources	Soil Retention	-	Hydrological Cycling
Ornamental Resources	Waste Assimilation	-	-

Although the list of services provided by wetlands includes climate regulation, it was unclear from the literature what valuation methods or sources, if any, were used for carbon sequestration. The science for estimating and valuing the benefits from carbon sequestration has advanced in recent years. As a result, although there is a possibility of double counting, the study team decided to consider the value of carbon sequestration separately from the aggregate ecosystem services valuation.

The study team also considered other metrics, such as the protection provided by wetlands to the extensive oil and gas infrastructure of Louisiana's coastal areas. Little literature exists, however, for the quantification of benefits for this metric.

As previously noted, the CMP analyzed a broader suite of marsh creation, ridge restoration, and shoreline protection projects than were presented in the SWCLA TSP. This suite's spatial coverage included the footprint of the majority of SWCLA TSP features, allowing for CMP analysis to be utilized to subset the SWCLA features' performance on the landscape as the best analytical prediction of outcomes. However, data availability limited the study team's ability to consider specific project types in the SWCLA TSP:

- Oyster reef restoration was not modeled in the CMP for its direct impacts on predictions of wetland acres present over time (it was only used for habitat suitability analyses for oysters). This restoration project type was also eliminated from the final NER Plan and is thus not included in the reanalysis below.
- Hydrologic Restoration projects often have broad benefit areas which, in the CMP's modeling framework, were unable to be attributed to specific geographic areas. This restoration project type was also eliminated from the final NER Plan and is thus not included in this BCA.
- Marsh terrace areas were modeled in the CMP either as marsh creation areas or not at all. In cases where terrace areas from the SWCLA TSP were modeled as marsh creation areas in the CMP, they were included in this analysis. CPRA CMP analysis used to generate geomorphic predictions was limited in its ability to capture the effects of tree planting and thus 0 values are recorded. It is likely this analysis limitation contributes to undercounting of potential ecosystem services benefits from this restoration action.

Table 4-2. Ecosystem services and associated benefit-relevant indicators considered in the Southwest Coastal Louisiana case study.

Action / approach	Primary metric	Quantifiable units	Sensitivity of change relative to project	Direct links to beneficial use	Quantification metric of beneficial use	Approach to monetize this change	PR&G goal(s)
Marsh Creation	Marsh area by wetland type	Unit area (acres)	Approximately 9,300 acres restored or protected.	Extensive list of ecosystem services provided by Louisiana wetlands (see Table 4-1 and surrounding text)	Valuation of multiple ecosystem services from benefit transfer literature.	• Use geomorphic prediction numeric modeling to estimate wetland acreage and vegetation type changes over 50-year planning horizon. • Apply existing literature of aggregated per-acre benefits.	Healthy and Resilient Ecosystems, Sustainable Economic Development, Floodplain Management, Watershed Approach
	Marsh area by wetland type	Unit area (acres)	Approximately 9,300 acres restored or protected.	Carbon sequestration, reduction in greenhouse gas emissions	Carbon sequestration potential ($/Tonnes/CO2/Acre)	• Use geomorphic prediction numeric modeling to estimate wetland acreage and vegetation type changes over 50-year planning horizon. • Apply benefit transfer from literature ranges of values for various wetland types. • Apply social cost of carbon to sequestration capacity per marsh type.	Healthy and Resilient Ecosystems, Sustainable Economic Development, Floodplain Management, Watershed Approach

Action / approach	Primary metric	Quantifiable units	Sensitivity of change relative to project	Direct links to beneficial use	Quantification metric of beneficial use	Approach to monetize this change	PR&G goal(s)
Shoreline Protection	Shoreline protection area	Unit area (Acres)	Approximately 70 acres restored or protected.	Shoreline protection features contribute to soil retention via reduction in marsh edge erosion from wave energy.	Valuation of multiple ecosystem services from benefit transfer literature.	Same as Marsh Creation Above	Healthy and Resilient Ecosystems, Sustainable Economic Development, Floodplain Management, Watershed Approach
	Shoreline protection area	Unit area (Acres)	Approximately 70 acres restored or protected.	Carbon sequestration, reduction in greenhouse gas emissions	Carbon sequestration potential ($/Tonnes/CO2/Acre)	Same as Marsh Creation above	Healthy and Resilient Ecosystems, Sustainable Economic Development, Floodplain Management, Watershed Approach
Chenier Restoration		Unit area (Acres)	0 acres restored or protected.		Benefit transfer from literature ranges of values	Use of geomorphic prediction numeric modeling to estimate wetland acreage and vegetation type changes over 50-year planning horizon. Application of existing literature of aggregated per-acre benefits at various time steps within 50-year planning horizon.	Healthy and Resilient Ecosystems, Sustainable Economic Development, Floodplain Management, Watershed Approach

4.4.1 Biophysical Outcomes

The NER TSP considered in this case study generated a net positive outcome, with CPRA CMP projections of approximately 11,000 benefited acres by year 50 (discussed further in Table 4-4). These wetland acres provide a wide range of ecosystem services, from preservation of critical and essential habitats to storm surge and wave reduction, nutrient cycling, and promoting sediment retention.

Implementation of a suite of integrated ecosystem restoration measures such as shoreline protection, marsh creation, and chenier ridge restoration has been proven analytically through the CMP to yield environmental and storm reduction benefits in which the whole is greater than the sum of the parts. As such, there are greater wetland persistence benefits (in acres) that occur beyond those areas directly within project footprints. Ecosystem restoration projects often have wide-ranging areas of influence and benefit under varying conditions and work collectively to benefit wetland habitat. Evidence of these benefit acres occurring outside of direct project implementation footprints are discussed later in Section 4.5.1.1, but were not included in this analysis or captured in the SWCLA study.

4.4.2 Benefit-Relevant Indicators

The benefit of the NER TSP was quantified in this study through the projection of wetland acres restored or maintained that otherwise would have been lost over time and through the estimation of carbon sequestration potential of those wetlands.

4.4.3 Additional Quantitative or Qualitative Outcomes of Interest

4.4.3.1 Economic

The NED TSP of the SWCLA study was composed of nonstructural risk reduction measures, which were geographically grouped into "reaches"[17] for BCA. In many cases, these measures were geographically disparate from NER TSP measures. To consider the co-benefits of restoration and flood risk reduction, the study team initially sought to refine the roughly 3,100 nonstructural locations to a smaller subset of only those reaches immediately adjacent to NER TSP features. However, the reporting and calculations for NED for the SWCLA study were consistently available only in summarized form, which did not allow for geographic filtering of this information.

At the time of this case study analysis, a significant portion of the NED TSP features (600–700 structures) were funded for implementation in the 2022 IIJA. Thus, this case study focused on the estimation of a BCR for the NER TSP measures, which may then be considered in conjunction with or independently from the NED TSP BCA. Future reporting of geographically explicit data on risk reduction benefits and costs would enable a more holistic BCA of the combined NED and NER plans.

[17] "Reaches" in this case was used by USACE to describe polygons of distinct geographic domains that were considered individually within the NED's nonstructural risk reduction analysis. In this context, "reaches" does not refer to riverine segments..

The federally authorized and maintained Calcasieu Ship Channel is proximal to many of the proposed NER measures discussed in the SWCLA feasibility study. The 2010 *Dredged Material Management Plan* produced by USACE MVN projected a 20-year requirement to remove approximately 97 million cy of material to maintain the channel in its authorized dimensions, while also noting existing confined disposal areas were nearing their capacities (USACE, 2010). SWCLA NER marsh creation measures could benefit from the use of Calcasieu Ship Channel dredged material while also reducing the overhead costs for dedicated dredging location suitability searches for restoration and ongoing maintenance, and/or expansion costs for the confined disposal areas serving the channel.

Another area which was not addressed in the economic analysis is the carbon sequestration potential of open water habitats. Although published literature does contain estimated values, the analysis team elected not to quantify potential carbon sequestration benefits after consultation with subject matter experts. This was due to the highly uncertain and rapidly evolving nature of that science; at the time of writing, there were no Louisiana-specific data available for the analysis. However, as the science evolves, future efforts may reliably estimate these values.

4.4.3.2 Environmental

Certain project effects were either unable to be modeled for their land-change properties (i.e., oyster reef restoration), or unable to be explicitly attributed to one or even a collection of implemented TSP projects (i.e., land sustained outside of project polygon footprints, land created or sustained by hydrologic restoration projects whose effects are not present in the modelled data available from the CMP). Future planning efforts that utilize biogeophysical numeric modeling tools may enable broader benefit attribution to NER projects for improved cost-benefit ratios.

Often, biogeophysical modeling efforts to predict long term landscape change are limited by computational capacity and/or analysis time. As such, it is common in efforts such as the CMP to perform analyses at timesteps on the multi-year to decadal scale. This creates a misalignment with benefit timing, as proposed restoration projects "appear" on the landscape in models at prescribed timesteps often all at once, and at timesteps often longer than those required to construct them. In reality, even projects that take several years to construct begin to accrue partial benefits before their construction is complete and full benefits are realized. This analysis does not capture such phenomena, and thus likely undercounts the ecosystem services and carbon sequestration benefits available.

4.4.3.3 Social

The 2017 CMP Social Vulnerability Index (SVI) indicates that parishes in the SWCLA study area are largely comprised of natural resource dependent communities, which are those populated by individuals employed in forestry, agriculture, fisheries, and oil and gas extraction (CPRA, 2017c). The continued rapid loss of wetlands in this area places these natural resource communities at medium-high to high degrees of socioeconomic vulnerability. Furthermore, despite a trend of population growth from 2000 to 2020 in Calcasieu Parish and the study area overall, the July 2021 Census estimates indicate a 5.3% drop in Calcasieu's population from 2020 to 2021 as a result of the 2020 storms, marking the ninth largest decline among all counties in the nation. When combined with Cameron Parish, this region experienced the largest percentage population decline in any metropolitan area nationwide (Smith, 2022).

The SWCLA NER Plan is atypical of most USACE projects in that all structural alternatives considered were set aside in favor of ecosystem restoration and nonstructural risk reduction measures. Should the NER Plan be fully funded by Congress, the $2.19 billion investment into restoring environmental conditions in these vulnerable communities ravaged by recent storms—particularly when coupled with the previously funded NED measures that support elevation of residential structures—could benefit economically disadvantaged populations in the study area. Federal investment of this magnitude could also assist in building public confidence in the long-term sustainability of the region. Conversely, significant investment in areas like SWCLA could encourage further development and population growth, placing more people and infrastructure at risk (Iglesias et al., 2021).

While there are potentially adverse impacts to this investment, it is more likely that the social benefits of the large-scale ecosystem restoration would outweigh the potential drawbacks. Furthermore, although not quantified by this case study, it is anticipated that the social benefits provided by SWCLA implementation would extend beyond the population residing in the study area. As Louisiana's coastline continues to erode, communities further inland have begun to experience hurricanes more frequently. For example, the city of Monroe, located in northeast Louisiana over 220 miles north of Cameron Parish, has been included in 10 hurricane-related federal disaster declarations since 2002 (FEMA, 2022). Prior to 2002, Monroe experienced only one hurricane-related federal disaster declaration (Hurricane Betsy in 1965; Monroe Hazard Mitigation Steering Committee, 2010). Though this increase may be attributed to several factors, wetlands can act as storm buffers and their continued loss can be expected to impact not only coastal populations but also those further inland (CPRA, 2017c). Therefore, if implemented, the measures included in the NER Plan have the potential to positively impact not only communities in the study area, but those beyond the study's boundaries.

4.5 MONETIZED VALUATION

4.5.1 Valuation Methods and Key Assumptions

4.5.1.1 Wetland Ecosystem Service Valuation

The assessment of the value of the land restored and preserved by the SWCLA TSP's NER Plan was drawn from two separate sources. The LSU-RAND study (S. R. Barnes et al., 2017) used for wetland ecosystem service valuation aggregated multiple meta-analyses from both nationwide and Louisiana-specific literature sources. These aggregated data were used to calculate a per-acre value of Louisiana wetlands across all ecosystem service types (Table 4-3 below). This BCA reanalysis uses the Kim and Petrolia (2013) values shown in the table (bolded) and converted to 2015 dollars.[18] These benefits were then transferred to wetland acreages predicted by the CPRA CMP's biogeophysical modeling suite.

[18] Kim and Petrolia (2013) values were applied because this is the most recent source. In addition, the other similarly timed source included an estimate of carbon sequestration that could have double-counted the benefits calculated separately in this case study reanalysis.

Table 4-3. Implied values per acre for Louisiana wetlands in 2015 dollars rounded to the nearest hundred.

Source	Low estimate ($/acre)	High estimate ($/acre)
Farber (1996)	17,500	19,600
Kim and Petrolia (2013)	**15,500**	**23,700**
Batker et al. (2010)	29,900	116,600

Source: adopted from Table 5.12 (S. R. Barnes et al., 2017). For the SWCLA cost-benefit analysis, Kim and Petrolia (2013) values were used for the subsequent analysis.

In order to fully utilize the CPRA CMP modeling data as a surrogate for wetland area and vegetation change inputs to the wetland value and carbon BCA, the timing of benefits between the two plans required alignment. Individual project implementation timelines differed between the two plans. The SWCLA TSP called for project implementation in three tiers:

- Tier 1 has a projected implementation of 2025–2034,
- Tier 2: 2035–2044, and
- Tier 3: 2045 through completion.

A comparison of the decadal model outputs from the CMP was aligned with the SWCLA TSP to ensure proper benefit accounting and timing was maintained. The study team made a conservative assumption that although some projects may require years to fully implement (and thus an incremental buildup to peak benefits), all benefits were not realized until the project was fully implemented on the landscape[19]. This results in 0 benefits realized for the first 10 years of the planning horizon, at which point projects are implemented and fully constructed. Table 4-4 below shows the acres of benefit by year estimated from the CMP for this BCA reanalysis.

Historically, as ecosystem restoration projects have been implemented across Louisiana's dynamic coastal landscape, the magnitude of direct acreage created (and its accompanying benefits) often tends to diminish with time, as relative sea level rise and wave erosion convert wetlands to open water. Counterintuitively, the magnitude of land sustained over the 50-year planning horizon does not diminish, but rather increases with time.

[19] Completion of project implementation in the context of NBS can have many definitions, such as completion of construction activities or the full realization of benefits once a project has not only been constructed, but also fully vegetated. In this case, full project implementation refers to the completion of construction of earthworks or fixed structures, as well as vegetation to maturity for increased impact, as applicable.

Table 4-4. Calculated benefit acreages from the CMP used in the SWCLA TSP BCA.

Benefit type	Year 0 (2015)	Year 10 (2025)	Year 20 (2035)	Year 30 (2045)	Year 40 (2055)	Year 50 (2065)
	Acres of benefit (rounded to tens column)					
Habitat value	0	0	1,200	2,350	5,750	11,110
Carbon sequestration	0	0	1,170	730	3,550	6,360

Note: habitat value and carbon sequestration benefit acreages vary slightly due to the methods by which the CMP modeling occurs: some land may be classified as bare land with no vegetation or vegetation types outside of the marsh types for which carbon sequestration potential literature was available.

Benefits were calculated by applying the acreages in Table 4-4 above to the dollar valuations for wetlands and carbon sequestration (with an intermediate step for carbon to convert from acres to tonnes sequestered) at decadal timesteps. Open water areas were not considered in the carbon sequestration analysis. Linear interpolation was used for all time in between these timesteps.

The CMP analysis used to predict outcomes for the SWCLA TSP measures report not only binary land loss/gain at annual timesteps over the 50-year planning horizon, but also a third change metric, land sustained. This category represents land that was not directly gained via marsh creation or other project alternative measures, but that indirectly benefits from project implementation. Land sustained is wetland that would have been otherwise lost in FWOA but for the TSP implementation of SWCLA NBS project alternatives. Land sustained was also counted as a benefit for wetland valuation and carbon sequestration analysis. Figure 4-3 displays an example of the CMP's land lost, gained, and sustained outputs used to evaluate the SWCLA TSP project performance and benefits.

Biophysical outcomes for the SWCLA TSP projects were calculated by using the project polygons to clip and extract CMP modeling results for land change (Figure 4-4) and vegetation (Figure 4-5). For shoreline protection, a 200-m buffer shoreward of the linear stone embankment was used to extract benefit area to represent the area behind the stone embankment in which wave energies would be significantly reduced and within which one would expect project benefits to exist (CMP uses a 200-m buffer within which wave energy in the ICM model is reduced by the proposed feature). A conservative assumption was used in that only benefits within the SWCLA TSP project polygons were used for the BCA. Although it is likely that restoration projects have broader benefits—as evidenced in the land sustained in Figure 4-3 that occurs outside of any restoration project polygon—these benefits were unable to be attributed to any particular project implementation and were thus excluded from the BCA. These additional benefits outside of specific project polygons on a map could be included in non-quantitative methods in future efforts via multi-objective and tradeoffs analysis.

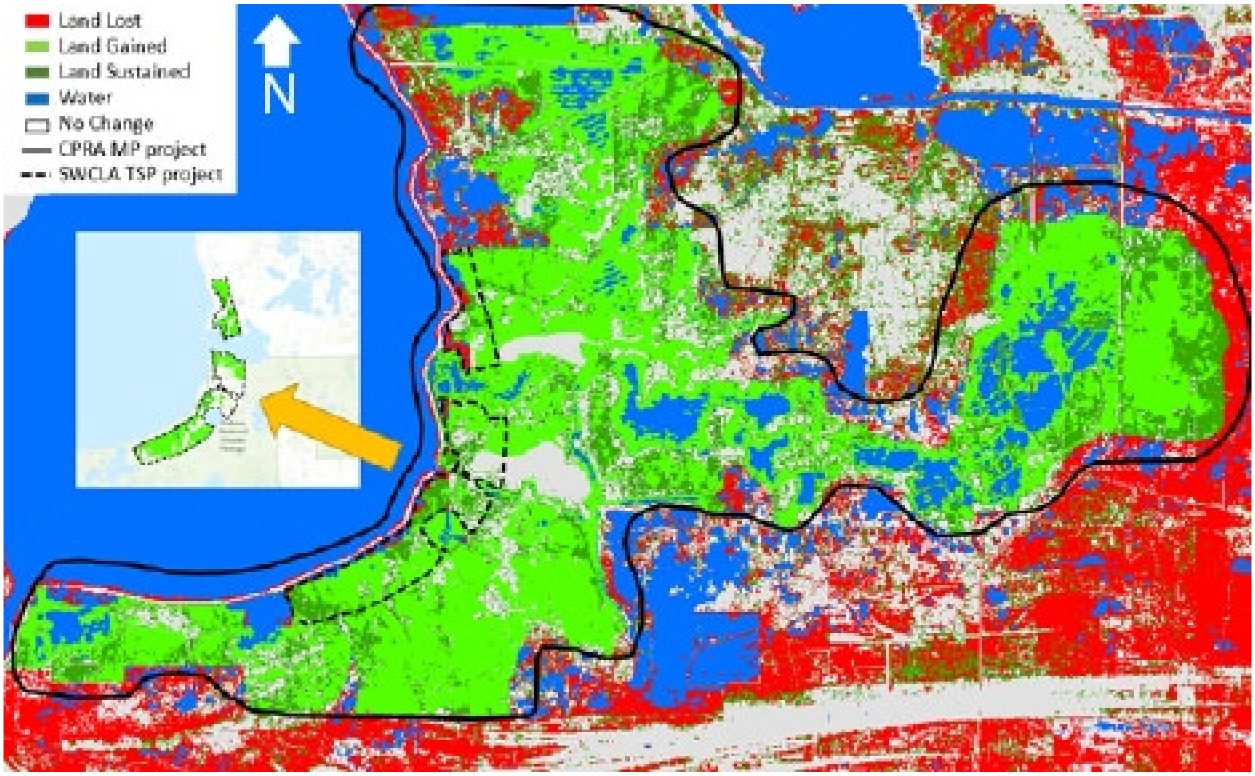


Figure 4-3. Example Coastal Master Plan results extraction for Southwest Coastal Louisiana Tentatively Selected Plan projects. SWCLA TSP project footprints (dashed black line example) were used to extract from the broader CMP project results (solid black line outline). Only extracted results inside the dashed SWCLA TSP polygon were used for the BCA, which is likely a conservative assumption.

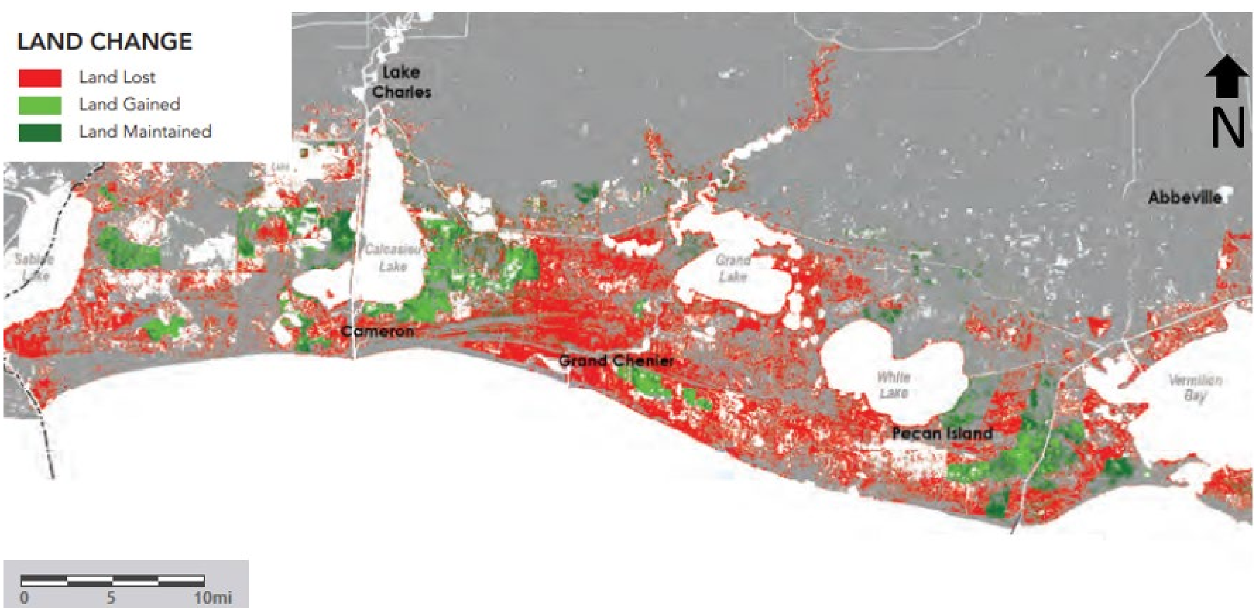


Figure 4-4. Coastal Master Plan land lost, gained, sustained at the end of its 50-year planning horizon under a medium relative sea level rise scenario. This information was used in wetland valuation analysis.

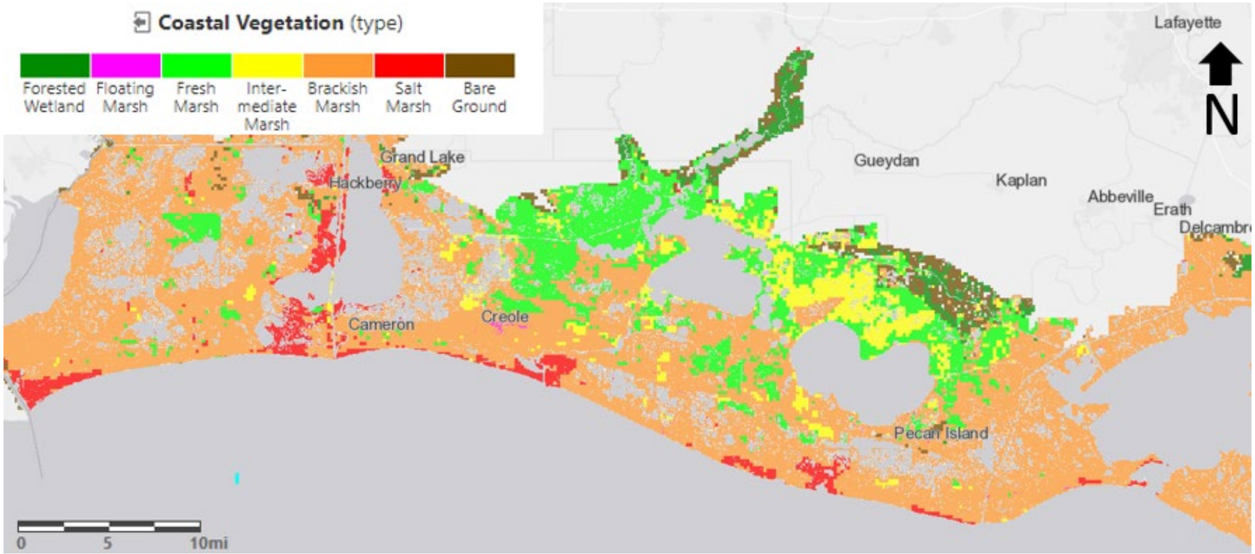


Figure 4-5. Coastal Master Plan wetland vegetation coverage prediction example at initiation of its 50-year planning horizon under a medium sea level rise scenario. This information was used in the carbon sequestration analysis.

4.5.1.2 Carbon Sequestration

The second source of monetized ecosystem service benefits focuses specifically on the carbon sequestration provided by coastal wetlands. These can range anywhere between $47 and $140 per ton sequestered (originally reported for the year 2020 but converted to 2015 dollars to align with the SWCLA economic analysis). Since the CMP analysis includes predictions of both land/water spatial predictions as well as vegetation coverage and type predictions (at a 30-m grid scale resolution for each) over a 50-year planning horizon, it was also possible to include the quantification of sequestered carbon as a valuation metric. This quantification includes the carbon stored within plant above- and belowground biomass, as well as dead and decaying plant detritus found in the soil.

For the carbon analysis, CMP land/water and vegetation coverage type predictions were used at decadal snapshots (years 0, 10, 20, 30, 40, and 50 of the 50-year planning horizon) in conjunction with Louisiana-specific ranges of carbon sequestration per unit area by wetland type. Wetland types analyzed include fresh, intermediate, brackish, and saline marshes (Baustian et al., 2022). Carbon sequestration values by wetland type were then applied to the social cost of carbon valuations[20] using a 3% discount rate

[20] White House Executive Order 13990 resulted in the Interagency Working Group on Social Cost of Greenhouse Gases (IWG), which produced a technical support document in 2021 that defines the social cost of greenhouse gases (SC-GHG) as:

> The monetary value of the net harm to society associated with adding a small amount of that GHG to the atmosphere in a given year. In principle, it includes the value of all climate change impacts, including (but not limited to) changes in net agricultural productivity, human health effects, property damage from increased flood risk natural disasters, disruption of energy systems, risk of conflict,

converted from 2020 to 2015 dollars, as this was the closest discount rate available in the IWG report to the USACE water resources discount rate used across all of the analysis of 3.125%.

4.5.2 Uncertainty Discussion

The combination of a dynamic coastal landscape, extended period of analysis (5 decades), and broad ranges of potential benefit valuations for wetland value and carbon sequestration introduce a broad range of uncertainty in both ecosystem outcomes and benefit-cost outcomes. This discussion is not intended as a quantitative uncertainty calculation, but rather an accounting of the general sources and magnitudes of uncertainty, where known, that contribute to this reanalysis.

4.5.2.1 Landscape Change

A large amount of uncertainty is inherent in the environmental drivers, including eustatic sea level rise, subsidence, precipitation, and evapotranspiration, used to force the ICM used in the CMP (Meselhe et al., 2017). The CMP addressed this uncertainty through the development of various environmental scenarios. For the illustrative purposes of this analysis, only values from one environmental scenario (the CMP's "medium" environmental scenario, which was used for its plan formulation) were used for wetland valuation and carbon sequestration benefits calculations.

Furthermore, other sources of uncertainty investigated were with regard to the calculations of ICM variables and their influence on model output. Across all of the uncertainty analysis run by Meselhe et al., variations in year 50 land area ranged several thousand square kilometers, or nearly +/-30% across Louisiana's entire coast.

4.5.2.2 Carbon Sequestration

Carbon sequestration potential for wetlands in coastal Louisiana is a rapidly evolving science. The most recent literature specific to Louisiana wetlands contains large inherent uncertainties in the sequestration capability ranges for the various wetland types addressed in this study (Baustian et al., 2022) and is presented in Table 4-5. Many of the uncertainty ranges are greater than 100% of the mean, and this element is the largest driver of uncertainty in this BCA reanalysis due to the magnitude of the ranges. For this reanalysis, low, mean, and high values were calculated from this range.

---

environmental migration, and the value of ecosystem services. The SC-GHG, therefore, should reflect the societal value of reducing emissions of the gas in question by one metric ton. The marginal estimate of social costs will differ by the type of greenhouse gas (such as carbon dioxide, methane, and nitrous oxide) and by the year in which the emissions change occurs. The SC-GHGs are the theoretically appropriate values to use in conducting benefit-cost analyses of policies that affect GHG emissions. (Interagency Working Group on Social Cost of Greenhouse Gases, 2021, p. 2).

Table 4-5. Carbon sequestration potential and uncertainty ranges by Louisiana wetland type,

Habitats	Mean	Uncertainty	Mean	Uncertainty
(Year 2020)	CO2e/ha/year		CO2e/ac/year	
Fresh forested wetland	-0.7	54.9	-1.7	135.7
Fresh herbaceous marsh	15.0	41.4	37.1	102.3
Intermediate herbaceous marsh	14.3	39.9	35.3	98.6
Brackish herbaceous marsh	-47.6	42.9	-117.6	106.0
Saline wetland	-36.3	35.2	-89.7	87.0
Fresh/intermediate open water	-8.6	73.0	-21.3	180.4
Brackish open water	-11.6	8.8	-28.8	21.7
Saline open water	-11.7	8.8	-28.8	21.7

Source: adopted from Baustian et al. (2022). Values converted from hectares to acres in righthand columns. Negative values are net sinks, positive values are net sources.

4.5.2.3 Wetland Valuation and Carbon Valuation

Wetland and carbon sequestration valuation metrics are also areas of evolving science and thus large uncertainty ranges for valuations. For wetlands, valuation ranges vary by tens of thousands of dollars per acre based on literature values, from as low as $17,550 to as high as $116,650 per acre in 2015 dollars (Table 4-4). For the social cost of carbon, values utilized for the BCA ranged from $47 to $140 dollars per metric tonne (Interagency Working Group on Social Cost of Greenhouse Gases, 2021).

4.5.3 Updated Benefits

Over the course of the project lifetime, approximately 11,100 acres are restored or preserved under the NER Plan (Table 4-4). By the end of the project, this would result in between $166 and $255 million dollars in benefits per year. However, because the NER restoration does not occur all at once at the beginning of the project, the AAEQ of these benefits using the study's water resources discount rate is between $28 million and $43 million. The equation for calculating the benefits in a given year is:

$$C_{ES,t} = B_{ES} * A_t$$

Where $C_{ES,t}$ is the equivalent cash value of the ecosystem services for year t, B_{ES} is the ecosystem services value per acre and A_t is the number of restored or preserved acres in year t.

By the end of the project, the total annual benefits from carbon sequestration of the restored or preserved wetlands is between $947,000 and $159 million. However, these benefits phase in over the course of the study, and the AAEQ of these benefits using the study's water resources discount rate is between $142,000 and $28 million.

$$C_{CS,t} = B_{CS} * S * A_t$$

Where $C_{CS,t}$ is the equivalent cash value of carbon sequestration for year t, B_{CS} is the dollar value per ton of carbon sequestered, S is the number of tons of carbon sequestered per acre and A_t is the number of restored or preserved acres in year t.

4.5.4 Updated Costs

The original SWCLA TSP costs are shown below in Table 4-6, and the study team made no updates to the costs detailed in the SWCLA TSP. It should be noted, however, that since the original SWCLA study was completed, many key market drivers which govern the cost of ecosystem restoration have changed, namely, the size of the U.S. domestic dredge fleet and the cost of fuel.

Estimates of economic damage, benefits, net benefits, NED costs and NER costs were reported in the SWCLA study using FY 2015 price levels (October 1, 2014). The year 2025 was identified as the base year for each of the NED and NER alternatives as the basis for plan comparison. Estimates of interest during construction and amortization of values were conducted using the FY 2015 Federal discount rate of 3.375 percent. The final net benefit results were updated to FY 2016 price levels (October 1, 2015) and the FY 2016 federal discount rate of 3.125%.

Table 4-6. National Ecosystem Restoration plan costs for the Southwest Coastal Louisiana Tentatively Selected Plan in 2015 dollars.

Item	Construction cost	Nourishment and maintenance costs		
		Year 15	Year 25	Year 30
Cost	$1,451,100,000	$22,500,000	$ 51,000,000	$238,000,000
Total	$1,762,600,000			

Note: 2015 dollars, rounded to hundred thousands.

4.5.5 Benefit-Cost Comparisons

4.5.5.1 Planning Analysis

A summary of the inputs used in the BCA calculation can be found in Table 4-7. Under the original NER analysis, no benefits were monetized; however, AAEQ costs of $67 million were calculated. Under the highest assumptions for both ecosystems services and carbon sequestration benefits are slightly higher than costs (1.06 BCR). However, lower values for these two sources of benefit would push the BCR below 1.0.

In addition to the NER project, there was also an NED project analysis with total AAEQ benefits of $203 million and total AAEQ costs of $36 million. If NER analysis had been incorporated into the NED BCR calculation, the overall project BCR would have been between 2.25 and 2.67 for the high and low estimates of NER benefits, respectively. These numbers indicate that while the NER project might have benefits that outweigh costs under certain assumptions, a combined NED and NER project BCA would consistently show greater benefit than cost.

Table 4-7. Table of average annual equivalent values of the benefits and costs of the Southwest Coastal Louisiana project using the USACE Planning Analysis assumptions.

	NER Plan low	NER Plan high
Benefit/Cost Source	AAEQ (millions of dollars)	AAEQ (millions of dollars)
Original Benefit	$203	$203
Original Cost	$36	$36
Original BCR	5.65	5.65
Original NER Costs	$67	$67
Ecosystems Services	$28	$43
Carbon Sequestration	$0.142	$28
NER BCR	0.42	1.06
Combined BCR	2.25	2.67

4.5.5.2 OMB Process Analysis

A summary of the numbers used in the BCA calculation can be found in Table 4-8 using the OMB discount rate of 7%. Using this higher discount rate, even under the highest assumptions about ecosystems services and carbon sequestration the NER Plan costs would exceed benefits. The reduction in BCR for the NER Plan by itself is due to the benefits of both carbon sequestration and ecosystem services the study team calculated largely accruing more than 30 years in the future, and thus being heavily affected by the increased discount rate. However, as when the NER analysis is incorporated into the NED BCR calculation, the overall project BCR would have been between 1.08 and 1.20 for the high and low estimates of NER benefits, respectively.

Table 4-8. Table of average annual equivalent values for the benefits and costs of the Southwest Coastal Louisiana project using the Office of Management and Budget assumptions.

	NER Plan low	NER Plan high
Benefit/Cost Source	AAEQ (millions of dollars)	AAEQ (millions of dollars)
Original Benefit	$203	$203
Original Cost	$65	$36
Original BCR	3.12	3.12
Original NER Costs	$136	$136
Ecosystems Services	$14	$22
Carbon Sequestration	$0.09	$15
NER BCR	0.10	0.27
Combined BCR	1.08	1.20

4.6 PRIORITIZATION AND ALTERNATIVE SELECTION

The reanalysis of the SWCLA study focused on identifying and valuing benefits and costs for the NER TSP rather than on competing alternatives, and as such MODA was not applied for this case study.

4.7 DISCUSSION

Under certain assumptions, the NER Plan has a positive BCR, despite the inability to quantify several known ecosystem restoration benefits. The benefit-cost calculation of the NER portion of the SWCLA TSP resulted in BCRs that, depending on the metric uncertainty applied, were on either side of the break-even threshold. Including the NER's valuation in conjunction with the NED's valuation resulted still in a positive BCR well above 1.0. The methods used to generate ecosystem service and carbon valuation were conservative, meaning they omitted several quantifiable benefits mostly due to lack of source data from either the USACE's original SWCLA study or CPRA's 2017 CMP analysis; however, with the data, the methods employed herein would be able to capture those benefits and increase the return on investment. Furthermore, carbon valuation in the U.S. is a relatively immature field, with no official regulated carbon markets such as those found in Europe. As climate change impacts continue to evolve in the future, shifts in carbon valuation may greatly alter the calculus behind BCR exercises such as those explored in this chapter.

The biogeomorphic modeling data used to quantify BCR data for this analysis captured the co-benefits of many restoration projects implemented as a suite and was able to prove that the performance of the suite was greater than the performance of the sum of all the individual restoration suite components implemented separately. This finding is especially important when considering all structural alternatives, when analyzed under the NED umbrella alone, were eliminated from consideration given their BCR's were all less than 1.0. Future efforts may consider both the integrated co-benefits of suites of restoration and risk reduction measures for a more accurate BCR analysis.

The methodologies developed herein are directly applicable to other USACE studies where biogeomorphic numeric modeling tools are available to predict landscape change and vegetation change on a multi-decade timescale. Louisiana is uniquely positioned in this regard due to CPRA's ICM model; however, other studies could purposefully develop similar tools in other geographies to support such future work, even if based upon other non-model analytical tools for wetland change over time such as Wetland Value Assessments' (WVAs') Average Annual Habitat Units (AAHUs; Roy, 2006). Notably, the SWCLA report notes AAHU benefits for NER projects; however, AAHUs were not used as a plan formulation metric.

Several limitations and areas of future improvement were identified during this case study. There were limitations in the available data and numerical model output that could be used to quantify some NBS benefits. Specifically, more detailed data tying NER projects to specific developed areas targeted for risk reduction would better enable a joint NER-NED BCA analysis. This could allow for an estimate of NER project effects on flood risk reduction, a metric which the case study team could not explore in this analysis. On a coastwide scale, other similar efforts such as CPRA's CMP (CPRA, 2017b) have shown that the addition of restoration features symbiotically works in conjunction with structural and nonstructural risk reduction measures on a coastwide scale to further reduce expected annual damages than risk reductions measures could on their own.

This analysis benefited from site-specific literature on wetland valuation and carbon sequestration methodologies, but such literature is either immature or nonexistent for many other regions of the country. Future USACE feasibility studies may consider NER valuation methods such as those presented herein mature in a site-specific or region-specific manner in other geographies.

The study is unique in that it is intended to respond to two enabling congressional actions: A resolution of the U.S. House of Representatives Committee on Transportation and Infrastructure, adopted December 7, 2005, and to Section 7003 of the Water Resources Development Act of 2007 (WRDA 2007).

- The resolution requested the Secretary of the Army to survey the coast of Louisiana in Cameron, Calcasieu, and Vermilion parishes, with particular reference to the advisability of providing hurricane protection and storm damage risk reduction and related purposes, including the feasibility of constructing an armored 12-foot levee along the Gulf Intracoastal Waterway.
- Section 7003 of WRDA 2007 authorized a program for ecosystem restoration for the Louisiana Coastal Area to be conducted substantially in accordance with the report of the Chief of Engineers dated January 31, 2005, which recommended further study of a various large scale restoration concepts.

Finally, although the reporting for both NER and NED plans occurs in one study document that acknowledges the theoretical co-benefits of NER and NED measures, the NER and NED analyses were nevertheless conducted entirely separately. As shown in this case study, a joint NER-NED BCR analysis could lead to different conclusions than two separate, independent BCR analyses of NED or NER measures.

5.0 SOUTH SAN FRANCISCO BAY

5.1 OVERVIEW

The South San Francisco Bay Shoreline Phase I Study Area is located in Santa Clara County, California between Alviso Slough and Coyote Creek along the southern shoreline of the San Francisco Bay. The area consists of a series of former commercial salt harvesting ponds as well as the adjacent community of Alviso and a wastewater treatment facility (Figure 5-1). The area is prone to tidal flooding due to its low-lying terrain, which is protected by non-engineered dikes. These dikes were designed and created as early as the 1920s primarily to protect salt pond production from tidal flooding, and they are inadequate to provide reliable tidal flood risk management for the adjacent urbanized areas and critical infrastructure. Tidal flood risk in the area is anticipated to significantly increase due to sea level rise.

Additionally, the creation of the commercial salt ponds has led to the loss of most of the area's tidal marsh habitat, and what remains is highly fragmented (USACE, 2015f). The entire San Francisco Bay estuary included 196,000 acres of tidal marshes prior to 1850; 92% has been lost since due to conversion to other uses, primarily agricultural fields in the North Bay and commercial salt ponds and other industrial uses in the South Bay (Lowe et al., 2013). The loss of tidal wetlands also meant severe degradation of habitat (both quantity and quality) for salt marsh plants and wildlife, including special-status and endangered species that rely on this habitat (USACE, 2015f). Additionally, all refugial high-tide habitats (the habitats resident species rely on to retreat during high-tide conditions) were lost because of diking.

Significant efforts have been underway for decades to restore tidal marshlands in the San Francisco Bay. The purchase of most of the commercial salt ponds in the South Bay by the State of California and the U.S. Government in 2002 created an opportunity for large-scale tidal marsh restoration. The South San Francisco Bay Shoreline Project exists within a broader collaborative effort among federal, state, and local agencies to restore these salt ponds to tidal marsh. Collectively, the effort is the largest tidal wetland restoration project on the West Coast (Collins & Grossinger, 2004).

Most of the salt ponds in the study area are part of the Don Edwards San Francisco Bay National Wildlife Refuge. Tidal marsh restoration in the area provides opportunities to also improve recreational opportunities for visitors to the Refuge and the Bay shoreline.

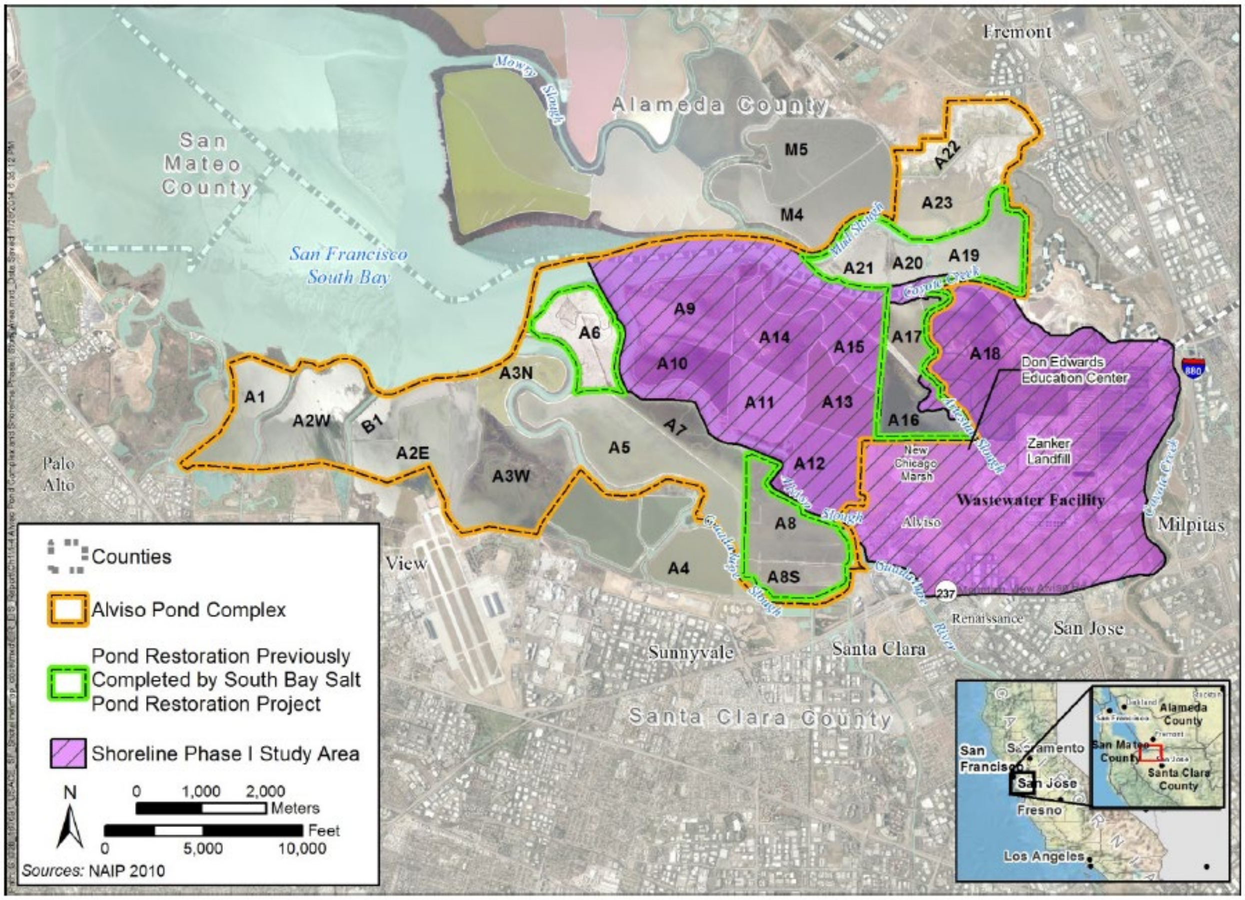


Figure 5-1. Map of Shoreline Phase I study area and completed pond restoration.

5.1.1 Project Goals

The South San Francisco Bay Shoreline Phase I Study was prepared in response to multiple congressional actions, beginning with the authorization of a San Francisco Bay Shoreline Study in WRDA of 1976. Following the purchase of commercial salt ponds in the southern San Francisco Bay by the State of California and the Federal government, a 2002 resolution from the Committee on Transportation and Infrastructure requested the review of the *Final Letter Report for the San Francisco Bay Shoreline Study* that was completed in July 1992 to determine whether modifications to recommendations were advisable given the new opportunity for large-scale tidal marsh restoration. The study was initiated in September 2005 to evaluate alternatives for tidal FRM, ecosystem restoration, and recreation. WRDA 2007 also authorized the South San Francisco Shoreline Study and provided additional direction on crediting non-Federal sponsor work and acquisition of real estate.

The final integrated document produced for the South San Francisco Bay Shoreline Phase I Study was released in 2015 by USACE and the non-federal sponsors: the Santa Clara Valley Water District, the California State Coastal Conservancy, and USFWS (USACE, 2015f). The primary goals were to increase tidal flood risk resiliency and ecosystem functions throughout the Alviso community through tidal marsh and transitional habitat restoration and provide opportunities for recreation associated with the restored habitat (USACE, 2015f).

The stated objectives of the USACE planning study were to:

- Reduce risks to public health, safety, and the environment caused by tidal flooding;
- Reduce potential economic damages from tidal flooding;
- Restore ecological function and habitat quantity, quality, and connectivity for native plant and animal species, including special-status species such as the salt marsh harvest mouse (SMHM), Ridgway's rail (RIRA), and steelhead trout; and
- Improve public access, education, and recreation (USACE, 2015f).

These objectives are highly interconnected in the study area. For example, the process of restoring tidal marsh habitat would require the breaching of the non-engineered pond dikes. This action, however, would further increase flood risk to adjacent areas that are currently protected from tidal flooding by the diked ponds (USACE, 2015f). The importance of these objectives to the local community and larger South Bay region and their inseparability drove the formulation of a multipurpose flood risk management and ecosystem restoration project.

The restoration of historic tidal marsh conditions provides opportunities for increasing habitat area and connectivity for special-status and native species while also providing other ecosystem services. However, the existing salt ponds also serve valuable ecological functions, including providing habitat to migratory waterbirds. The Shoreline Phase I study balanced these competing objectives but prioritized the goal of restoring historic tidal marsh, consistent with local support for conversion of 50–90% of salt ponds to tidal habitats (USACE, 2015f).

The project also provides an important linkage to larger-scale regional restoration plans, most notably the South Bay Salt Pond Restoration Project (SBSP Restoration Project), which is managed by the State of California, USFWS, and local entities (USACE, 2015f). Prior to the 2015 USACE study, the SBSP Restoration Project restored tidal and pond habitat and developed a new bay trail segment and viewing access for the wildlife refuge using federal, state, and private funds. Though both projects were closely coordinated, they are separate efforts and are not dependent on each other. For these reasons, the study team solely examined the NBS from the 2015 USACE study for this analysis.

5.1.2 Alternative Formulation Process

The USACE San Francisco District (SPN) formulated a multipurpose FRM, ecosystem restoration (ER), and recreational plan in multiple phases (USACE, 2015f). SPN first identified, evaluated, and screened options for each FRM and ER separately, and then considered combinations of FRM and ER options together with recreation measures in a final array of alternatives. From this analysis, SPN identified the combined NED and NER Plan and a second Locally Preferred Plan (LPP; Figure 5-2).

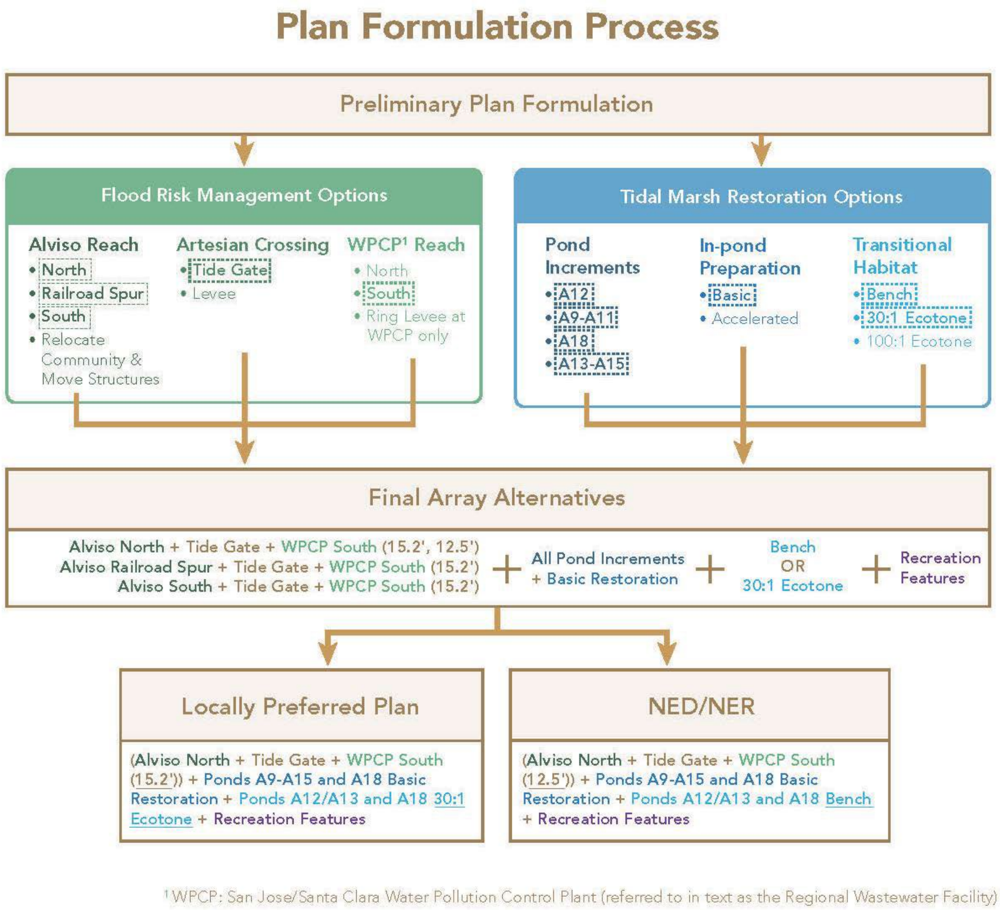


Figure 5-2. Plan formulation process for the South San Francisco Bay Shoreline Phase I Study (USACE, 2015f). The first row of boxes shows the key options considered for flood risk management and tidal marsh analysis, with options selected to proceed further highlighted with dashed outlines. The Final Array of Alternatives (second row) brings together these selected options along with other levee, restoration, and recreation features. The final row shows key differences between the Locally Preferred Plan (left box) and recommended National Economic Development/National Ecosystem Restoration plan (right box).

5.1.2.1 Ecosystem Restoration

The study effort adopted the recommendations from the SBSP Restoration project and City of San Jose planning efforts on specific ponds (A9–A15 and A18; Figure 5-1) to target for tidal marsh restoration. The ER options initially identified included different groups of ponds for restoration: a "basic" in-pond preparation prior to breaching or an "accelerated" option that would recreate natural restoration processes on a more expedient time frame, with additional options for transitional habitats adjacent to the ponds on the bayside of the FRM levee.

The SPN used PR&G criteria of completeness, effectiveness, efficiency, and acceptability to evaluate the ER options and determine which would advance to the final array of alternatives. The SPN evaluated the efficiency of ER options by comparing their costs to their outputs in habitat units, as determined through analysis using the Combined Habitat Assessment Protocols (CHAP). Four pond groupings were identified as "Best Buy Plans" with the largest restoration of all of the pond complexes being selected as the NER option. “Basic” in-pond preparation was determined to be more cost-effective than “accelerated” preparation (see Figure 5-2). An ecotone with a 30:1 slope was identified and evaluated as a transitional habitat between the FRM levee and the tidal marsh. It did not meet the efficiency criteria, and the study acknowledges limitations of the CHAP analysis in accounting for the benefits of the ecotone. However, the 30:1 ecotone was advanced to the final array alternatives at the request of the non-federal sponsors based on current scientific understanding of the benefits provided by transitional tidal habitats (USACE, 2015f).

5.1.2.2 Flood Risk Management

FRM options were screened to identify the most cost-effective levee alignment and subsequently to determine the levee height with the highest net benefits to serve as the NED Plan. An initial nonstructural-only alternative was also developed, which included gradual relocation of residential and commercial structures in the community of Alviso and a ring levee around the wastewater treatment facility. However, the nonstructural-only option was determined to have a high cost of implementation and excluded from further study (USACE, 2015e).

The SPN used the USACE Hydrologic Engineering Center-Flood Damage Reduction Analysis (HEC-FDA) model to analyze flood risk under FWA and FWOA conditions. The modeling team calculated FWA annual damage for eight different levee height increments (11, 11.5, 12, 12.5, 13, 13.5, 14, and 15-foot). These levee heights were also analyzed within low, medium, and high USACE SLC scenarios. The 12.5-foot levee was identified for the NED Plan because it maximized net benefits under the Low and Intermediate SLC scenarios and could be raised in the future if necessary to accommodate sea level rise under the High SLC scenario (USACE, 2015f). A 15.2’ levee was also included in the final array of alternatives based on input from the non-federal sponsors. This height represents an elevation 2 feet above the mean 1% AEP water surface elevation at year 2067 (the end of the period of performance based on a 2017 anticipated project start date) under the high SLC scenario and would address the local sponsor goal of meeting FEMA freeboard requirements for levee accreditation in year 2067.

The final array analysis included five alternatives. Alternative 1 was a combined no action FRM or ER features scenario. Alternatives 2 and 3 included the same levee alignment and “basic” pond restoration for all ponds. However, Alternative 2 included a 12.5-foot levee with a 50-foot bench and Alternative 3 included a 15.2-foot levee with a 30:1 ecotone. Alternatives 4 and 5 assessed two additional levee alignments and each included a 15.2-foot levee with a 50-foot bench and “basic” restoration for all ponds.

5.1.2.3 Recreation

Recreation measures were incorporated into the final array of alternatives consistent with project objectives. These measures included two pedestrian bridges and ancillary recreational facilities such as viewing platforms, benches, and signage.

5.1.2.4 Recommended and Locally Preferred Plan

Alternative 2 (Alviso North levee alignment, 12.5-foot levee height, 50-foot levee bench refugia, basic in-pond preparation, restoration of Ponds A9–A15 and A18) was identified as the NED/NER Plan. Alternative 3 (Alviso North levee alignment, 15.2-foot levee height, 30:1 ecotone, basic in-pond preparation, restoration of Ponds A9–A15 and A18) was identified as the LPP. The key differences between the two plans were the levee heights and the fact that Alternative 3 included the 30:1 ecotone feature instead of a 50-foot bench refugia to provide a more gradual transitional habitat for species to the Bay side of the new levees (USACE, 2015f). Figure 5-3 shows the levee and marsh restoration configuration for the NED/NER Plan (top pane) and LPP Plan (bottom pane).

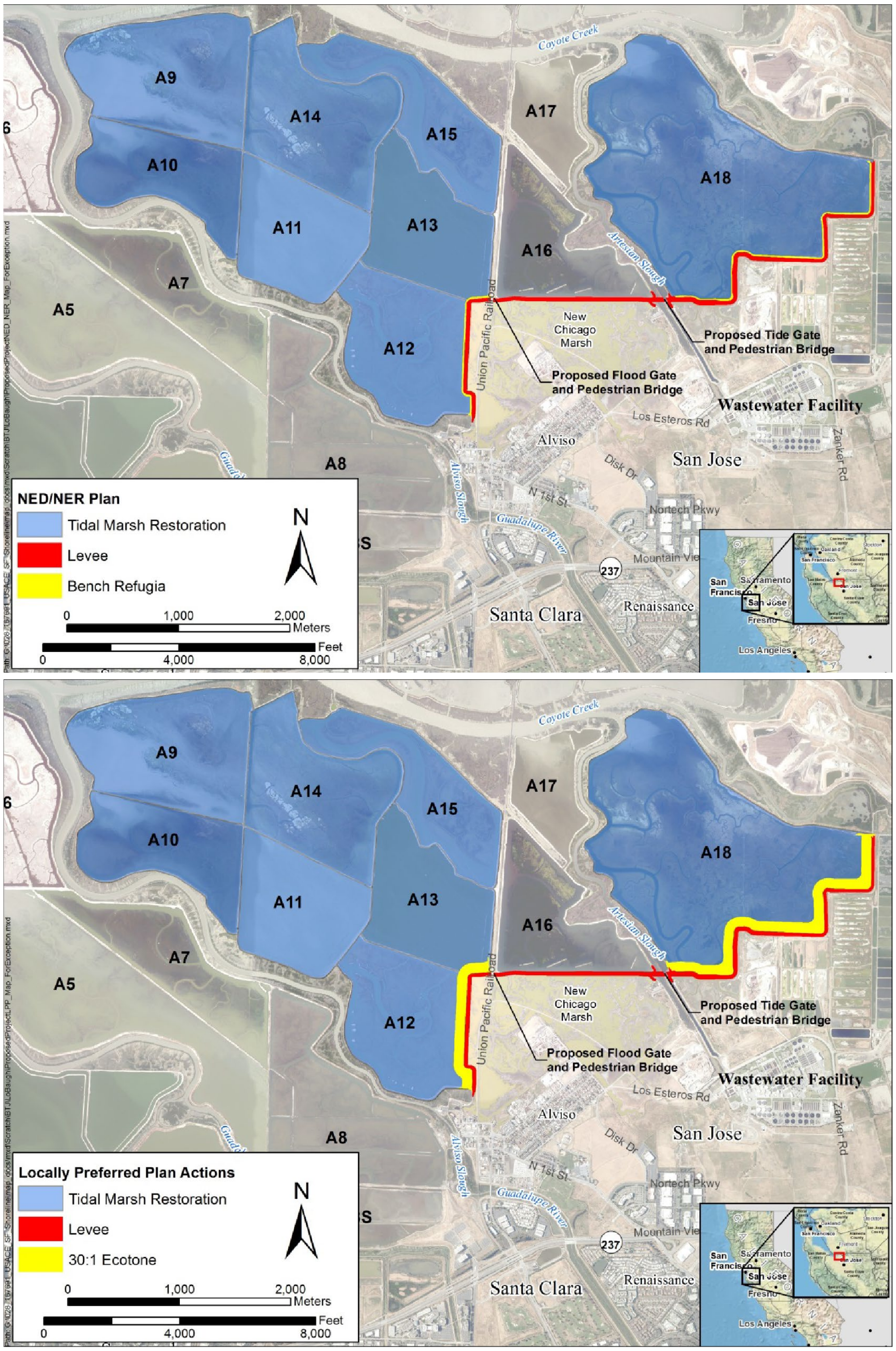


Figure 5-3. National Economic Development/National Ecosystem Restoration Plan and Locally Preferred Plan (USACE, 2015f). Figure shows the spatial levee and marsh restoration configuration for the NED/NER Plan (top) and LPP Plan (bottom).

5.1.3 Consideration of Nature-Based Solutions

The restoration of former commercial salt harvesting ponds to historic tidal marsh conditions were incorporated into all alternatives, with the exception of the FWOA alternative. As a result, all alternatives within the final array included tidal restoration of approximately 2,900 acres across all pond groupings in the study area. Restoration of tidal marsh habitats was a primary ER goal of the project, with the intent to restore ecological structure, function, and connectivity to marsh habitats that have experienced overwhelming loss both within the study area and estuary wide. The Shoreline Phase I Study also makes qualitative note of the resiliency benefits provided by vegetated tidal marsh in front of flood protection infrastructure, including the reduction of wave heights and slowing of tidal surge velocity (USACE, 2015f). However, these resiliency co-benefits are not explicitly explored in the cost-effectiveness evaluation of the ER components of the project (USACE, 2015e).

The project's tidal marsh restoration measures are underpinned by an adaptive management process. This structured and iterative process aims to reduce uncertainty over time via system monitoring. The conversion of salt ponds to tidal wetlands will occur in phases over a period of approximately 13 years (2018–2031), and monitoring and applied studies will support corrective action based on lessons learned to maximize restoration goals. This strategy is consistent with a similar adaptive management approach taken by the SBSP Restoration Project planning effort (USACE, 2015f).

SPN initially considered two in-pond preparation strategies: a "basic" option and an "accelerated" option that would accelerate the restoration process within the ponds (Figure 5-2). However, the "accelerated" option was not included in the final array of alternatives because it was determined to be less cost-effective than the "basic" preparation. The economics analysis acknowledges that the CHAP model used to evaluate ER options did not include acceleration functions and that "the lack of cost-effectiveness was due solely to the inability to obtain required predictions of future habitat conditions for this measure in GIS format under schedule and budget limitations" (USACE, 2015e). However, environmental planners in the project delivery team expected that under real world conditions, accelerating the restoration process would increase annual habitat outputs.

An ecotone with a 30:1 slope, to provide a transitional zone between the levee and the tidal marsh, was included in the LPP, and a longer and more gradual 100:1 ecotone was initially considered as well (Figure 5-2). Naturally rising transition zones in the San Francisco Bay between upland habitats and tidal wetlands have largely been lost or disconnected from marshes (Beagle et al., 2019; USACE, 2015f). Ecotone levees have been promoted by local experts and advocates in the San Francisco Bay as a nature-based sea level change adaptation measure and are included in the SBSP Restoration Project (Lowe et al., 2013; Plane & Iknayan, 2021). The gentle ecotone slope and its elevation and salinity gradients provide high-tide refuge and habitat connectivity for tidal marsh wildlife and allow space for marsh migration upland with sea level change. Ecotone levees provide additional benefits of attenuating waves and reducing levee erosion (Figure 5-4; Figure 5-5; Beagle et al., 2019; Lowe et al., 2013; Plane & Iknayan, 2021; USACE, 2015f).

The Shoreline Phase I Study qualitatively acknowledges the co-benefits of wave attenuation and marsh migration under sea level change conditions that the ecotone may additionally provide. However, these resiliency co-benefits are not explicitly explored in the cost-effectiveness evaluation of the ecosystem restoration components of the project (USACE, 2015e). Additionally, as with the "accelerated" in-pond preparation alternative, the CHAP model does not include functions and calculations to capture transitional habitat benefits provided by the ecotone. Due to these resource constraints, the ecotone did not meet the efficiency criteria and was not included in the federal investment (USACE, 2015f).

While not considered as a potential management measure for this project, local analysis has also evaluated the potential water quality benefits of a "horizontal levee" design in areas of the San Francisco Bay. A "horizontal levee" is an ecotone levee that incorporates subsurface wastewater discharge from an adjacent municipal wastewater treatment plant (Cecchetti et al., 2020; Plane & Iknayan, 2021).

The SPN included barrier islands in the very initial identification of potential management measures, but they were eliminated as they would not meet ER goals and were considered a short-term solution to FRM goals.

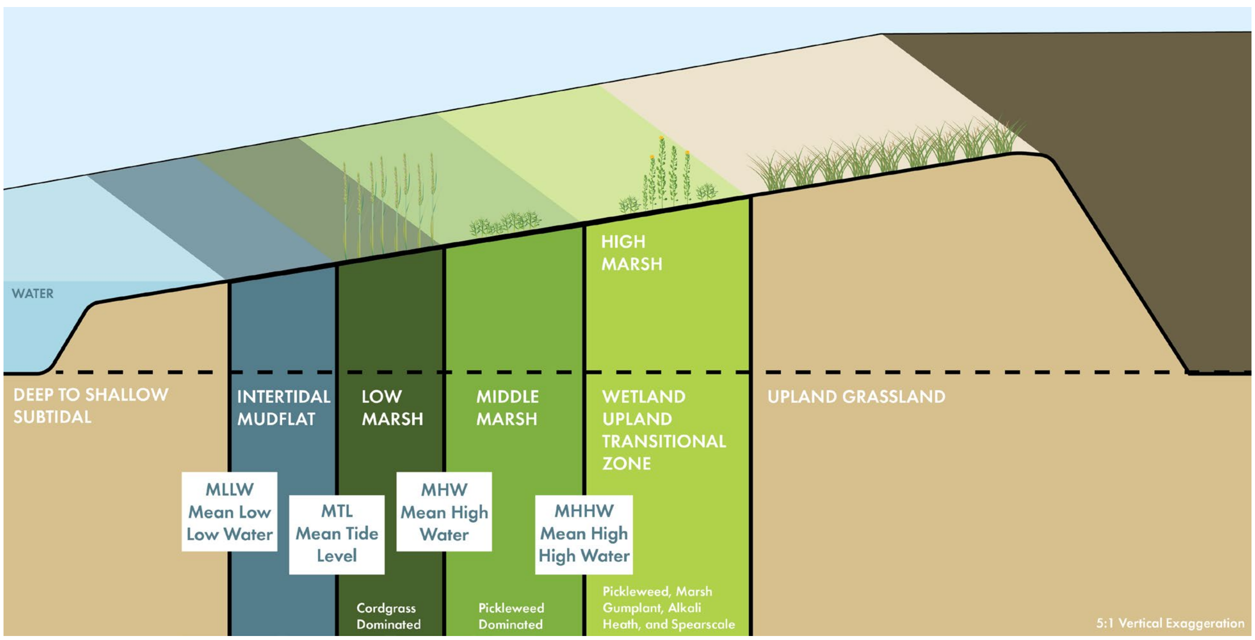


Figure 5-4. Ecotone levee (30:1), year 2020.

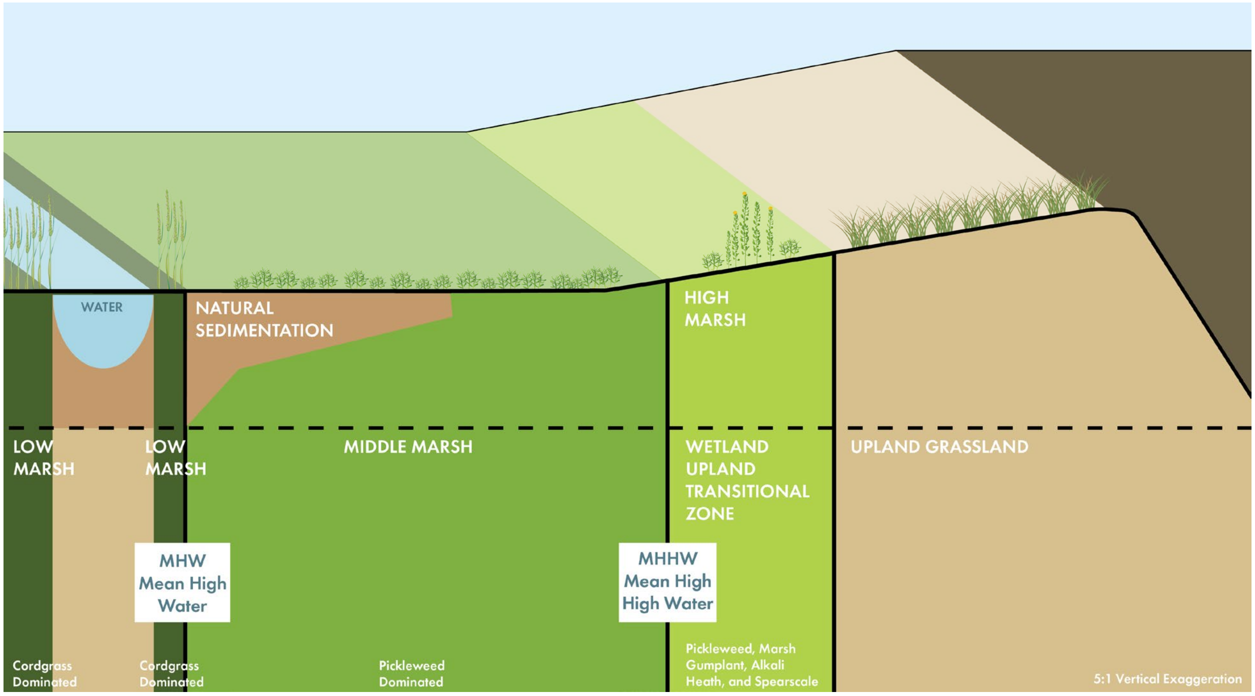


Figure 5-5. Ecotone levee (30:1), year 2067

5.1.4 Outcome of Chief's Report

On December 18, 2015, the Chief submitted the LPP as the RP, with the non-federal sponsors responsible for 100% of costs above the NED/NER Plan. The Chief's Report separates out a summary of costs and benefits for each of the separate accounts (FRM, ER, recreation) provided by the multi-objective project (USACE, 2015c).

The RP is anticipated to reduce annual flood damage from coastal flooding by nearly 100%. Based on a 3.125% discount rate, a 50-year period of analysis, and October 2015 price levels, the annualized FRM benefits were estimated to range from nearly $19 million under the Low SLC scenario to nearly $42 million under the High SLC scenario. The FRM BCRs (accounting only for the FRM levee costs and associated reduced flood damage) were estimated to range between 4.2 to 9.6 depending on SLC scenario.

The average annual ER costs of the RP were estimated to be $3,679,000. This cost was justified by the restoration of approximately 2,900 acres of aquatic habitat, the generation of 48,308 AAHUs, and an increase in habitat for the endemic SMHM and endangered RIRA.

The BCR estimated for recreation measures was 1.14 to 1, based on an anticipated 20% increase in visitation to the Don Edwards National Wildlife Refuge and the creation of key connections in the San Francisco Bay Trail.

In FY2021, USACE updated the overall project cost estimate, and additional efforts were made to secure sufficient funding for all project components. In August 2021, Reaches 1–3 were funded and design work for Reach 4/5 continued (Figure 5-6). Additionally, construction is still ongoing for Reaches 1–3, and the design work for Reaches 4/5, Artesian Slough Closure Structure, UPRR Closure Structure, Pedestrian Bridge, and Ecotone is ongoing (USACE, 2021d).

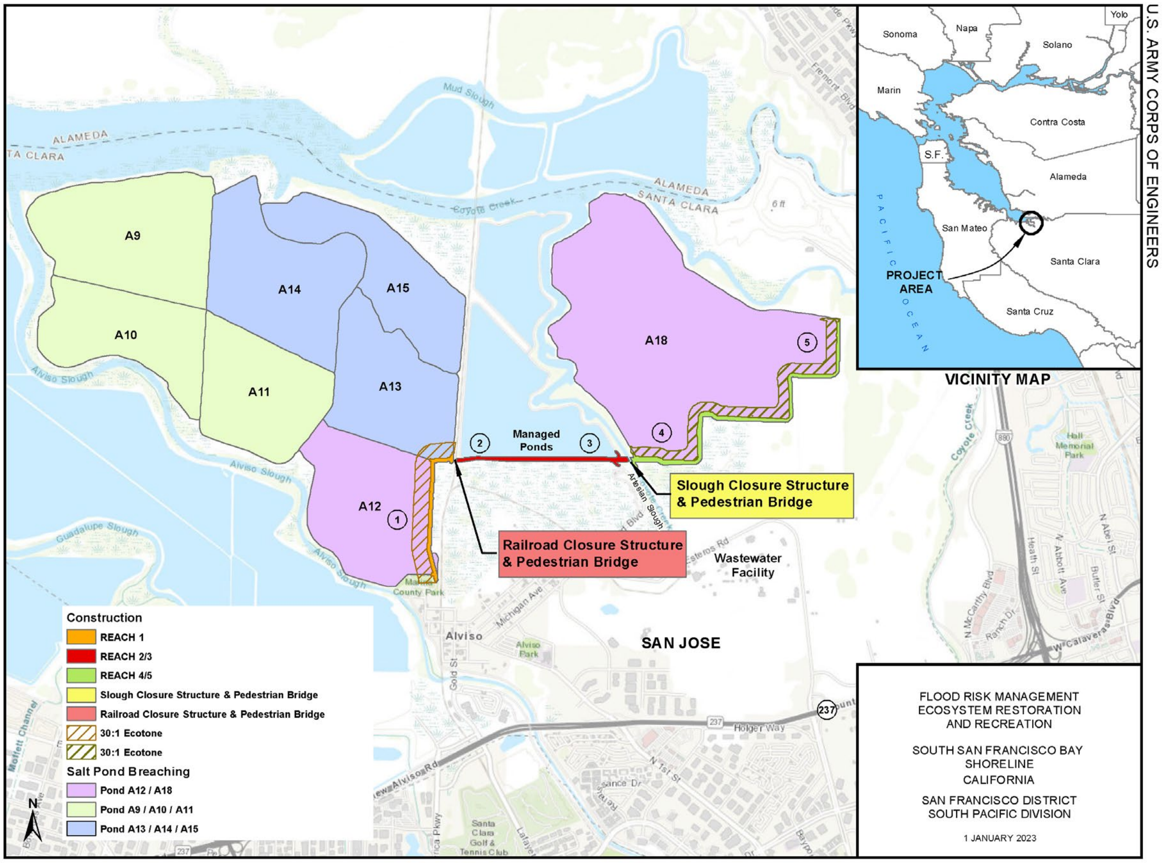


Figure 5-6. South San Francisco Bay Shoreline Phase I Project Map. This map shows the locations of levee reaches, ecotones, and salt pond breaching.

5.1.5 Other Key Considerations

SPN used a Unit Day Value (UDV) method, commonly used in USACE feasibility studies, to value changes in recreational value associated with the recreational improvements as well as the ER components of the project. This method approximates the average willingness to pay of users of recreational resources based on expert judgment. The SPN evaluated UDV across five categories: recreational experience, availability of opportunity, carrying capacity, accessibility, and environment. SPN assigned UDV points in each category to the existing recreational resources, the ER project features without additional recreational features, and to the project with both ER and recreational project features. This method was used to develop the recreational BCR (USACE, 2015e), and is applied elsewhere in this case study reanalysis as tool for counting recreational co-benefits.

5.2 CASE STUDY REANALYSIS: STUDY SCOPE

Two primary NBS were identified in the Feasibility Study for the South San Francisco Bay Shoreline Phase 1 project (USACE, 2015f):

- Restoration of historic tidal marsh habitat in former commercial salt harvesting ponds ("basic" or "accelerated" restoration options); and
- An ecotone built adjacent to the FRM levee (with 30:1 or 100:1 slopes).

Both NBS were included in the RP (the LPP); however, only the tidal marsh restoration was included in the NED/NER Plan.

While a literature review of studies conducted in the region additionally identified a "horizontal" seepage levee utilizing treated freshwater from the adjacent San Jose-Santa Clara Regional Wastewater Facility as potentially feasible at this location (Beagle et al., 2019; Plane & Iknayan, 2021), the study team did not incorporate this NBS feature in the rescoped study because of a lack of sufficient information to support an analysis.

5.3 ALTERNATIVE FORMULATION

The study team considered two alternatives in reviewing the South San Francisco Bay Shoreline project (Table 5-1). These alternatives represent the NED/NER Plan (Alternative 2 in the Feasibility Study) and the LPP (Alternative 3 in the Feasibility Study). Both alternatives include NBS features; however, only the LPP includes the ecotone option. The study team considered including alternatives that incorporated "accelerated" restoration practices as well as a 100:1 ecotone. However, due to limited data, these were not incorporated into the rescoped study, but will be addressed in the discussion. In addition, the team benchmarked the two selected alternatives against a FWOA scenario.

Table 5-1. Selected alternatives considered for analysis.

Feature	NED/NER Plan	Locally Preferred Plan
Future Without Action		
12.5 ft Levee, Alviso North Reach (appx. four miles)	X	
15.2 ft Levee, Alviso North Reach (appx. four miles)		X
Tidal Marsh Restoration in Ponds A9-A15 and A18, "Basic" in-pond preparation	X	X
30:1 Ecotone Transitional Habitat		X
50-ft Bench	X	
Recreational Features (pedestrian bridges, trails, viewing platforms, benches, signage)	X	X

5.4 NON-MONETIZED OUTCOME EVALUATION

The study team identified ecosystem service metrics based on the NBS actions. These included recreational use, non-use benefits associated with habitat restoration and an increase in special-status species, water quality benefits, and resiliency co-benefits and cost savings associated with wave attenuation and reduced levee erosion.

Table 5-2. Ecosystem services and associated benefit-relevant indicators considered in the South San Francisco Bay case study.

Action / approach	Primary metric	Quantifiable (units and method)	Sensitivity of change relative to project	Direct links to beneficial use	Quantification metric of beneficial use	Example of approach to monetize this change	PR&G goal(s)
Tidal Marsh Restoration	Marsh habitat quality, quantity, and connectivity improvement for fauna	Area (Acres)	Approximately 2,900 acres of tidal marsh restored.	Recreation: birding, fishing, walking/biking, viewshed from shoreline	Change in visits to Don Edwards National Wildlife Refuge and number of people using trails; Change in quality of recreational experience	Monetary value of day use recreation	Healthy and Resilient Ecosystems
				Protection of endangered and special-status species	Number and density of special status species	Willingness to pay for protection of special status/endangered species	Healthy and Resilient Ecosystems
	Wave attenuation	Wave height/energy	Limited for this project area. Wave-driven contributions estimated to be small in this part of SF Bay.	Reduced flood risk from levee overtopping	Reduction in annual flood damages	Reduced cost from flood damage	Sustainable Economic Development; Public Safety
	Water Quality Improvement	% Avoided Nitrogen and Phosphorus discharges into San Francisco Bay	Amount of nitrogen and phosphorus removed from marsh area	Recreation: kayaking, fishing: Quality of life	Nitrogen and Phosphorus future removal efficiencies in San Francisco Bay within project area	Benefits-transfer method	Healthy and Resilient Ecosystems; Environmental Justice
30:1 Ecotone Levee	Wave attenuation	Wave height/energy	Limited for this project area. Wave-driven contributions (wind wave and swell) estimated to be small in this part of SF Bay.	Reduced flood risk from levee overtopping	Reduction in annual flood damages; reduced design height of levee	Reduced cost from flood damage; difference in cost of lower height levee with ecotone versus levee without	Sustainable Economic Development
				Reduced erosion of levee	Reduction in maintenance of levee over time	Reduction in O&M Cost over 50-year project lifecycle	Sustainable Economic Development

Action / approach	Primary metric	Quantifiable (units and method)	Sensitivity of change relative to project	Direct links to beneficial use	Quantification metric of beneficial use	Example of approach to monetize this change	PR&G goal(s)
	High tide refugia and habitat connectivity value for marsh species, including special status species	Length (Miles); Area (Acres)	Approximately 4 miles of 30:1 sloped ecotone	Protection of endangered and special-status species	Number and density of special status species	Willingness to pay for protection of special status/endangered species	Healthy and Resilient Ecosystems; Watershed Goals
	Space for marsh migration to higher elevations with SLC	Maintenance and extension of benefits of tidal marsh over time with SLC	Provides upland habitat for marsh migration along 4 miles of the Bay. High rates of sediment accretion in the study area may suggest tidal marshes in the study area will keep up with SLR through sediment capture over the next 60 years. However, given the accelerated rate of SLR anticipated later in the century, a transition zone for marsh migration may help to maintain the benefits of the tidal marsh beyond the study period.	*See tidal marsh restoration benefits	*See tidal marsh restoration benefits	*See tidal marsh restoration benefits	Healthy and Resilient Ecosystems; Watershed Goals

Action / approach	Primary metric	Quantifiable (units and method)	Sensitivity of change relative to project	Direct links to beneficial use	Quantification metric of beneficial use	Example of approach to monetize this change	PR&G goal(s)
Recreational Features (pedestrian bridges, walking/biking trails, viewing platforms, benches, signage)	Quality of recreational improvement	Number and quality of recreational features	Existing resources include 21 miles of trails that are located in and around the Don Edwards San Francisco Bay National Wildlife Refuge and are part of a larger regional Bay Trail. Approximately 150,000 visitors per year use the trail in the study area. Anticipate increase in visitors of 20% with project improvements.	Recreation: birding, fishing, walking/biking, viewshed from shoreline, environmental education	Change in visits to Don Edwards National Wildlife Refuge and number of people using trails; Change in quality of recreational experience	Monetary value of day use recreation	Healthy and Resilient Ecosystems; Environmental Justice

5.4.1 Biophysical Outcomes

Both alternatives considered in this case study produce positive biophysical outcomes for the South San Francisco Bay ecosystem and adjacent communities when benchmarked against the FWOA.

Both alternatives significantly reduce risk of tidal flooding in the study area over the period of analysis under all SLC scenarios (Low, Intermediate, and High) compared to the FWOA. The expected annual damage in 2017 is at or near zero for both alternatives and very low in 2067 under the Low and Intermediate SLC scenarios. However, under the high SLC scenario, the 12.5-foot levee in the NED/NER Plan has greater residual risk than the 15.2-foot levee in the LPP in later years in the period of analysis (USACE, 2015e). In addition to flood risk reduction benefits provided by the levee, the vegetated marsh features in both alternatives and the ecotone in the LPP provide additional lines of defense against tidal flooding by attenuating waves and reducing erosion of the levee.

Both alternatives result in the creation of approximately 2,900 acres of tidal marsh. There is strong support among residents of the Bay Area for the protection and restoration of the San Francisco Bay, evidenced by Bay Area voters passing a ballot initiative by a 69% vote in 2016 to create a $500 million fund to invest in regional restoration efforts in the Bay over a 20-year period (Sommer, 2016). The tidal marsh of the San Francisco Bay provides critical habitat for special-status species endemic to California such as the RIRA and the SMHM. The approximately 90% loss of historic tidal marsh area has threatened these species that reside in this habitat (USACE, 2015f). The restoration of tidal marsh would support conservation efforts for special-status species.

The 30:1 ecotone in the LPP provides a transitional habitat zone, allowing for high tide refugia and habitat connectivity for tidal marsh species. The ecotone may also support marsh migration under SLC scenarios. Sea level rise can threaten restoration efforts over time by drowning restored marshes (Lowe et al., 2013). Upland transitional habitats allow for the transgression of tidal marsh to higher elevations as sea levels rise. This adaptive measure enables the benefits associated with tidal marsh features to extend for a longer period of time.

Both alternatives also provide increased recreational access and quality in the study area, due to the improved experience and connectivity provided by the recreational features and improved aesthetic quality associated with the restored tidal marsh. However, without the recreational features, the FRM and ER project components were estimated to have an overall adverse effect on recreation due to the removal of 7.4 miles of an existing 11-mile loop trail that is located on top of the existing dike structures surrounding the ponds that will need to be breached to support the tidal marsh restoration. The addition of pedestrian bridges and other trail connections in the recreational features of both alternatives offset the anticipated losses in visitors to the trails per year and provide additional linkages to the regional Bay Trail as well as improved environmental aesthetic quality (USACE, 2015e).

Potential water quality improvements provided by vegetated tidal marsh were not deliberately measured in the Feasibility Study, but the impacts of wetlands on water quality have been studied in other parts of San Francisco Bay and adjacent areas like San Pablo Bay. According to a 2019 study in McInnis Marsh (located in Marin County, CA) that utilizes research from a study measuring nutrient removal by wetlands from river water, "coastal wetlands scavenge nitrogen and phosphorus from freshwater inputs (notably urban stormwater), reducing primary biological productivity and risks of eutrophication in receiving waters" (Jing et al. 2001).

5.4.2 Benefit-Relevant Indicators

5.4.2.1 Flood Risk Reduction

USACE SPN estimated reduced flood damages using the HEC-FDA model to combine water surface profile data and economic data to derive a stage-damage function for each impacted area under Low, Intermediate, and High SLC scenarios for the FWOA and each alternative levee height. Major inputs included water surface profile, levee failure function, interior-exterior flood elevation relationship, value and location of assets in the floodplain, and the relationship between depth of flooding and structure and content damage (USACE, 2015e).

5.4.2.2 Wave Attenuation

The study team explored ways to capture the attenuation of wave energy provided by the vegetated tidal marsh and ecotone and its associated reduction in wave height and erosive force (Lowe et al., 2013). The Feasibility Study did not include modeling of wind-waves and the impacts of the ecotone on attenuation, however, so the study team determined there is currently not enough data to support this analysis. Additionally, the Hydrology and Hydraulics report included fetch-limited wave growth analysis[21] and concluded that wave-driven contributions are minimal along this section of the San Francisco Bay shoreline (USACE, 2015b). This suggests that for this study area, the ER features of each alternative may not provide significant additional reductions in flood damage to those provided by the levee alternatives.

5.4.2.3 Habitat for Special Status Species

The study team explored ways to capture the unique habitat benefits provided by the restored tidal marsh by focusing on the protection and conservation of special-status species. The RIRA is listed as an endangered species, and it resides almost solely in the marshes of the San Francisco Bay. A review of local literature suggests it is a good indicator or "umbrella" species for other elements of marsh-dependent biodiversity and overall habitat health and biodiversity (Calder et al., 2019; Guerry et al., 2022).

The study team incorporated analysis from Guerry et al. of the estimated RIRA habitat area provided by restored tidal marsh. This study used a simple linear regression to define the relationship between tidal marsh habitat and RIRA distribution to approximate how marsh area might translate to RIRA habitat under future scenarios (Guerry et al., 2022). This linear regression is calculated using the following equation:

$$RIRA\ area\ =\ -0.0745 +\ 0.80805 * marsh\ area$$

---

[21] Wave analyses are a series of calculations which consider the unimpeded length over which wind can blow (fetch) and the slope and depth of the seafloor in order to predict wave behavior, such as shoaling and breaking. Wave growth is limited either by fetch or by depth.

Based on this equation the study estimated that the 2,900 acres of tidal marsh restored in both scenarios would result in approximately 2,343 acres of RIRA habitat. More detailed modeling would be required to capture habitat quality and connectivity provided by the restored marsh and the transitional habitat of the ecotone.

5.4.2.4 Recreation

The study team incorporated the UDV analysis from the feasibility study into an integrated BCA. After assigning point values to the five criteria (recreation experience, availability of opportunity, carrying capacity, accessibility, and environmental), the total annual recreation value of the project area increased from $1,142,100 (under baseline condition) to $1,220,768. The annual total recreation benefit (with both NED/NER in place) was $290,630.

5.4.2.5 Water Quality

The study team considered the utility of a method that could measure water quality improvements in South San Francisco Bay through a removal efficiencies measure (percentage of loading taken out by wetland). This method would rely on direct transfer for value distributions and local data regarding incoming concentrations of nitrogen and phosphorus per liter of inflow into South San Francisco Bay (Calder et al., 2019). Though the inflow data needed to apply this method was publicly available through USGS, a significant number of assumptions would have had to be made. It was determined (through expert opinion) that any potential water quality benefits identified using this method would not be significant enough to impact the BCR for this project in any substantial way.

5.4.2.6 Marsh Migration with Sea Level Change

Because of high observed sediment accretion rates in this part of the San Francisco Bay, SLC is not expected to cause significant loss of tidal marsh within the study area before the end of the evaluation period in 2067 (USACE, 2015b). However, SLR may accelerate to higher rates in subsequent decades, particularly under the High SLC scenario. Local research on tidal marsh sustainability in the face of SLR in the San Francisco Bay found that under a high SLR scenario (1.65 m/century), mid marsh habitat restoration in areas of very high sediment concentrations (250–300 mg/L) could only be sustained for an 80-year time period (Stralberg, 2011). One of the benefits of an ecotone levee is that it provides room for marshes to migrate upland with SLR (Beagle et al., 2019). The ecotone feature in the LPP may extend the life and benefits of the tidal marsh restoration over a longer period than the NED/NER. However, these additional benefits may not be realized until after the 50-year period of performance.

5.4.3 Additional Quantitative or Qualitative Outcomes of Interest

5.4.3.1 Economic

The study team considered including an alternative with an ecotone at a lower levee height than the highly protective 15.2 feet to explore the potential added protection and associated lower levee construction costs. The study team also explored the potential of capturing lower O&M costs over time to the levee due to reduced erosion with the ecotone. However, limited data and limited wave-driven contributions in the study area provided challenges to this approach.

5.4.3.2 Environmental

The upland-estuarine transition zone between wetland and upland habitats is critical to tidal marsh biodiversity and provides high-tide refugia for special-status species like the SMHM and RIRA. It is also a habitat type that has largely disappeared from the San Francisco Bay (Lowe et al., 2013). The ecotone levee alternative restores this habitat type that provides additional regional ecosystem benefits. However, the study team was limited in methods to capture additional benefits of habitat quality and connectivity provided by the ecotone.

Additionally, the study team explored opportunities to quantify marsh restoration benefits accrued sooner with the “accelerated” restoration measures. However, there was not enough data to support this analysis.

The study team also considered measuring Land Use Land Cover (LULC) change and calculating costs and benefits through a benefit-transfer method. Lack of information about the values associated with salt ponds meant that the study team would have had to use a habitat “equivalent” to salt ponds, with no ready substitute in the literature. The study team agreed that the process of using a habitat equivalent would be arbitrary and could compromise the integrity of a benefits-transfer. The study team decided not to move forward with the method for this case study.

5.4.3.3 Social

The study area includes the community of Alviso, which is located adjacent to South San Francisco Bay at 13 feet below sea level and has historically been impacted by riverine flooding. According to the Feasibility Study, Alviso’s residents are “mostly low-income, minority individuals and families” (USACE, 2015e). When compared to the rest of the county, the state of California, and neighboring counties, the local census area maintains a lower median household income, higher rates of unemployment, and a higher percentage of the population at or below poverty level (Table 5-3).

Table 5-3. Comparison of selected economic indicators.

Category	Local Census area*	Santa Clara County	Alameda County	San Mateo County	California
Median Household Income	$52,202	$86,850	$69,384	$85,648	$60,883
Unemployment Rate	12.4%	8.2%	8.9%	6.8%	10.5%
Percentage of Population at or Below Poverty Level	15.6%	8.9%	11.4%	7.0%	13.7%

*Sources: State/County: 2010 Census, State of California. Alviso: US Census, American Community Survey. *Census Tract 5046.02*

The project captures FRR benefits to Alviso as well as recreational benefits, but the demographic characteristics of the area show that there is an opportunity to expand upon the analysis with a focus on equity and environmental justice in follow-on research to this effort.

5.5 MONETIZED VALUATION

5.5.1 Valuation Methods and Key Assumptions

No additional benefits and costs were calculated in this case study given the limitations noted in previous sections. However, the case study team developed an additional set of BCRs that unified the separate accounting of FRM, NER, and recreation costs and benefits into overall project costs and benefits. Because no NER benefits were calculated, the overall project benefit was the sum of FRM benefit and recreation benefit, while the overall project cost was the sum of FRM, NER, and recreation costs.

5.5.2 Updated Benefits

Benefits were not updated for this analysis.

5.5.3 Updated Costs

Costs were not updated for this analysis.

5.5.4 Benefit-Cost Comparisons

5.5.4.1 Planning Analysis

A summary of the combined BCRs can be found in Table 5-4. For both the NED Plan and the LPP, regardless of the SLC scenario applied, the unified account BCR is well above 1.0, indicating that the combined benefits outweigh the combined costs. Under the most extreme SLC scenario, the benefits can be up to 7.46 times the cost. This is especially noteworthy as the unified accounts analysis includes all of the costs but no benefits for the NER portion of the plan.

Table 5-4. Updated planning analysis benefit cost ratios.

SLC scenario	BCR calculated for NED FRM Plan (2015)	BCR for unified accounts (NED FRM, NER, & Recreation)	BCR calculated for Locally Preferred FRM Plan (2015)	BCR for unified accounts (LPP FRM, NER, & Recreation)
Low	4.97	3.52	4.22	2.29
Intermediate	6.18	4.37	5.26	2.85
High	10.62	7.46	9.40	5.06

The LPP's lower BCR reflects that several of its benefits relative to the NED Plan were not monetized. It is worth considering how high these additional uncalculated benefits from the unified accounts LPP plan would need to be to yield a higher BCR than the unified accounts NED Plan. Under the Low SLC scenario, an additional $10 million in uncalculated annual benefits under the LPP would be enough to increase the unified accounts BCR above the NED Plan. This number rises to $12 million and $20 million for the Intermediate and High SLC scenarios, respectively.

5.5.4.2 OMB Process Analysis

Information on the combined BCRs is provided in Table 5-5. For both the NED Plan and the LPP, the combined BCR is above 1.0 for all SLC levels, though to a lesser extent than the planning analysis due to the higher discount rate. The additional benefits that would need to be provided by the LPP plan to have a higher BCR than the NED Plan are slightly higher under the OMB discount rate but are of approximately the same order of magnitude: $11, $14, and $22 million for the Low, Intermediate, and High SLC scenarios, respectively.

Table 5-5. Updated Office of Management and Budget analysis benefit cost ratios.

SLC Scenario	BCR calculated for NED Plan (2015)	OMB BCR for unified accounts (NED, NER, & Recreation)	OMB BCR calculated for Locally Preferred Plan (2015)	OMB BCR for unified Accounts (LPP, NER, & Recreation)
Low	2.90	1.96	2.44	1.23
Intermediate	3.61	2.43	3.04	1.52
High	6.20	4.15	5.43	2.72

After unifying the three separate accounts (LPP, NER, and Recreation), the study team concluded that adding in the NER and Recreation costs into the LPP BCA lowered the BCR, but the benefits still outweigh the costs for this project across all scenarios and discount rates considered.

5.6 PRIORITIZATION AND ALTERNATIVE SELECTION

The project team was unable to monetize many of the benefits described above using available data. Additional modeling studies or analysis would be required to project the likely outcomes and assign a monetary value to the benefits of wave attenuation, habitat for special status species, water quality, marsh migration, and LULC change. However, these factors can be considered as part of MODA using a simple relative ranking system (Table 5-6.).

This ranking system includes the four goals articulated by the USACE Planning Study and adds the additional goals of improving water quality and supporting the adaptation and resilience of the shoreline and ecosystem under potential SLC scenarios. For each project goal, the alternatives of the FWOA, NED/NER Plan, and the LPP are assigned a ranking score of -2 (very negative impact) to +2 (very positive benefit) based on the analysis of data available.

For the goals of “Reduce risks to public health, safety, and the environment caused by tidal flooding” and “Reduce potential economic damages from tidal flooding” the FWOA is assigned a score of -2 because of the significant risk of no action combined with SLR. The total equivalent annual damage for the 50-year period of analysis is $18.2M under the Low SLC scenario and $40.2M under the High SLC scenario based on the USACE Planning Study. The NED/NER Plan, which includes a 12.5’ levee and restored tidal marsh, is given a 1 because of the significant reduction in flood risk. The expected annual damage at 2017 is near zero. However, there is significant residual risk under the High SLC scenario in year 2067. The LPP with the 15.2’ levee and a 30:1 ecotone is given a score of 2 because of the low likelihood of the levee being overtopped over the period of analysis, even under the High SLC scenario, and the additional wave attenuation benefits provided by the ecotone.

For the goal of "Restore ecological function and habitat quantity, quality, and connectivity for native plant and animal species, including special-status species," the FWOA scenario is assigned a score of -1 because of some anticipated further degradation of existing habitat under SLR scenarios, particularly for special-status species. The NED/NER Plan is assigned a score of 1 because of the benefits anticipated from the 2,900 acres of restored tidal marsh, including 2,343 acres of RIRA habitat created. The LPP is assigned a 2 because of the additional benefits of high tide refugia and habitat connectivity provided by the ecotone transitional habitat.

For the goal of "Improve public access, education, and recreation," all alternatives were scored positively. The existing condition of the project study area is part of the Don Edwards San Francisco Bay National Wildlife Refuge, includes a visitor and education center, and approximately 21 miles of trails that are part of the larger regional Bay Trail. Given these existing recreational resources, the FWOA was given a score of 1. Both the NED/NER Plan and the LPP include additional recreational features as well as improved recreational quality associated with the restored tidal marsh. Both alternatives were given a score of 2.

For improving water quality, the FWOA alternative was assigned a score of 0 and the NED/NER Plan and the LPP plan were given a 1 for anticipated water quality improvements provided by the tidal marsh.

For supporting the adaptation and resilience of the shoreline and ecosystem under potential SLR scenarios, the FWOA was given a score of -2 because of the vulnerability of the existing shoreline and ecosystem to even moderate SLR scenarios. The NED/NER Plan was assigned a score of 1 given its anticipated ability to keep up with even the High SLC scenario through the 50-year period of performance. The LPP was assigned a score of 2 because of the higher levee heigh and ecotone supporting adaptation under SLR scenarios extending beyond the 50-year period of performance.

Based on this simple ranking method, the LPP ranks highest across all project objectives. However, the LPP also has the highest project construction cost (and thus, is assigned a score of -1 for that criteria). A central tradeoff within this case study is whether the added project costs outweigh the benefits associated with the ecotone and the higher levee height.

Table 5-6. Stoplight chart comparison of alternatives for key project goals and metrics.

	FWOA	NED/NER Plan	LPP
Reduce risks to public health, safety, and the environment caused by tidal flooding	-2	1	2
Reduce potential economic damages from tidal flooding	-2	1	2
Restore ecological function and habitat quantity, quality, and connectivity for native plant and animal species, including special-status species	-1	1	2
Improve public access, education, and recreation	1	2	2
Improve water quality	0	1	1
Support adaptation and resilience of the shoreline and ecosystem under potential SLR scenarios	-2	1	2
Project Construction Cost	2	0	-1

5.7 DISCUSSION

While conducting research for the South San Francisco Bay Shoreline Phase I case study, the study team recognized this effort as one of the strongest examples of a multi-objective planning study with NBS and determined that several components of this case study were both transferrable and generally a defensible model for future USACE studies.

The study team developed several recommendations to improve data collection and modeling for this case study (and perhaps other future case studies with similar limitations), but also agreed that the plan formulation process was thoughtful and transparent, and the USACE District articulated very clear FRM, ER, and Recreation goals up front.

The study team chose to unify the three accounts (FRM, ER, and Recreation) to capture the multi-objective project and benefits from project features across multiple objectives. All alternatives meet a cost reasonableness threshold simply by doing this, and this could be easily replicated across other multi-objective studies.

The South San Francisco Bay Shoreline Phase I Case Study highlights important potential non-use benefits of ecosystem restoration as well as the challenges with valuing these benefits. This may be an area for additional research, modeling, and data collection standards.

For example, the study team consulted several ecosystem service-related studies and considered whether the methods used would be transferrable to the South San Francisco Bay Shoreline Phase I case study and others like it. Based on work done in a contingent choice coastal preservation study that asked survey respondents to evaluate the attributes for two parcels of coastal land that were hypothetically available for preservation (McGonagle & Swallow, 2005), the study team identified that there was likely a willingness to pay for habitat restoration for endangered species or historic landscape conditions among residents in areas around South San Francisco Bay. However, from a contingent valuation/resident perspective, it was difficult to transfer willingness to pay numbers because of the method in which USACE considered species within the CHAP model.

In the literature, there are different anticipated distributions for the species that residents care about, and the study team did not have enough information to support a standard meta-analysis. To apply the contingent choice valuation method to the South San Francisco Bay Shoreline Phase I planning process, the modeling would have needed to include actual or estimated values for specific desirable or special status species rather than just Habitat Units, which are calculated by assessing the condition and function by incorporating multiple species, habitat components and functions into the analysis. The CHAP model used in the South San Francisco Bay Shoreline Phase I study places a higher value on local habitat conditions that result in more species being present, and all species are treated equally (USACE, 2015d).

Within existing ecosystem restoration models as well as the ecosystem service valuation literature, there are limitations in fully valuing system-wide benefits, such as habitat connectivity of certain important habitat types, such as the transitional habitat provided by the ecotone. Research on the benefits of habitat connectivity and habitat density may support a more robust evaluation.

Another area for additional research and modeling is assessing the FRM benefits of ecosystem restoration. The study team explored the possibility of assessing wave attenuation benefits of the tidal marsh and ecotone. Because the flood risk modeling did not incorporate the added benefits of NBS, the team was unable to assess any potential wave attenuation benefits.

This case study also highlights the limitations of a 50-year period of performance and suggests that a longer period of performance may be preferable for projects that include NBS and/or where the objectives of local sponsors and stakeholders extend beyond that timeframe. Restoration projects such as this one may take several decades to fully establish but may provide benefits well beyond a 50-year period of performance. For example, the ecotone levee in the South San Francisco Bay Shoreline Phase I case study could potentially provide space for marsh migration with sea level rise and prolong the lifespan of the levee, but benefits might not be seen until after the 50-year period of analysis.

Central to this case study is the trade-off between the added project cost and the associated FRM and ER benefits of the ecotone levee, as well as the accelerated restoration methods. Both of these enhanced NBS features proved difficult to fully value in monetary terms. However, the project easily reaches a cost-effectiveness threshold even with the added ecotone. Especially in situations where the known benefits of NBS features are difficult to value, economic efficiency may not be the most appropriate driving criteria for selecting one alternative over another. The ranking and simple tradeoff analysis applied by the study team provides another simple method for USACE to consider in evaluating alternatives.

6.0 WEST SACRAMENTO

6.1 OVERVIEW

West Sacramento is located in California's Central Valley, has a Mediterranean climate, and is surrounded by water during winter months. As such, the area is dependent on levees for the protection of residents and infrastructure (USACE, 2014b). Sacramento is located towards the south (downstream) of the 26,300 square mile Sacramento River Watershed. As a result, this area is prone to flooding, and experienced 10 major floods during the 20th century alone. If a major levee failure was to occur, the flooding through West Sacramento could reach depths of 20 feet (USACE, 2016d). Currently, over 50,000 people live in West Sacramento, and the area has seen rapid expansion in population with associated residences and services since 2000. This has dramatically increased the consequences of levee failure and resulting flooding. The area includes 13,000 acres of mixed-use land divided by the Sacramento River Deep Water Ship Channel (DWSC) and Barge Canal in the north and south of West Sacramento (Figure 6-1; USACE, 2016b).

The original levees were built to surround West Sacramento in the early 1900s as part of initial system-wide flood management with a focus on protecting lives and property by increasing movement of floodwaters through the system. The aim of increasing river velocity was to maximize flushing; this process had the consequence of constraining river alignment and increasing isolation of the river from the historic floodplain (USACE, 2014b). After the authorization of the 1917 Sacramento River Flood Control Act, the Sacramento River Flood Control Project provided further protection and included water bypass structures to initiate reconnection of the river to the flood plain and greatly reduced the number of levee breaches (USACE, 2016d).

The levees built through the early 1900s are now outdated and experience seepage, instability, and erosion (USACE, 2016d). The greatest flood risks in West Sacramento, as reported by USACE and the State of California, are levee failures, through-seepage, under-seepage, and stability concerns. Due to the levees being built so close to the river with little room for expanded flow and the urban setting, many of the levees are also threatened by development encroachment. For the same reason, they are threatened by vegetation growth and have poor access for emergency response and management personnel and vehicles during flood events or even for regular maintenance (USACE, 2016d).

To address these challenges, USACE was authorized to conduct the West Sacramento General Reevaluation Report, completed in 2016, designed to improve, strengthen, or raise levees and replace or rebuild levees where needed. One proposed action included rebuilding a section of levee on the Sacramento River as a setback levee and another to widen the Sacramento Wildlife Bypass to the north of West Sacramento. The study also considered actions to widen river bypass structures or use setback levees to continue making room for the river to expand during flood events, in addition to providing protection through improved levee barriers (Figure 6-2).

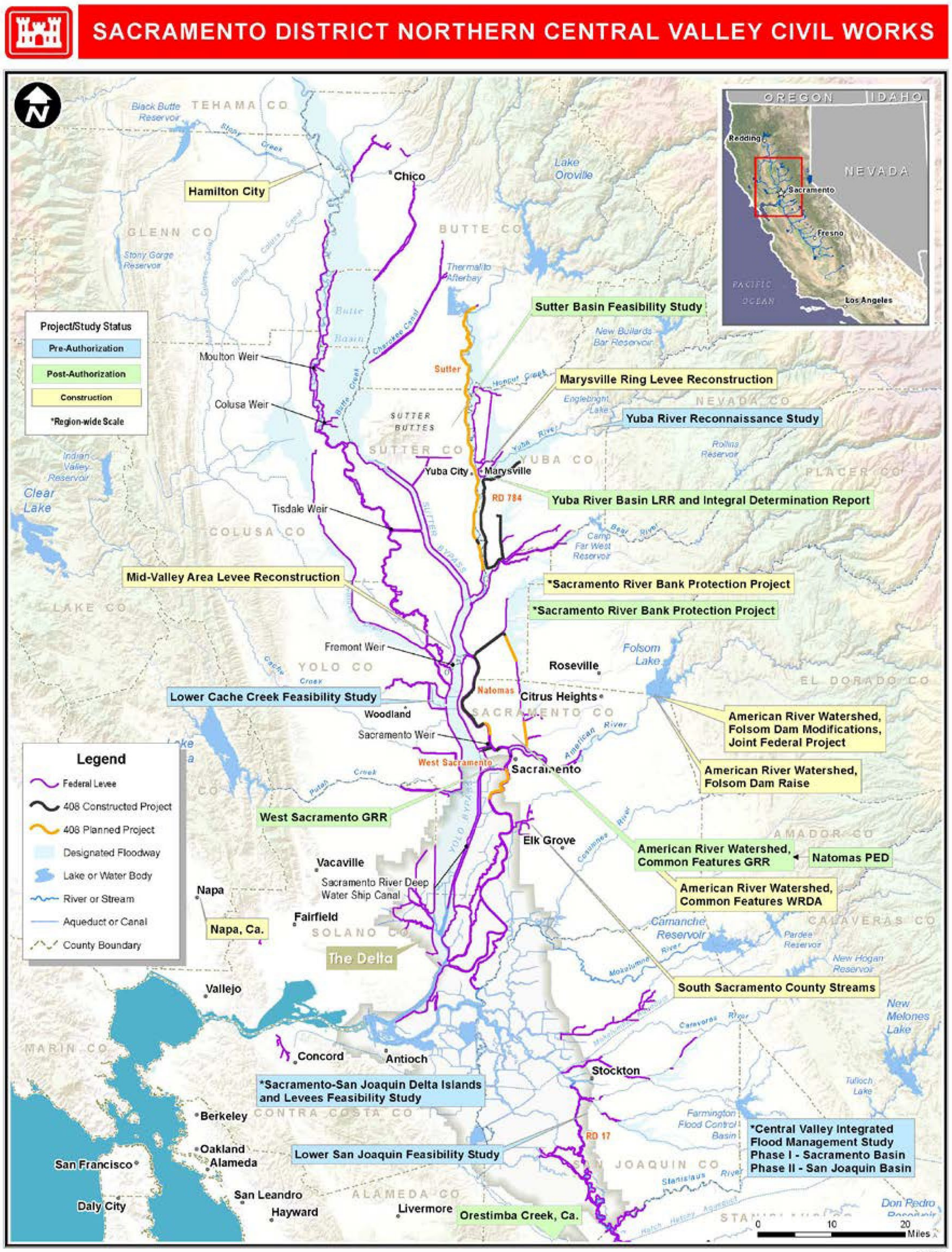


Figure 6-1. Map of Sacramento River Watershed and Civil Works Projects.

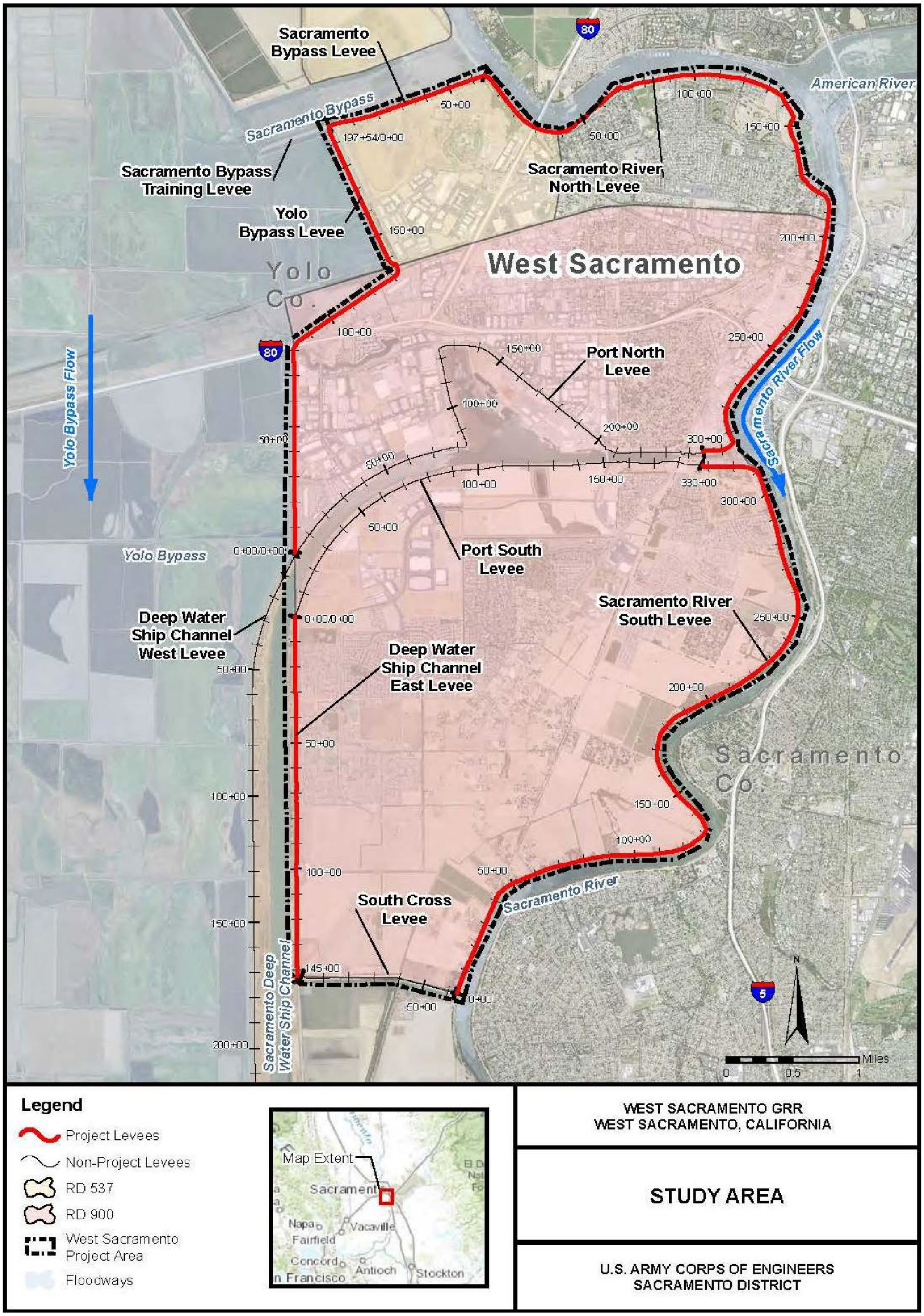


Figure 6-2. West Sacramento project area.

6.1.1 Project Goals

The goals for this project were to:

- Reduce the risk of flooding in West Sacramento
- Reduce the impacts to critical infrastructure in West Sacramento
- Encourage wise use of the floodplain
- Educate the public about ongoing residual flood risk (USACE, 2016d)

The primary focus and most important needs were to reduce the number of people at risk of flooding and to reduce the cost of expected annual flood damage.

6.1.2 Alternative Formulation Process

An initial evaluation of the 37 management measures (a feature of activity at a site) formulated for this study was conducted by the Sacramento District, and measures were assessed based on how well they met the project objectives. This included eight measures intended to reduce flood stage, six to reduce levee seepage and under-seepage, four to address levee stability, six to address levee overtopping, three to address erosion and 11 nonstructural measures (Table 6-1; USACE, 2016b). Overall, 36 and 37 of the proposed measures addressed the objectives of reducing flood risk and reducing risk to critical infrastructure, respectively, while 12 addressed the objective to encourage wise use of the floodplain and three addressed the objective to educate the public (Table 6-1).

Table 6-1. Proposed measures (features or activities) categorized by benefits and objectives addressed (USACE, 2016d).

	Objective			
Categories of measures (a feature or activity)	**Reduce the risk of flooding**	**Reduce risk to critical infrastructure**	**Encourage wise use of floodplain**	**Educate the public about ongoing risk**
Measures to reduce flood stage	8	7	-	-
Measures to reduce levee seepage and under-seepage	6	6	1	-
Measures to address levee stability	4	4	1	-
Measures to address levee overtopping	6	6	1	-
Measures to address erosion	3	3	-	-
Nonstructural measures	9	11	9	3
Totals	**36**	**37**	**12**	**3**

A preliminary screening, based on recent construction and best professional judgement, was carried out prior to combining measures into alternatives. The screening criteria included the number of acres of waterside vegetation and habitat for listed species affected, number of residential relocations, cost of real estate impacted, number of project objectives addressed, cost effectiveness, expected reduction in annual flood damages, and qualitative assessment of safety to residents (USACE, 2016d). Generally, the rationale for dropping measures was due to the relatively small scale of benefits. For example, if the measure did not have sufficient reduction of stage height to preclude actions downstream, it was likely to be dropped. Floodwalls were considered to either be too costly and/or likely to be unacceptable to the public.

For the nonstructural measures, permanent relocation was too costly and raising or flood proofing existing structures considered impractical or impossible, especially considering much of the area potentially has flood depths greater than 10 feet (USACE, 2016d). One important note was that an attempt was made to assess potential environmental impacts through costing of appropriate mitigation for different measures. However, due to the difficulty of costing some appropriate mitigation actions, the degree of impact was ultimately reported as a qualitative estimate of high, medium, or low impact to the ecosystem (USACE, 2016d).

The retained actions were combined to construct a series of preliminary alternatives, with actions across multiple river reaches, that would comprehensively reduce flood risk (Table 6-1). Thirteen alternatives were developed, and the District conducted a preliminary analysis to calculate preliminary BCRs for 12 of these alternatives. Alternative 9 was a fully nonstructural alternative and was not carried forward because, while being cost effective, it did not meet three of the four primary objectives, and was not considered implementable in terms of acceptability to politicians and the public (USACE, 2016d).

After removal of the nonstructural plan, Alternative 0.5 A and 0.5 B were removed as they each only addressed flood risk in either the north or south sections of West Sacramento. Most other alternatives provided roughly the same level of protection and equally addressed the flood reduction evaluation criteria. The exception was Alternative 5 which included the Sacramento River Reach setback levee, not only encouraging wise use of the floodplains (an additional project objective) but additionally reducing the overall environmental impact through creation of grassland and wetland, as well as providing a potential location for mitigation actions. Alternatives 1, 3, and 5 were carried forward to the final array of alternatives for further evaluation and comparison (Figure 6-3).

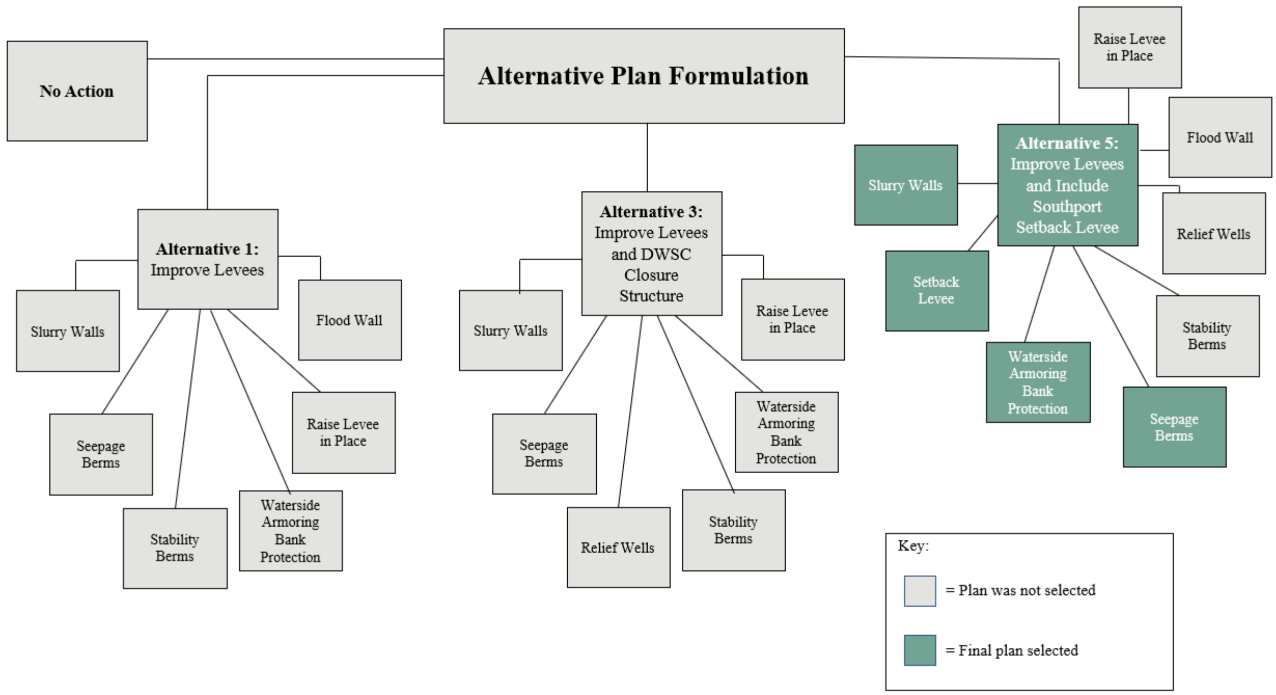


Figure 6-3. Alternative formulation and selection process (DWSC – Deep Water Ship Channel)

6.1.3 Consideration of Nature-Based Solutions

Two measures were included in the initial list that can be considered as NBS. These were a widening of the of the Sacramento Weir and Bypass, north of West Sacramento and the replacing of the levee along the Sacramento River South reach with a new levee constructed further inland, called a setback levee. The other actions, including building of slurry/cutoff walls, seepage berms, stability berms, or relief wells, were expected to have little or no impact upon the ecosystem or habitats of West Sacramento and surrounding waterways. However, many of the river reaches included proposed improvements by raising the levee in place with an associated widening of those levees and a resultant burial (i.e., loss) of grassland, wetland, or agricultural land.

Much of the evaluation of ecosystem benefits of different plans in this re-assessment is based upon minimizing the loss of ecosystem benefits where raising levees in pace would result in burial of current habitat. The one exception was Alternative 5 which included the setback levee along the Sacramento River South reach. Throughout this assessment, levees were considered as ‘urban’ with respect to LULC classification, therefore having no ecosystem benefits.

6.1.3.1 Setback Levee – Sacramento River Reach

The replacement levee along the Sacramento River South reach was planned as a setback from the river and approximately 30,000 feet long (Figure 6-4). Since the original levee was directly adjacent to the riverbank, it reduced the channel and increased velocity of the river through that reach. One outcome of constructing the setback levee was to restore 60 acres of the floodplain to being seasonally inundated, potentially restoring this habitat to better support associated ecosystem functions. Proposed benefits included allowing for the river to expand during flood events and slow down through the shallow waters of the inside bend of the river in that reach, providing wetland and habitat for avian and aquatic flora and fauna. It was recognized that this measure reduced the overall environmental impact of all actions in the project and provided an opportunity to establish riverbank and wetland plants as mitigation for the habitat being lost through raising levees in place (USACE, 2016d). The new setback levee was included in Alternative 5 for final analysis and ultimately in the preferred plan for implementation.

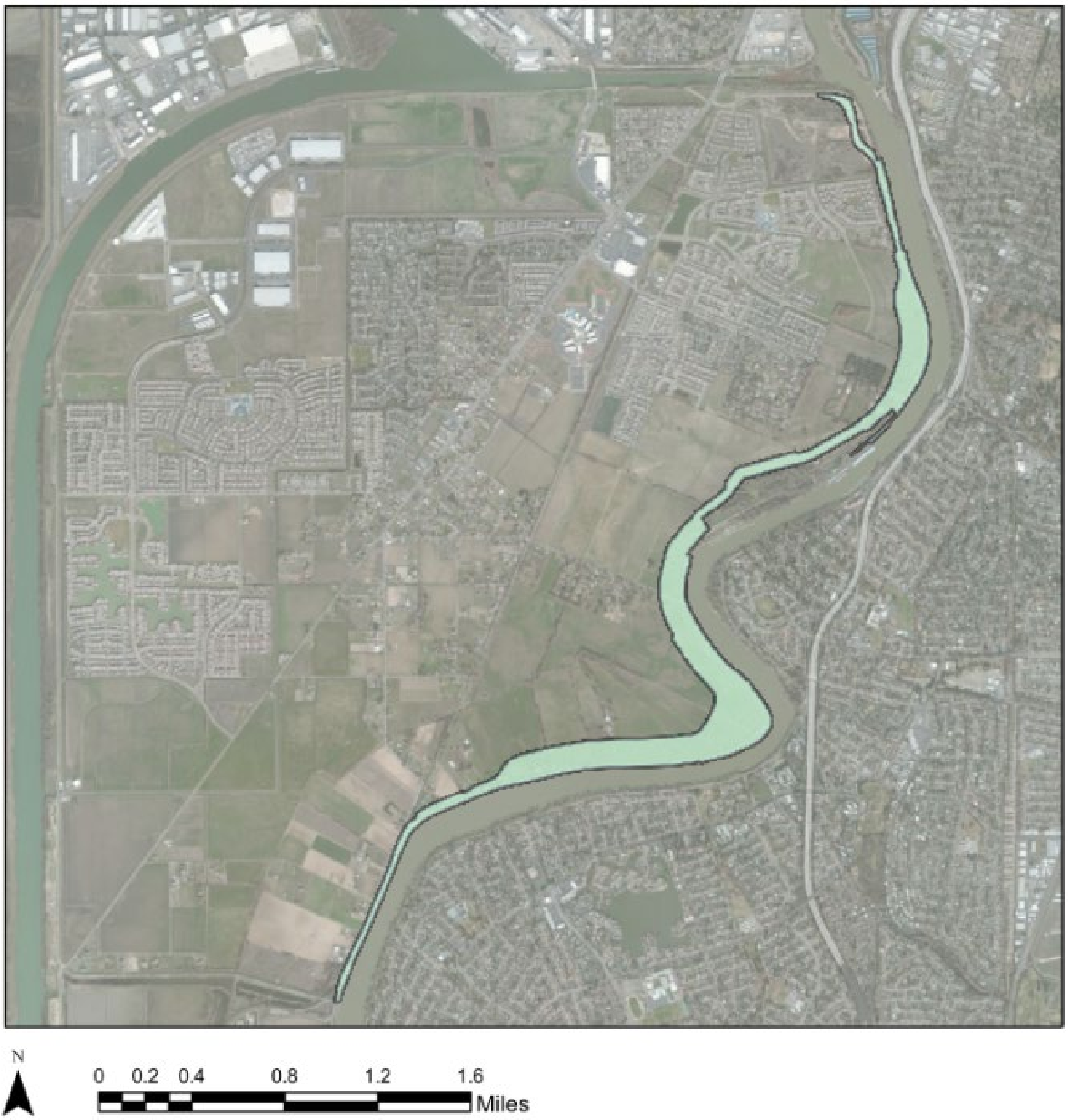


Figure 6-4. Location of proposed setback levee along Sacramento River, light green area indicates the 60 acres of river floodplain to be restored: A component of Alternative 5.

6.1.3.2 Sacramento Weir and Sacramento Bypass Wildlife Area – North Levee and South Levee Reaches of Sacramento River

The Sacramento Bypass Wildlife Area is primarily a flood control measure on the northern boundary of West Sacramento. The bypass is opened for flood control every 3–5 years. The 360 acres of varied vegetation provides habitat for game birds, raptors, songbirds, and native mammals as well as water features supporting white catfish, black crappie, largemouth bass, and bluegill. Originally acquired in 1962, the property was designated a wildlife area in 1988 by the Fish and Game Commission. It provides abundant recreational opportunities for fishing, wildlife viewing, bird watching and hunting, including waterfowl during the periods when the Bypass is flooded. The habitat is primarily grassland, but includes cottonwood trees, willows, and valley oaks. It becomes an intermittent wetland when the Sacramento River is in flood and the gates are opened. The proposed measure was to approximately double the width (and therefore the area) of the Bypass, converting agricultural land to the north of the current Bypass into additional wildlife area (Figure 6-5). This measure was not carried forward as the cost of the widening was estimated at $200,000,000 and the flood reduction benefits (reducing overtopping along Sacramento River North) could be achieved through only modest levee raising along that River reach. However, the Sacramento and Weir and Bypass widening is being further considered through other project implementation mechanisms (USACE, 2016d).

Figure 6-5. Location of proposed widening of the Sacramento Weir and Sacramento Bypass Wildlife Area north of West Sacramento: A component of Alternatives 2, 4, 7, and 8.

6.1.4 Consideration of Nonstructural Actions

The project development team (PDT) formulated 10 nonstructural actions, and then dropped three of them to develop nonstructural "Alternative 9." Alternative 9 was screened out early in the formulation process (Table 6-2) because the nonstructural actions alone did not meet the project criteria. While these nonstructural measures would potentially reduce the consequences of flooding, they would not reduce the probability—and therefore overall risk—of flooding. While nonstructural measures were grouped together as one of the alternative plans, it was noted that these could potentially be added beneficially to any of the other plans in addition to the structural measures (USACE, 2016d).

Table 6-2. Identified nonstructural actions.

<table>
<tr><th>Initial formulation of nonstructural actions</th><th>Formulation of Alternative 9</th><th>Preliminary screening</th></tr>
<tr><td>Permanent relocation</td><td>Removed in initial screening</td><td rowspan="10">Alternative 9—which included all the nonstructural options only—was screened out in second screening step.</td></tr>
<tr><td>Raising structures in place</td><td>Removed in initial screening</td></tr>
<tr><td>Flood proofing of existing structures</td><td>Removed in initial screening</td></tr>
<tr><td>Floodplain management</td><td>X</td></tr>
<tr><td>Providing floodplain information to regulatory agencies</td><td>X</td></tr>
<tr><td>Annual publication of residual risk</td><td>X</td></tr>
<tr><td>Improve flood warning system</td><td>X</td></tr>
<tr><td>Improve emergency evacuation plans</td><td>X</td></tr>
<tr><td>Add evacuation routes</td><td>X</td></tr>
<tr><td>Secure hazardous material tanks</td><td>X</td></tr>
</table>

6.1.5 Outcome of Chief's Report

The 2014 General Reevaluation Report (GRR) was approved by USACE HQ through a signed Chief's Report and was funded to begin the engineering, design, and construction process for FY22. The Chief's Report includes Alternative 5, with actions to improve levees and build the Sacramento River Reach setback levee, as the RP. The report also recommends modifications to the authorized West Sacramento project to include construction of levee improvement measures to address seepage, stability, and erosion concerns identified for the Sacramento River North and South, Yolo Bypass, DWSC east and west, Port South, and South Cross levees. Actions include raising the levee in place, waterside armoring bank protection, building of slurry walls, two channel closure structures, and a 30,000 feet long setback levee along the Sacramento River. The RP's BCR was 2.9, with a project first cost of the NED Plan estimated at $1,190,528,000, based upon 2015 price-levels (USACE, 2016c). Equivalent average annual costs are estimated at $64,795,000 based upon a 3.125% discount rate over a 50 year analysis period (USACE, 2016c).

6.2 CASE STUDY REANALYSIS: STUDY SCOPE

Across all the alternative plans there were 13 unique flood risk reduction actions (Table 6-3). The goals of the project were to reduce the number of people impacted by flooding and reduce the cost of damage from flood events. No NBS alternatives were specifically included. However, two actions: the setback levee along the Sacramento River and the Sacramento Weir and Bypass Widening (Table 6-3) had potential to provide ecosystem benefits. Table 6-3 indicates the potential for ecosystem impacts across project actions.

Table 6-3. List of unique flood reduction actions identified for West Sacramento and potential for ecosystem benefits and/or impacts (USACE, 2015g; see Table PAC-7 Post Authorization Change Report).

#	Flood protection action	Ecosystem benefits	Adverse ecosystem impacts
1	slurry wall or seepage berm	none	minimal
2	waterside armoring bank protection	none	loss of fish habitat
3	slurry wall	none	minimal
4	raise levee in place	none	habitat loss
5	stability berm	none	minimal
6	relief wells	none	minimal
7	seepage berm	none	minimal
8	cutoff wall	none	minimal
9	Sacramento Weir and Bypass Widening	habitat restoration	habitat loss
10	DWSC Closure Structure	none	minimal
11	I Street Diversion	n/a	loss of fish habitat
12	DWSC Closure Structure	none	minimal
13	Setback Levee	habitat restoration	habitat loss

6.3 ALTERNATIVE FORMULATION

Alternatives 1, 3, and 5 were the final array of alternatives included in further analysis, evaluation, and comparison. Alternative 5 included the setback levee along Sacramento River South, however the other NBS considered (widening of the Sacramento Weir and Sacramento Bypass Wildlife Area) was screened out in the initial BCA due to high cost. For this reason, Alternative 5 was also considered further in this case study to allow assessment of potential ecosystem benefits of the two NBS measures. Nine different river reaches were considered in this study (Figure 6-6; Table 6-4). The two actions that included NBS were the construction of a setback levee along the Sacramento River to replace the previously existing levee (see Reach 5) and the second was the widening of the Sacramento Weir and Sacramento Bypass Wildlife Area to the north of West Sacramento (see the Sacramento Bypass Levee adjacent to Reach 4).

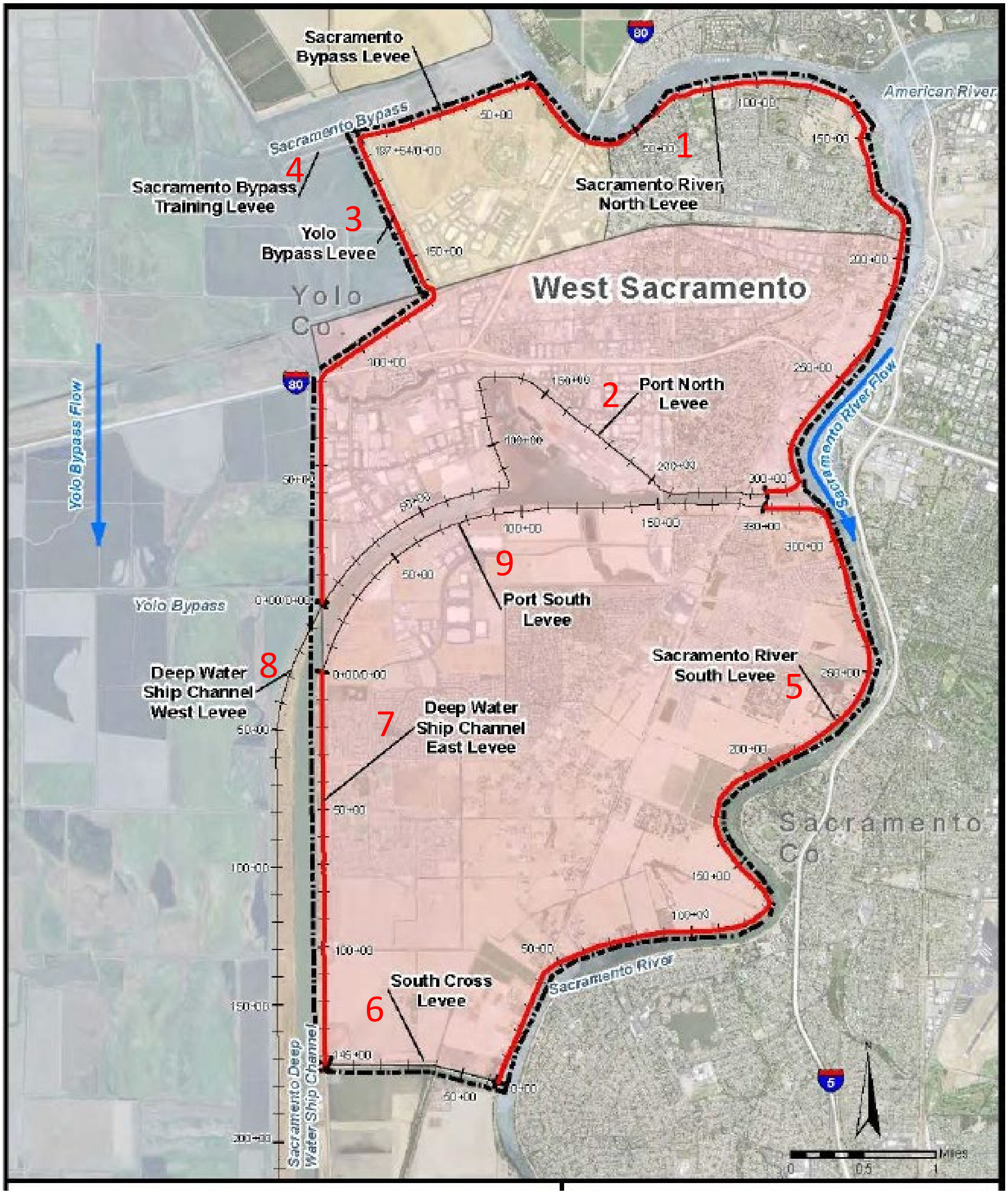


Figure 6-6. West Sacramento River Reaches used for continued comparative analysis.

Table 6-4. Detailed measures for each alternative selected for further analysis, categorized by river reach.

	Alternative number			
	1	2	3	5
	Alternative name			
	Improve Levees	Improve Levees, Sacramento Weir, and Bypass Widening Alternative, and DWSC Closure Structure	Improve Levees and DWSC Closure Structure	Improve Levees and Include Southport Setback Levee
	Preliminary BCR			
	2.5	1.8	2.1	2.9
	Final BCR			
	2.4	-	2.0	2.6
River Reach	**Actions**			
Sacramento River North Levee	slurry wall waterside armoring bank protection Raise levee in place	slurry wall waterside armoring bank protection **Sacramento Weir and Bypass widening**[22]	slurry wall waterside armoring bank protection Raise levee in place	slurry wall waterside armoring bank protection Raise levee in place
Sacramento River South Levee	slurry wall and seepage berm waterside armoring bank protection raise levee in place	slurry wall and seepage berm waterside armoring bank protection **Sacramento Weir and Bypass widening**	slurry wall and seepage berm waterside armoring bank protection raise levee in place	**setback levee with slurry wall and seepage berm** waterside armoring bank protection new setback levee
Port North	flood wall or raise levee in place	DWSC Closure structure		flood wall or raise levee in place
Yolo Bypass Levee		slurry wall	slurry wall	slurry wall
Sacramento Bypass Training Levee	waterside armoring bank protection	waterside armoring bank protection	waterside armoring bank protection	waterside armoring bank protection
South Cross Levee	relief wells stability berm raise levee in place	relief wells stability berm raise levee in place	relief wells stability berm raise levee in place	relief wells stability berm raise levee in place
Deep Water Ship Channel East Levee	slurry wall raise levee in place	slurry wall raise levee in place	slurry wall raise levee in place	slurry wall raise levee in place
Port South Levee	slurry wall waterside armoring bank protection raise levee in place	slurry wall waterside armoring bank protection levee raise	slurry wall waterside armoring bank protection raise levee in place	slurry wall waterside armoring bank protection raise levee in place

Note: measures with potential ecosystem benefits are indicated in bold text.

6.4 NON-MONETIZED OUTCOME EVALUATION

The primary focus of this case study reanalysis was the costs and benefits associated with land cover change. The LULC data layer for West Sacramento was used to identify all land use categories present prior to project construction, and additional categories were included for potential new LULC categories that could conceivably be created through project construction (Table 6-5). Project plan shapefiles were obtained from USACE planners within the USACE Flood and Storm Risk Reduction Section and Flood Risk Management Program in Sacramento. The construction plans were simplified to show the overall location and extent of each planned measure. The footprint shapefile for each measure was then overlayed on the 2015 LULC data, and the areas of each of the seven LULC categories quantified. These values were then recalculated with best professional judgement as to what LULC categories would be present after project construction (possibly with additional restoration such as planting of vegetation). For this analysis it was assumed that all projects were constructed as detailed in the GRR (USACE, 2016d). This provided a land area in acres for each of the seven LULC categories before and after construction of each measure (Figure 6-*7*).

The primary conservative assumptions were made to attribute ecosystem benefits for the Sacramento Wier Wildlife Bypass as "temperate grassland" for the entire year and not include the ecosystem value for "wetland" ("wetland" is substantively higher). Similarly for the Sacramento River South Levee setback levee it was assumed that the setback would be flooded for roughly four months a year and therefore attribute the area as "wetland" for four months (1/3) of the year and "temperate grassland" for eight months (2/3) of the year. However, to test the sensitivity of results to these assumptions, ecosystem service value was also calculated assuming that these areas provided ecosystem value benefits of "wetlands" for the full 12 months of the year. The primary analysis displays these two extreme cases separately.

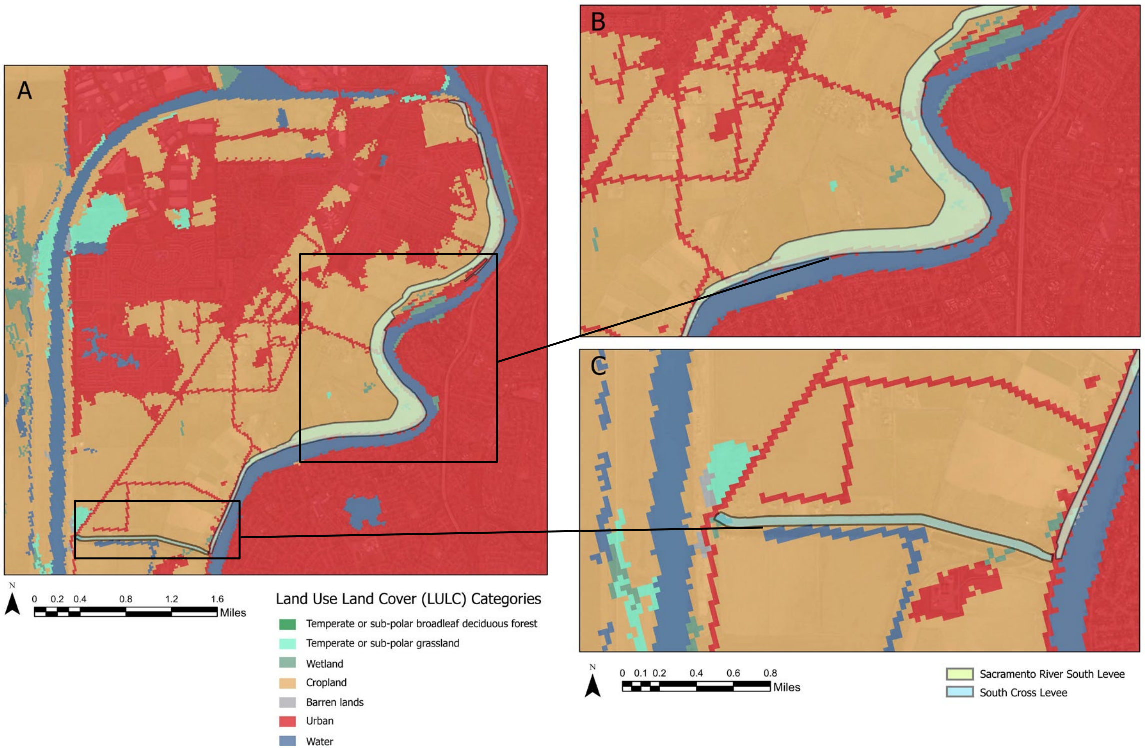


Figure 6-7. West Sacramento A: 2015 Land Use Land Cover (LULC) and inset examples of detail for B: Footprint of Sacramento River South Levee project, C: Footprint of South Cross Levee project.

6.4.1 Biophysical Outcomes

After removal of measures that were assumed to be neutral with respect to change in ecosystem value based on habitat area (LULC category areas) there were 10 remaining measures that were assessed in detail for changes in LULC category areas before and after measure implementation (Table 6-5). For raising levees in place, building flood walls or the DWSC closure structure, the LULC changes were summarized as a change in area of "urban land" (ecosystem value of zero, e.g., underneath levee) ranged from a 2.4 acre increase in Port North River reach up to a 44.2 acre increase in Sacramento River North Levee reach. These differences primarily reflected the footprint of those measures, with the total footprint of the levee in Port North reach being 7 acres and 115.6 acres in Sacramento River North Levee (Table 6-5).

Consistent with the findings of the GRR, the study team observed that raising levees in place resulted in loss of functional habitat areas (USACE, 2016d). The increase in urban land was due to the loss of cropland, temperate grassland, wetlands, or water areas (Table 6-5). The two measures that resulted in an increase in potentially functional habitat area were in the Sacramento River North and Sacramento River South reaches. The Sacramento Weir Bypass widening was planned to remove 449.8 acres of cropland and 12.6 acres of levee (LULC urban) to create 462.4 acres of temperate grassland. The new Setback Levee was planned to remove 71.2 acres of cropland and 49.4 acres of levee (LULC urban) to create 81.2 acres of temperate grassland, 27.9 acres of wetland, 4.5 acres of water, and 10.8 acres of barren land (Table 6-5). These changes for the Sacramento Weir Bypass and Setback Levee were based on the most conservative of assumptions. If it were instead assumed that the created habitat had the ecosystem value of wetland, the areas of wetland created would have been 462.4 acres and 109.1 acres, respectively (Table 6-6).

Table 6-5. West Sacramento Land Use Land Cover area change (acres) resulting from implementation of each measure using conservative assumptions.

Reach	Measure	Land Use Land Cover (LULC) change with project implementation (acres)							Total measure footprint (acres)
		Barren lands	Cropland	Temperate or sub-polar broadleaf deciduous forest	Temperate or sub-polar grassland	Urban	Water	Wetland	
Sacramento River North	1. Raise levee in place	0.0	-0.3	0.0	-2.7	44.2	-39.8	-1.4	115.6
Sacramento River North	2. Sacramento Weir and Bypass widening	0.0	-449.8	0.0	462.4	-12.6	0.0	0.0	494.7
Port North	3. Flood wall or raise levee in place	0.0	-5.9	0.0	-0.2	7.2	0.0	-1.1	28.4
Sacramento River South	4. Raise levee in place	-1.6	-4.9	0.0	0.0	4.0	1.1	-0.4	39.6
Sacramento River South	5. New setback levee	10.8	-71.2	0.0	81.2	-49.4	4.5	27.9	262.0
South Cross	7. Raise levee in place	0.0	-24.6	0.0	0.0	25.3	0.0	-0.7	25.4
DWSC East	9. Raise levee in place	-2.2	-30.2	0.0	-5.8	38.7	0.0	-0.4	64.7
DWSC West	10. Raise levee in place	-1.1	-22.9	0.0	-3.0	30.1	-2.9	-0.2	30.2
Port South	11. Raise levee in place	0.0	-27.4	0.0	-5.8	36.8	-3.5	0.0	48.9
Port North	13. DWSC closure structure	0.0	-0.8	0.0	0.0	2.4	-1.6	0.0	7.0

Note: This table includes the most conservative assumptions of LULC change for action two and five.

Table 6-6. West Sacramento Land Use Land Cover (LULC) area change (acres) resulting from implementation of each measure using wetland ecosystem values .

Assumption of post implementation ecosystem value equivalent habitat	Reach	Measure	Barren lands	Cropland	Temperate or sub-polar broadleaf deciduous forest	Temperate or sub-polar grassland	Urban	Water	Wetland	Total measure footprint (acres)
100% Temperate grassland	Sacramento River North	Sacramento Weir and Bypass widening	0.0	-449.8	0.0	462.4	-12.6	0.0	0.0	494.7
100% Wetland	Sacramento River North	Sacramento Weir and Bypass widening	0.0	-449.8	0.0	0.0	-12.6	0.0	462.4	494.7
Wetland 1/3 of time; Temperate Grassland 2/3 of time	Sacramento River South Levee	New setback levee	10.8	-71.2	0.0	81.2	-49.4	4.5	27.9	262.0
100% Wetland	Sacramento River South Levee	New setback levee	10.8	-71.2	0.0	0.0	-49.4	4.5	109.1	262.0

Note: White rows include more conservative assumptions (lower ecosystem value) and beige rows include less conservative assumptions (higher ecosystem values).

6.4.2 Benefit-Relevant Indicators

The evaluation of flood protection measures for West Sacramento was based on the benefit transfer of monetized value of habitat type, as assigned through LULC categories. These results are reviewed in Section 6.5.

6.4.3 Additional Quantitative or Qualitative Outcomes of Interest

6.4.3.1 Environmental

Project planning identified that constructing levee improvements would result in significant loss of vegetation and wildlife habitat. Replanting, including within the setback levee (preferred alternative) and/or widening of the Sacramento Wildlife Area Bypass (not selected) were identified as potential mitigation measures to offset vegetation and habitat loss (USACE, 2016d). Here, the ecosystem value of this was quantified by habitat area alone. However, the value of that habitat to wildlife depends upon condition, and direct quantification of target flora and fauna of interest may demonstrate additional ecosystem value.

There is potential for consideration of benefits to fish and fish catchability, or the reduction in this metric with hardening of riverbanks for bank stabilization. Due to the footprint (length of shoreline) in these river reaches, it is considered unlikely that these additional metrics would change conclusions or prioritizations in project selection for West Sacramento.

6.4.3.2 Social

Based on the flood risk modeling done for the West Sacramento project area, the northern region (north of Port South Levee) is the most at-risk for flooding based on a single levee break (USACE, 2016d).The demographic information for the northern region of the project area also demonstrates indicators of potentially increased vulnerability when compared to the southern region of the project area. The area north of Port South Levee contains a higher percentage of adults who are not high-school graduates. It also contains a higher percentage of households with income below 150% of the poverty level, households with limited-English, and households lacking broadband internet (Table 6-7). The clear demographic disparities between the two regions present an opportunity to consider the equity of benefits and for a potential follow-on analysis that could consider the level of impact that certain proposed project actions might have on proximal census tracts.

Table 6-7. West Sacramento demographics, 2016–2020 ACS; 5-year estimates.

	Average percent of adults (25 or older) who are not high-school graduates	Average percent of population with income below 150% of poverty level	Average percent limited-English households	Average percent of households lacking broadband internet
Census Tracts North of Port South Levee	19.47	33.68	10.67	11.17
Census Tracts South of Port South Levee	6.78	12.16	3.66	4.62

Sources: 2016–2020 American Community Survey 5-year estimates; Census 2020 PL94-171

6.5 MONETIZED VALUATION

The goal of the USACE study was solely to reduce flood risk and reduce damage during a major river flow event. Therefore, NBS measures were not specifically included. Two alternatives did include the potential to increase area of habitat with potential to support additional ecosystem benefits. Therefore, the analysis primarily focused on the "minimum potential habitat loss" through the increased footprint area from actions such as raising levees in place, with the favored alternative that included a large setback levee (Alternative 5) and Alternative 2 which included widening of the Sacramento Weir and Wildlife Bypass having potential to increase area of beneficial habitat. The primary assumptions of the benefit transfer approach applied to assess potential ecosystem benefits were that the valued habitats would be equivalent to those created or destroyed with project implementation and that throughout the project area, each LULC habitat category had uniform value.

6.5.1 Valuation Methods and Key Assumptions

The change in land area was used to quantify the change in ecosystem service value (both gains and losses) for that measure footprint with construction. The land area that changed between each possible combination of LULC category was valued through a benefit transfer, applying estimated monetary values of the ecosystem service value for each LULC category (Table 6-8, Figure 6-7). Constructed levees were classified as barren and therefore having zero ecosystem service value. In these cases construction of the measure may have had a negative balance in ecosystem service value due to change of vegetated habitat to barren. While some levee areas and seepage areas may support vegetation, this analysis did not have the spatial resolution to account for that level of accuracy. This was noted in the GRR as potential impacts of the planned measures (USACE, 2016d). Benefit transfer monetary equivalence values were taken from the Ecosystem Service Database which was developed through synthesis of more than 300 case studies covering 10 main biomes (de Groot et al., 2012; Li & Fang, 2014).

Table 6-8. Land Use Land Cover (LULC) categories and benefit transfer values used to evaluate ecosystem service benefits for West Sacramento flood reduction projects.

	Ecosystem service benefit values ($2014/acre/year)		
LULC category	**De Groot (median)**	**De Groot (mean)**	**Li and Fang**
Barren lands	-	-	-
Cropland	616	616	616
Temperate or sub-polar broadleaf deciduous forest	105	667	1,602
Temperate or sub-polar grassland	462	658	2,453
Urban	-	-	-
Water	2,083	3,856	-
Wetland	6,434	102,541	103,045

Source: Benefit transfer values from work by de Groot et al. and Li and Fang. (de Groot et al., 2012; Li & Fang, 2014).

For the measures to solely strengthen or raise levees or add flood control structures, the loss of ecosystem service value ranged from a loss of $497 to $6,491 for the DWSC closure structure in the Port North

River reach up to a loss of $93,341 to $151,960 for the raised levee in place for the Sacramento River North River reach (Table 6-9). There were two measures that had potential to provide improvements to ecosystem service value as assessed by area of beneficial habitat, Sacramento Weir and Bypass Widening and the Sacramento River South Setback Levee.

The Bypass widening had potential to lower or increase ecosystem service value with a loss of $63,181 as the lower bound and a gain of $47,367,059 depending on the equivalent transfer rates used and the assumptions of created habitat (LULC) type (Table 6-9). For the same range of assumptions, the Setback Levee had the potential to increase ecosystem service value from anywhere between $182,702 and $47,367,059. Using the benefit transfer methodology based upon creation or loss of habitat types with potential for ecosystem service value, the aerial extent of the measures is a critical component of the calculations.

In general, the case study team notes that measures that have an inherently small footprint can only have a relatively small change in ecosystem service value, even though that same small-scale action may have a large effect on other monetary measures such as flood reduction. In contrast, as soon as a large area of land is being considered for a flood protection action, it becomes much more likely that the ecosystem service monetary benefits may become significant in decision making as to preferred options.

Table 6-9. Monetized ecosystem service values of the 10 independent measures calculated for three different quantifications of habitat ecosystem service value.

River reach[23]	Implemented measure	Assumed resulting LULC habitat category	Source of habitat monetary ecosystem values		
			De Groot, 2021b median	De Groot, 2012b mean	Li & Fang, 2014
Sacramento River North Levee	1. Raise levee in place	See Table 6-5	$(93,341)	$(299,710)	$(151,960)
Sacramento River North Levee	2. Sacramento Weir and Bypass widening	100% Temperate Grassland	$(63,181)	$27,317	$857,142
		100% wetland	$2,697,788	$47,134,200	$47,367,059
Port North	3. Flood wall or raise levee in place	See Table 6-5	$(11,077)	$(120,883)	$ (121,716)
Sacramento River South Levee	4. Raise levee in place	See Table 6-5	$(3,529)	$(42,145)	$(46,417)
Sacramento River South Levee	5. New setback levee	2/3 Temperate Grassland and 1/3 Wetland	$182,702	$2,890,308	$3,032,761
		100% Wetland	$667,327	$11,158,850	$11,196,520
South Cross Levee	7. Raise levee in place	See Table 6-5	$(19,715)	$(88,171)	$(88,530)
Deep Water Ship Channel East Levee	9. Raise levee in place	See Table 6-5	$(24,194)	$(67,624)	$(78,110)
Deep Water Ship Channel West Levee	10. Raise levee in place	See Table 6-5	$(23,023)	$(51,241)	$(45,600)
Port South Levee	11. Raise levee in place	See Table 6-5	$(26,898)	$(34,258)	$(31,194)
Port North	13. DWSC closure structure	See Table 6-5	$(3,735)	$(6,491)	$(497)

Note: values in brackets are negative (i.e. losses in ecosystem service value). Sources: de Groot et al. (2012), Li & Fang (2014).

[23] There are two different assumptions of resultant habitat type for Sacramento Weir and Bypass Widening and the South Sacramento River Setback Levee.

6.5.2 Updated Benefits

The study team calculated the monetary benefits of land use/land cover changes by first calculating the change in acres under pre and post project conditions under several different land use categories: barren land, agriculture/crop land, temperate forests, temperate grasslands, urban, water and wetlands. The areal change in land use category (acres) was then re-calculated based upon the new LULC category. The annual value of an additional acre of each type of land use was drawn from the best available science in the published literature to cover the greatest range of potential ecosystem service value and therefore allow a robust sensitivity analysis (de Groot et al., 2012; Li & Fang, 2014). The equation for calculating the annual cashflow is thus:

$$C_{LU,t} = \sum_{h} \Delta L_h * B_h$$

Where $C_{LU,t}$ is the annual benefit cashflow, h is an index of the different land use categories, B_h is annual benefit of an additional acre of land type h, and ΔL_h is the change in the number of acres of land use category h going from pre to post project conditions. The AAEQ benefits for each plan using three different sources for the annual value of an acre of land are in Table 6-10. Using the most conservative assumption on LULC categories (only grassland results from project), even the largest value in the table is about two orders of magnitude smaller than the AAEQ benefits calculated in the original analysis and thus changes in land use are unlikely to affect the final BCAs. However, if less conservative assumptions regarding the amount of wetland produced (as opposed to grassland) are made for Alternatives 2 and 5, the AAEQs for Alternatives 2 and 5 grow substantially. They are, however, still an order of magnitude smaller than the AAEQ benefits used in the original analysis. Even when high value habitats are created, the area of created high value habitat is what drives the potential monetary benefit equivalent, so only very large projects would be potentially re-prioritized when including ecosystem benefits within BCA analysis. The AAEQ benefits for each project are given in Table 6-11.

Table 6-10. Dollar values associated with Land Use Land Change based upon most conservative assumptions of resultant habitat type (grassland).

Plan	De Groot median	De Groot mean	Li & Fang
0.5A	$(116,364)	$(350,951)	$(197,560)
0.5B	$(97,359)	$(283,438)	$(289,850)
0.5C	$(178,533)	$(573,715)	$(428,579)
0.5D	$(174,879)	$(669,774)	$(532,333)
1	$(201,777)	$(704,031)	$(563,526)
2	$(168,087)	$(334,859)	$491,993
3	$(163,802)	$(548,891)	$(410,616)
4	$(133,847)	$(186,210)	$644,406
5	$(15,545)	$2,228,422	$2,515,651
6	$(198,247)	$(661,886)	$(517,109)
7	$(261,428)	$(634,569)	$340,033
8	$(261,428)	$(634,569)	$340,033

6.5.3 Updated Costs

No updates were made to the cost calculations.

6.5.4 Benefit-Cost Comparisons

6.5.4.1 Planning Analysis

Table 6-11 contains cost benefit and BCR information for Alternatives 1, 3, and 5 using the planning analysis discount rate. Because the LULC benefits the study team calculated were so small relative to the original benefits, the study team opted to use the largest values for each plan from Table 6-10. Overall, the additional benefits of LULC change are negligible when compared to the overall benefits in this study, however these additional benefits could still represent millions of dollars each year.

Table 6-11. Table of AAEQ (in millions of dollars) of the benefits and costs of the West Sacramento project using the USACE planning analysis assumptions.

	Alternative 1	Alternative 2	Alternative 3	Alternative 5	Alternative 2 all wetlands	Alternative 5 all wetlands
Original Benefit	$264.27	$255.38	$264.27	$264.27	$255.37	$264.27
Original Cost	$108.47	$115.35	$128.50	$103.15	$115.36	$103.14
Original BCR	2.44	2.21	2.06	2.56	2.21	2.56
LU Benefit	-$0.20	$0.49	-$0.16	$2.51	$47.00	$10.68
Updated BCR	2.43	2.22	2.06	2.59	2.62	2.67

OMB Process Analysis (Table 6-12) contains cost benefit and BCR information for Alternatives 1, 3, and 5 using the OMB discount rate. As under the planning analysis assumption, the study team opted to use the largest values for each plan from Table 6-10. Notably, all of the plans have BCRs below 1.0 and the additional monetized benefits were not enough to move the BCRs above 1.0, except under very extreme assumptions about the additional wetlands created by Alternatives 2 and 5.

Table 6-12. Table of AAEQ of the benefits and costs of the West Sacramento project using the OMB assumptions.

	Alternative 1	Alternative 2	Alternative 3	Alternative 5	Alternative 2 all wetlands	Alternative 5 all wetlands
Benefit/ Cost Source	AAEQ (millions of dollars)	AAEQ (millions of dollars)	AAEQ (millions of dollars)	AAEQ (millions of dollars)	AAEQ (millions of dollars)	AAEQ (millions of dollars)
Original Benefit	$2642.7	$255.38	$264.27	$264.27	$255.38	$264.27
Original Cost	$278.97	$278.97	$288.60	$275.81	$278.97	$275.81
Original BCR	0.98	0.92	0.92	0.96	0.92	0.96
LU Benefit	-$0.20	$0.49	-$0.16	$2.51	$47.00	$10.68
Updated BCR	0.97	0.92	0.92	0.97	1.08	0.99

6.6 PRIORITIZATION AND ALTERNATIVE SELECTION

The primary approach for monetizing ecosystem service benefits for the West Sacramento case study NBS was quantifying LULC change. However, these benefits were estimated to be relatively small given the footprint of alternatives, using habitat creation would only impact the overall BCA for projects with large areas of habitat being created (even the 450+ acres of the West Sacramento River Bypass would not have influenced the final selection).

Other potential approaches for quantifying benefits included increased value of fish and fish catchability, as well as bank stabilization, species and persistence of vegetation, and quantification of wildlife abundance. The baseline data and monitoring data were not available to quantify, estimate, or numerically model what these benefits could potentially have been. Additional considerations were related to the flood risk protection provided to a potentially vulnerable population, but it was not possible to differentiate the alternatives based on differentiating the more vulnerable communities. The results of the BCA are therefore likely to differentiate the alternatives within the limits of the assumptions described in the previous sections (e.g., uncertainty in the valuation of different habitat types, as well as the type of habitat that acreage should be classified as.) This result is consistent with the need for a modular and adaptable approach to alternative selection and prioritization: in some feasibility studies, the scale of the project or targeted nature of the need may result in BCA being the sole factor considered, rather than applying MODA to a wider suite of benefits and costs.

6.7 DISCUSSION

The major conclusion from this case study reanalysis was that, in the absence of fish, wildlife, or recreational use data specific to these river reaches, the assumptions of post-project habitat and the selected benefit transfer values were the primary determinants of the order of magnitude of calculated ecosystem benefits. Therefore, these assumptions also determine the importance of the ecosystem service value in relation to the flood reduction benefits. Since the highest end estimates of the monetary value of ecosystem benefits is the same order of magnitude as flood reduction benefits, reducing the uncertainty in these habitat-based ecosystem service benefits is essential to successfully add these additional benefits into the overall project prioritization and decision-making process.

The benefit transfer approach, as based upon project footprint and LULC data, could be applied as an initial screening process to determine if in-person use surveys and/or specific flora and fauna surveys are warranted. The potential value of the ecosystem benefits for West Sacramento flood reduction project was 10s of millions of dollars (up to 50% of the monetary value of the flood reduction benefits). Therefore, the additional cost (likely less than $1 million) to carry out use surveys, targeted flora and fauna surveys, or willingness to pay assessments for ecosystem preservation or creation would be offset by the potential benefit if ecosystem service value were an explicit project aim in addition to reduction of flood costs.

Alternative 9 was a nonstructural alternative and was not carried forward. While being cost effective, it was not standalone, it did not meet three of the four primary objectives, and was not considered implementable in terms of acceptability to politicians and locals (USACE, 2016d). These nonstructural measures could potentially reduce the consequences of flooding, but they would not reduce the probability of flooding. While nonstructural measures were all grouped together as one of the alternatives, it is noted that these could potentially be added beneficially to any (or all) of the other plans in addition to the structural measures, integrated plans of structural and nonstructural components are recommended (USACE, 2016d).

Most of the alternatives provided roughly the same level of protection and equally addressed the evaluation criteria. The exception was Alternative 5 which included the Sacramento River Reach Setback Levee, not only encouraging wise use of the floodplains (an additional project objective) but additionally reducing the overall environmental impact through creation of grassland and wetland, as well as providing a potential location for mitigation actions.

Measures that have an inherently small footprint can only have a relatively small change in ecosystem service value, even though that same small-scale action may have a large effect on other monetary measures such as flood reduction. In contrast, as soon as a large area of land is being considered for a flood protection action, it becomes much more likely that the ecosystem service monetary benefits may become significant in decision making as to preferred options.

It is apparent from the analyses of BCA conducted for West Sacramento that combining measures into grouped alternatives has a major influence over selection of some measures. For example, a relatively small-scale project may well not change the monetary benefit (and/or the final BCR) result of a group of projects whether it is included or not. This becomes particularly apparent when a small number of the measures have ecosystem benefits and they are being combined into alternatives that have a majority of measures with no ecosystem component (except some loss of habitat requiring mitigation). Analyzing ecosystem benefits of all measures prior to combining them into alternatives of multiple measures with different spatial scales and/or with and without potential ecosystem benefits, can provide greater insight into the potential for overall realization of ecosystem benefits. This assessment of measures for ecosystem benefits would be more effective at identifying measures to maximize ecosystem benefits. If ecosystem benefits were an explicit additional goal of the project, these measures could be added to all flood reduction alternatives, for overall BCA assessment.

7.0 SOUTH PLATTE RIVER AND TRIBUTARIES

7.1 OVERVIEW

The South Platte River forms in Park County, CO and flows 439 miles northeast through Denver, Brighton, and Sterling before reaching a confluence point with the North Platte River in western Nebraska to form the Platte River. Two primary tributaries connect to the South Platte River; the Weir Gulch connects in the river's southern portion, near to Phil Milstein Park, while the Harvard Gulch connects to the river south of the Weir Gulch. Together, the South Platte River and its tributaries provide abundant recreational opportunities and are considered "nationally significant ecosystems providing critical habitat linkages between the Rocky Mountains and Great Plains river systems" (USACE, 2019b).

The riparian, wetland, and aquatic habitats along the South Platte River provide an important resource in an otherwise semi-arid region. The riparian and aquatic habitats represent approximately 2% of Colorado's land area but are used by 80% of the state's wildlife species (USACE, 2019b). These habitats, however, have been impacted by river alteration and urbanization. Three USACE reservoirs are in operation along the South Platte River at Chatfield, Cherry Creek, and Bear Creek, which are flow regulated and as such there has been disruption to the natural flow regime of the area. Urban development, meanwhile, has led to the installation of buildings, paving, and turf on the South Platte River's stream corridors, which consist of riparian floodplain areas that follow the river's course and provide a connection between habitat areas.

The South Platte River runs directly adjacent to downtown Denver, and efforts to improve the river have coincided with increased development and population growth. Designation of "The Lower Downtown Denver Historic District" by the Denver City Council in 1988 sparked downtown's transformation from "a long-neglected part of town" (Vela, 2018) to the vibrant area complete with amenities, trails, and transportation networks that it is today. This designation spurred mixed-use development downtown and soon, local businesses such as breweries, bookstores, bars, and restaurants began moving in. Construction of Coors Field (home of Denver's Major League Baseball team, the Colorado Rockies) which was completed in 1995, further contributed to revitalization of the downtown neighborhoods directly adjacent to the South Platte River (Vela, 2018).

Downtown Denver's transformation has "refocused the South Platte River as a centerpiece of the region," (Metro Water Recovery, n.d.) and efforts to restore the river have occurred in tandem with increased population growth and development. Through local improvements, what was once considered a "dying river" (Metro Water Recovery, n.d.) is now considered an amenity, with the river serving as a recreation corridor for residents and tourists alike. For example, Confluence Park, where Cherry Creek meets the South Platte, is a popular park and "one of the first nationally recognized urban riverfronts" (Wenk Associates Inc., 2013). It is anticipated that the riverfront's popularity will only increase, as private developers will fund additional restoration work alongside construction of the "River Mile" development. The River Mile will include 7,600 residences and will require relocation of Elitch Gardens, the popular amusement park, as well as reconfiguration of the river's whitewater rapids near Confluence Park that have been popular with kayakers (Harris, 2021; *The River Mile*, n.d.).

Previous restoration projects have been successfully implemented on the South Platte River. However, the City of Denver has continued to grow rapidly, adding over 113,000 residents between 2010 and 2020 alone (Colorado Department of Local Affairs, State Demography Office, 2022), and bringing with it increased development pressure on limited water resources. Further, prior restoration efforts of the South Platte River have occurred at small scales with limited funding that have largely served to improve recreational use of the river for kayaking, tubing, fishing, and river surfing (Bane, 2021; Simpson, 2018). As such, a larger scale, federally funded and coordinated effort is required to improve the ecosystem quality of the river, and the quality and connectivity of adjacent habitats.

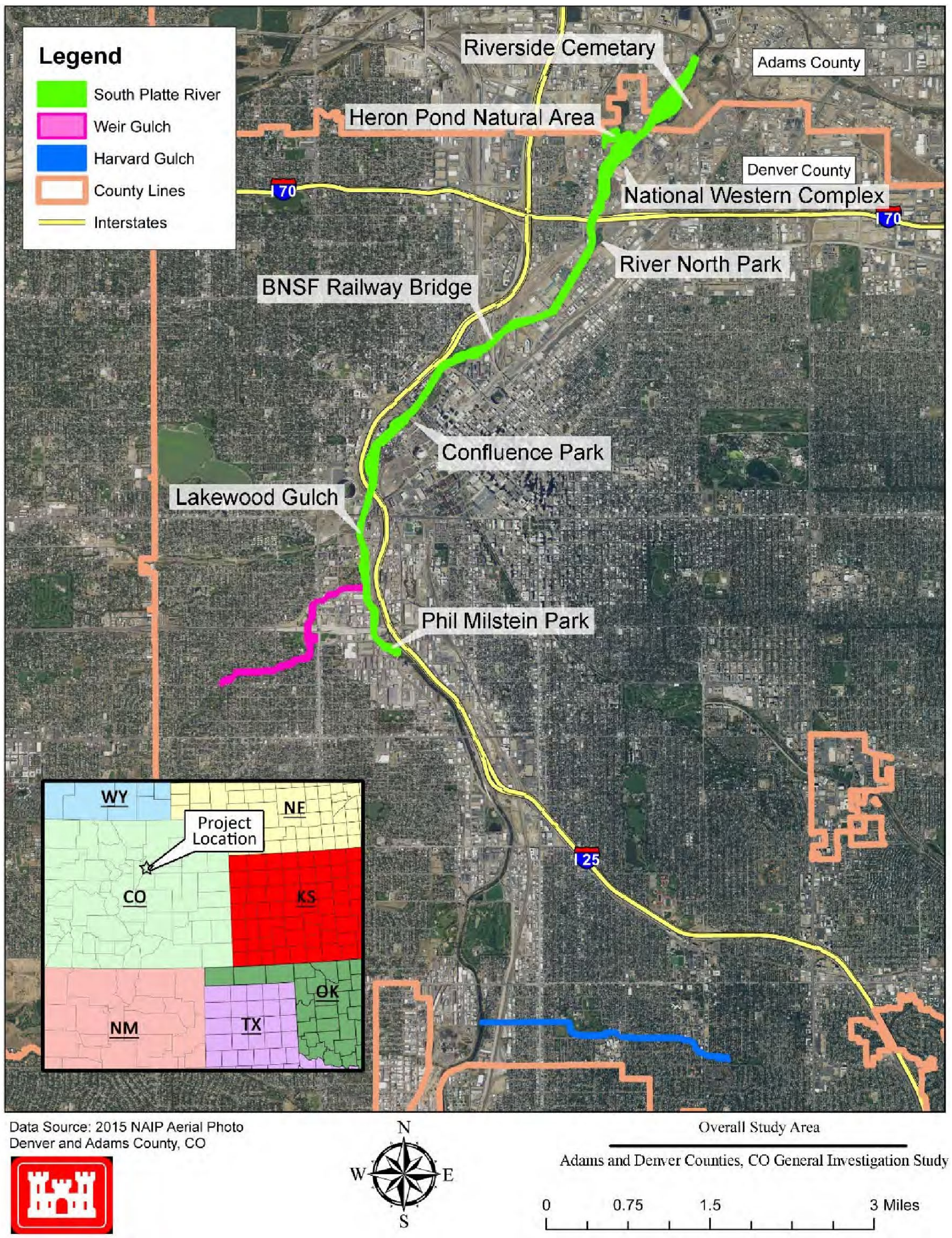


Figure 7-1. The South Platte River study area in Denver, CO, including the Harvard and Weir gulches. Source: USACE (2019b).

7.1.1 Project Goals

USACE Northwestern Division (NWD) Omaha District (NWO) initiated a feasibility study, published in 2019, that focused on a 6.5-mile stretch of the South Platte River in Adams and Denver counties, Colorado, between 6th and 5th Avenues (Figure 7-1). This feasibility study included the development of separate alternatives for the Harvard and Weir Gulch watersheds, which were not considered as part of this case study.[24]

The stated goal of the Feasibility Study's South Platte River portion is to "identify an ecosystem restoration plan that reasonably maximizes NER benefits, provides secondary [FRR] benefits, and improves recreation opportunities." This goal was developed with four specific objectives:

- Objective 1: Restore riparian and wetland habitat quantity, quality, and connectivity in the South Platte River for migratory birds protected under the Migratory Bird Treaty Act and native species of plants and animals.
- Objective 2: Restore in-channel habitat complexity and connectivity in the South Platte River for native aquatic species.
- Objective 3: Reduce flood damages along the South Platte as an incidental benefit of ecosystem restoration measures.
- Objective 4: Improve public recreation opportunities, connectivity, and accessibility along the South Platte River.

In addition to the NER Plan formulations for the South Platte River, two Gulch tributary areas were studied for economic development benefits. These project alternatives focused on flood risk mitigation with objectives of reducing flood risks, restoring habitat where possible, and providing incidental recreational and connectivity improvements.

7.1.2 Alternative Formulation Process

USACE divided the 6.5-mile stretch of the river into six reaches, then developed measures within each reach. These measures were sometimes grouped into "sub-alternatives" based on location and a "minimum" versus "maximum" scale. Maximum measures focused on restoring the largest possible area within each reach, and included options to relocate infrastructure, whereas restoration work in the minimum measures would be concentrated in smaller areas without infrastructure relocation (USACE, 2019c). The alternative formulation process grouped together different sets of measures in different reaches for evaluation. In addition to the FWOA alternative, USACE formed twelve alternatives, beginning with Plan 1, which included only one measure in one reach, up to Plan 12, which contained 11 measures in all six reaches. Each subsequent alternative essentially built upon the previous one by

[24] While this case study focuses on the South Platte study area, the rescoped analysis did return to the Gulches to examine how costs and benefits were calculated in the original report.

incorporating all of its measures and either adding a new one to it, or replacing a minimum measure with a maximum measure (USACE, 2019b).

The USACE team evaluated each alternative plan by the amount of habitat units it created, its cost effectiveness, and whether it met the project's connectivity goal. The first cost effective plan identified was Plan 4; however, it did not achieve the connectivity objective because it only included measures in three out of six reaches. The first project to meet all criteria was Plan 8, but USACE ultimately selected Plan 9 as the NER RP (Table 7-1), as it achieved all planning objectives and offered a significant amount of habitat restoration benefits at a high level of cost effectiveness in the South Platte River study area.

7.1.3 Consideration of Nature-Based Solutions

NBS were integral to plan formulation for the South Platte River. To meet the project goals of river connectivity and aquatic habitat restoration, the NBS selected emphasized wetland and riparian habitat creation. Features added to accomplish these benefits ranged from removing non-native and invasive species and replacing with native vegetation, to adding wetlands benches and jetties, to removal or relocation of infrastructure, such as sanitary sewers. Though the latter is not typically considered a NBS, infrastructure relocation would remove wildlife barriers, thereby allowing for fish passage, as well as offer NBS implementation where it would not previously have been feasible. Other NBS considered in plan development involved regrading of the river to stabilize banks and prevent erosion, as well as widening of the river to create riparian habitat that would connect existing riparian areas to the river corridor (USACE, 2019b).

Table 7-1. Ecosystem restoration measures selected for inclusion in the final National Ecosystem Restoration Plan ("Plan 9").

Measures	Groupings of measures ("sub-alternatives") by reach								
	1-2	2A-2	2B-2	3-3	4-6	5-4	6A-2	6B	6C
Add wetland benches to narrow low flow channel	•					•			
Add wetland benches to improve aquatic habitat		•		•	•				
Add jetties to improve/restore aquatic habitat	•	•		•	•		•	•	•
Relocate sanitary sewers to widen riverbank(s)		•							
Relocate sewer in Reach 1 and widen river to the existing canal	•								
Remove invasive species and plant native vegetation	•	•		•	•	•		•	
Relocate Burlington Canal	•								
Relocate existing Globeville Landing Park Pedestrian Bridge				•					
Replace Confluence Park Diversion with Flashboard Gates						•			
Relocate trolley tracks to widen riverbanks						•			

Measures	Groupings of measures ("sub-alternatives") by reach								
	1-2	2A-2	2B-2	3-3	4-6	5-4	6A-2	6B	6C
Regrade to address bank erosion and stability	•								
Regrade to widen river and connect existing wetland and riparian area to river corridor (p. 137)	•								
Modification of large storm outfall to support new wetlands channel (pp. 138, 139)					•				
Riprap invert and submerged banks of the channel to accommodate deep thalweg (p. 139)						•			
Vegetate existing sand bar to increase wetland area (p. 140)								•	
Convert some existing riparian area to wetlands (p. 137)					•				
Widen through Northside Park to add wetland and riparian area (p. 137)		•							
Restore wetlands channel at 51st Ave storm outfall (p. 137)			•						
Create riparian connection between this riparian area and the South Platte River corridor riparian areas. (p. 137)			•						
Regrade and vegetate approximately 28 acres of habitat through Heron Pond Natural Area and restore approximately 10 acres of upland area (p. 137)			•						
Remove existing concrete ditch and modify storm outfalls (p. 137)			•						
4' tall retaining wall for compensatory conveyance area (p. 138)				•					
Widen into RTD parking lot on west bank and at CDOT parcel on east bank (p. 138)				•					
Add wetland bench and jetties in area of widening (p. 138)				•					
Remove drop downstream of 16th St/ Highlands Bridge (p. 138)					•				
Widening into Cuernavaca Park on west bank to increase riparian area (p. 138)					•				
Two 2' drop structures with fish passage downstream of the RTD drop to tie into existing invert (p. 139)						•			
Add freeboard levees where the top of bank freeboard for the 100-year event is less than 1 foot (p. 139)						•			
Add new section of riffles at upstream end of channel excavation between Colfax Ave and the RTD Bridge (pp. 139, 140)						•			

Measures	Groupings of measures ("sub-alternatives") by reach								
	1-2	2A-2	2B-2	3-3	4-6	5-4	6A-2	6B	6C
Remove upland vegetation and replace with native riparian vegetation along existing banks (p. 140)							•		
Widen east bank to restore wetland and riparian area within the river corridor (p. 140)								•	
Lower bench on east bank at Phil Milstein to restore wetland and riparian area within the river corridor (p. 140)									•

7.1.4 Outcome of Chief's Reports

The Chief's Report, signed July 29, 2019, recommended a combined NER/NED Plan, which, at a 2.875% federal discount rate and a 50-year period of analysis, arrives at an estimated $520.6 million project cost based on 2019 price levels (USACE, personal communication, July 29, 2019). The NER portion of the Chief's Report is focused on the six reaches of the South Platte River defined within the study area, while the NED portion addresses the Harvard and Weir gulches and is focused on FRR. The majority of the project cost is allocated for ecosystem restoration features, at a project first cost of $345.7 million, with $118.2 million estimated for flood risk management features and $32.3 million for recreation (USACE, personal communication, July 29, 2019). In addition to connecting over 450 acres of wetland, riparian, and aquatic habitat, the combined plan also provides an estimated $2.36 million in annual net NED benefits. A BCA was performed on the Gulch plans (NED) but the NER Plan for ecosystem restoration was evaluated on a cost reasonableness basis using habitat units. Although there is no BCR for the NER portion alone, the USACE team calculated the BCR for combined flood risk management and recreation benefits to be 1.39.

In April 2022, USACE announced that $350 million had been secured for the project from 2021 IIJA funding (USACE Omaha District, 2022). Project construction is expected to begin as early as 2024 and is slated for completion by 2043 (USACE, 2019b).

7.1.5 Other Key Considerations

An additional Section 1135 study[25] completed in 2018 examines 2.4 miles of the South Platte River in Denver, south of area covered within this case study (USACE, 2018). The Section 1135 study also examines ecosystem restoration benefits in the NER account, and thus a BCR was not calculated. However, a cost-effective plan was selected by the study, which would cost just under $12.4 million, inclusive of local cost-share from the City and County of Denver. Though this study was completed prior

[25] Section 1135 is part of the USACE Continuing Authorities Program (CAP), which allows for project modifications for improvement of the environment. It was originally authorized in WRDA 1986. Source: Congressional Research Service.

to the 2019 study examined here, it is unclear whether a PPA has been signed with the non-federal sponsor, which is also the City and County of Denver, to begin the project.

7.2 CASE STUDY REANALYSIS: STUDY SCOPE

Table A-5 in Appendix A of this report shows the set of project components that formed the selected alternative, Plan 9, for this case study, including NBS such as:

- Wetlands restoration
- Wetland benches
- Vegetating sandbars
- Addition of jetties and riffles
- Regrading and vegetating additional habitat acreage
- Invasive species removal
- River widening

7.3 ALTERNATIVE FORMULATION

For this case study, the study team examined two alternatives. Plan 8 was the first plan to achieve the project objective of longitudinal connectivity, and as such it was not significantly different from Plan 9 (the RP). Therefore, the first plan examined was Plan 9. The second alternative, Plan 12, is the maximum cost plan considered in both the USACE study and this case study and includes more extensive aquatic habitat restoration in addition to commercial property acquisition for river widening. Plans 10 (adds riffles in Reach 6) and 11 (additional measures in Reach 4) were not easily differentiated in this analysis from Plans 9 and 12. Therefore, Plans 9 and 12 were chosen for comparison in this case study.

7.4 NON-MONETIZED OUTCOME EVALUATION

The study team identified several ecosystem service benefits associated with the riparian, wetland, and aquatic habitat that would be created through the NBS measures identified for this case study (Table 7-2). These included recreational use, flood risk reduction, and impacts to native fauna (abundance, health, and connectivity of habitat).

Table 7-2. Ecosystem services and associated benefit-relevant indicators considered in the South Platte River and Tributaries case study.

Action / approach	Primary metric	Quantifiable (units and method)	Sensitivity of change relative to project	Direct links to beneficial use	Quantification metric of beneficial use	Example of approach to monetize this change	PR&G goal(s)
Riparian habitat creation and restoration	Riparian habitat extent	Acres	Unknown	Recreation	Change in number of recreators or change in the quality of the recreation experience	Measure change in revenue to recreation businesses, contingent valuation methods (willingness to pay, hedonic pricing)	Healthy and Resilient Ecosystems Sustainable Economic Development
			Unknown	Flood risk reduction	Reduction in water surface elevation for a design storm	Direct damages reduced	Public Safety Sustainable Economic Development
	Riparian habitat value for fauna	Edge to area ratio	Unknown	Fauna abundance	Change in abundance of fauna	Natural capital	Healthy and Resilient Ecosystems
		Connectivity	Unknown				Healthy and Resilient Ecosystems Watershed Approach
		Species composition	Unknown	Health of native species	Change in native species and invasive species	Natural capital	Healthy and Resilient Ecosystems
Wetland habitat creation and restoration	Wetland habitat extent	Acres	Unknown	Recreation	Change in number of recreators or change in the quality of the recreation experience	Measure change in revenue to recreation businesses, hedonic pricing models	Healthy and Resilient Ecosystems Sustainable Economic Development
			Unknown	Flood risk reduction	Reduction in water surface elevation for a design storm	Direct damages reduced	Public Safety Sustainable Economic Development
	Wetland habitat value for fauna	Edge to area ratio	Unknown	Fauna abundance	Change in abundance of fauna	Natural capital	Healthy and Resilient Ecosystems
		Connectivity	Unknown				Healthy and Resilient Ecosystems Watershed Approach
		Species composition	Unknown	Health of native species	Change in native species and invasive species	Natural capital	Healthy and Resilient Ecosystems
Aquatic habitat creation and restoration	Habitat value for aquatic fauna	Water quality (sediment, oxygen, flow, pollutants)	Unknown	Fauna abundance	Change in abundance of fauna	Natural capital	Healthy and Resilient Ecosystems
			Unknown	Recreation	Change in number of people fishing or using the river for recreation	Measure change in revenue to recreation businesses, contingent valuation methods (willingness to pay, hedonic pricing)	Healthy and Resilient Ecosystems Sustainable Economic Development
		Connectivity	Unknown				Healthy and Resilient Ecosystems Watershed Approach

One method for quantifying the benefits alternatives provide for recreational use is through evaluating the number of users per day. While the South Platte River and Trails are already popular areas for recreation, this project would improve several key areas of quality, including trail connectivity, water quality and river health, riparian and wetland habitat, and relocation of nuisance or degraded infrastructure.

These quality improvements are significant and enabled the study team to use an abbreviated version of the USACE UDV method of valuing recreation, looking at the change between pre-project and post-project quality improvements (Table 7-3). The study team reviewed the existing UDV methodology detailed in Appendix N of the Feasibility Study (USACE, 2019c) and determined that the analysis did not fully incorporate the improved environmental quality benefits of the restoration actions proposed in the project, as desk research had shown that Coloradans in particular show a high willingness to pay for improved water quality (Loomis et al., 2000). As a result, the study team also developed a second set of UDV scores for Plan 12 to compare the recreation values for Plan 9 and Plan 12.

Table 7-3. Unit Day Value Analysis for the alternatives considered in the South Platte River and Tributaries case study.

Criteria	Range of point values	Plan 9 pre-project UDV points	Plan 9 post-project UDV points	Plan 9 pre-project UDV points (USACE)	Plan 9 post-project UDV points (USACE)	Plan 12 post-project UDV points (compare to Plan 9 pre-project)
Recreation Experience	0-30	10	23	11	22	25
Availability of Opportunity	0-18	7	12	7	12	12
Carrying Capacity	0-14	5	9	5	9	9
Accessibility	0-18	8	14	7	11	14
Environmental Quality	0-20	4	10	4	10	12
Total Points:	0-100	34	68	34	64	72

This analysis generally followed the points and scoring used in the USACE analysis. The same number of annual Recreation Days were used (365) owing to Colorado's mild climate and the variety of recreational uses available in different kinds of weather. The General Recreation category was used, rather than Special Recreation.

For *Recreation Experience* this pre-project score was lowered from USACE's, as that analysis did not appear to account for the degraded ecological function of the river, invasive species, and disconnected nature of the trails. The post-project score was subsequently raised higher than in the USACE analysis, due to the removal of those invasive species and improvement of ecological function, which will enhance the recreational experience. In particular, activities such as birding will improve as a result of the habitat restoration elements of the project. The Plan 12 post-project score is even higher due to the additional regrading and habitat restoration elements, as well as the river widening, included in the plan. Those elements would further improve multiple forms of recreation on and along the river.

For *Availability of Opportunity* and *Carrying Capacity*, the scores were the same as in the USACE analysis.

For *Accessibility*, the pre- and post-project values were slightly higher than in USACE's analysis. The South Platte River in this study area is within urbanized Denver, and thus has Denver's municipal roads available for accessing the site. However, in several reaches, access is severely constrained by sewer, electrical, and railroad infrastructure. Improving accessibility is a major goal of the project. The project will create improvements in accessibility, including relocating sewers and canals, bank regrading, modifying storm outfalls, and improving trail access. The USACE analysis undervalued the trail access improvements from Denver's parks and the relocation of infrastructure components which presently hamper recreation.

For *Environmental Quality*, the pre-project scores were unchanged from USACE values, but the post-project score was higher than USACE's analysis. Just as the NBS in this project enhance the recreational experience, they also improve the aesthetic and ecological function of the South Platte River and the habitat quality for wildlife, fish, and birds. The relocation of infrastructure reduces the risk of pollution, and the removal of invasive species improves habitat function. For these reasons, the score was higher, and higher still in Plan 12, which increases the acreage amount for habitat restoration.

The estimates for *Number of Daily Users* were substantially similar to those used by USACE.

7.4.1 Biophysical Outcomes

The alternatives in this case study all improve the biophysical outcomes of the river and its surrounding habitats. This ecosystem restoration project put forth by USACE is also just one of many projects from local governments and partners to improve the health of the river and its surrounding habitat. The project components such as relocating canals, sanitary sewers, and bridges allow for natural features like bank regrading, river widening, wetland conversion, wetland benches, and riffles. The project also calls for removal of invasive species, to be replaced with native vegetation. These features will improve aquatic habitat for fish by improving water quality, and improve ecosystem health overall, including avian and wildlife habitat.

7.4.2 Benefit-Relevant Indicators

A significant challenge in analyzing this project was isolating pre- and post-project condition and attributing qualitative improvements in ecological function to only the project elements from this study, rather than the many additional projects completed by other agencies and the private sector. South Platte River restoration has been a continuous focus for multiple municipal administrations and has featured in numerous plans. Therefore, many studies, indicators, and metrics are relevant to the project, but not usable in this specific analysis due to risks of double counting, overlap with pre- or post-project condition, or overlap of geographic focus area. However, the literature review showed extensive benefits of ecological restoration beyond what was quantifiable in this rescoped analysis.

For example, the current South Platte River trail is disconnected in portions, and the project will extend trails and create access to the river corridor in areas where none exist. However, the length of the new trail portions is unclear, and the study does not specify which entity is responsible for implementation—USACE or the nonfederal sponsor. Further, the study's alternatives require trail replacements after impacts from project construction or implementation, and as such it is unclear in the study whether the trails in question would be newly created or replacements of existing trails. However, the improved connectivity, and improved design, of trails would provide significant benefits to recreation and transportation in the corridor. However, missing information and clarity prevented the study team from quantifying this benefit.

7.4.3 Additional Quantitative or Qualitative Outcomes of Interest

7.4.3.1 Economic

A major source of benefits that was not incorporated into the analysis was the increase in property values that occurs adjacent to improvements such as those analyzed in this study. The difficulty in separating property value increases from this study alone, compared to property value increases attributable to other improvements in Downtown Denver, is apparent, despite the demonstrable impact of South Platte River improvements on property values overall. Summit Economics, LLC completed a study for the Greenway Foundation in 2017 that estimated the economic and fiscal impacts of improvements made to the South Platte River to downtown Denver and surrounding areas over the past 50 years (Doedderlein & Binnings, 2017). The study emphasized that these improvements have generated $18 billion in property values that would not otherwise exist today. The study also estimated economic benefits of the river's improvements on Denver's recreation, tourism, health, transportation, and natural capital.

The other major source of economic benefit that were not considered is FRR. The ecological improvements to the South Platte River are dependent on the relocation of critical infrastructure such as sewers and culverts. This relocation away from the river hardens that infrastructure against flooding impacts, while the improvements to the natural systems of the river provides more room for the river to manage stormwater overflows. The additional connections to park space along the river also provide stormwater management features. The USACE study team noted that for the South Platte ecosystem restoration portion, incidental FRR benefits could occur, but that based on past efforts, were not likely to be cost-beneficial. However, combined with other sources of benefits, the FRR benefits may have outweighed the costs. Qualitatively, the study team anticipates valuable FRR benefits from this project.

7.4.3.2 Environmental

An environmental benefit that was not quantified was connectivity of wetland and riparian habitat. Despite an abundance of literature on the value of connecting similar habitats and wildlife corridors for greater ecosystem benefits, the majority reflect forest connectivity in rural and exurban areas and are too dissimilar to the study area. The study team was unable to locate literature analyzing the fiscal benefits of connecting wetland and riparian zones in densely populated, highly developed urban landscapes. Therefore, although riparian and wetlands connectivity almost certainly provide an abundance of benefits (financial, social, and environmental), without empirically proven $/acre values to rely upon, this metric was dropped from quantification. Exploring the value of this type of habitat connectivity may be an area for future study.

Similarly, the benefits of river infrastructure removal, which connects the river itself, were qualitatively beneficial for aquatic wildlife and vegetation. However, specific metrics quantifying the benefits of this connectivity were difficult to identify, and as such the study team deemed valuation of natural capital to be an appropriate substitute. This type of benefit may also be an area for future study.

Additional literature showed that Colorado residents specifically are willing to pay for water quality improvements and ecosystem services; the study found that Coloradans would pay an additional $21 per month on their water bill (Loomis et al., 2000). The study extrapolated this value to a total range of $19 million to $70 million, which exceeded water leasing and conservation easement costs to produce those services. This is strong quantitative and qualitative evidence that Denverites, and Coloradans more broadly, would value the ecosystem restoration components of this study. This metric could not be incorporated into the analysis because of the uncertainty range, the risks of double-counting, and the unclear pre- and post-project condition.

7.4.3.3 Social

Like many U.S. cities, Denver has encouraged residential and commercial development in its downtown core. Amenities like the South Platte River trails and adjacent parks are highly desirable and increase property values, as noted by the Summit Economics study. Additional residential density in downtown, as is projected by the River Mile project and others, has an ecological benefit of increasing population in urbanized Denver, rather than the fringes of the metropolitan area, which is part of the wildland-urban interface (WUI) and faces increased wildfire risk. Amenities and ecological restoration projects that encourage development in the core, rather than the fringe, may reduce wildfire damages in the future.

7.5 MONETIZED VALUATION

The study team performed additional analysis to revalue both the selected NER alternative, Plan 9, as well as the more comprehensive Plan 12.

7.5.1 Valuation Methods and Key Assumptions

The rescoped study focused on two factors for comparison and valuation of Plans 9 and 12: recreation and natural capital. Because the South Platte River and Trails are already somewhat improved from their industrial condition, popular with Denverites for recreation, and a key focus of regional ecosystem restoration efforts, determining pre- and post-project values was critical. The site is home to a number of recreational opportunities, including walking, kayaking, tubing, and birding.

The UDV for Recreation method was used to value these activities. The entire South Platte watershed in Colorado was the subject of an EPA Urban Waters Partnership effort that valued the natural capital assets in great detail, developing a comprehensive report and decision support tool (Ecosystem Sciences Foundation, 2017); this rescoped BCA used these values for the natural capital assets component of the project. By limiting the valuation to these broader metrics, and considering pre- and post-project condition, the study team limited the potential impacts of double counting or over-valuing project benefits.

7.5.1.1 Recreation

The study team's additional sources of value for the project come from two sources. First, the study team calculated the benefit from recreation services using a unit day methodology for Plan 12 using the same approach as was used to calculate recreation services for the South Platte region more broadly in the USACE study. While this is a standard USACE method, it does require certain assumptions about what broad range of quality a particular recreation area falls under. Additionally, it is not typically performed for restored habitat, so using it to assess the improvement in recreation under Plan 12 requires assuming that habitat restoration improves. The total annual benefit increase from UDV was calculated at FY19 price levels to be $1.95 million for Plan 9, and $2.13 million for Plan 12 (Table 7-4).

Table 7-4. Unit Day Value analysis for South Platte River and Tributaries using FY 2019 price levels.

Criteria	Range of point values	Plan 9 pre-project UDV points	Plan 9 post-project UDV points	Plan 9 pre-project UDV points (USACE)	Plan 9 post-project UDV points (USACE)	Plan 12 post-project UDV points (compare to Plan 9 pre-project)
Total Points:	0-100	34	68	34	64	72
UDVs for General Recreation	$4.50 - $13.50	$6.83	$10.00	$6.83	$9.79	$10.31
Daily Users	-	1500	1560	1480.5	1554.5	1560
# Of Annual Recreation Days Used	-	365	365	365	365	365
Total Recreation Value	-	$3,739,425	$5,694,000	$3,690,812	$5,554,773	$5,870,514
Annual Benefit Increases (UDV) resulting from project	-	-	$1,954,575	-	$1,863,960	$2,131,089

7.5.1.2 Natural Capital

The study team additionally considered the increased value of natural capital from both projects. This requires knowing both how many additional acres of natural habitat are created and improved by each project as well as placing a value on the improvement. Unfortunately, the report does not provide a breakdown of how many additional acres are created under Plan 12 as compared to Plan 9, so the study team used the acreage numbers for Plan 9 for both (336 acres). The study team assumed that each acre provides the same natural capital value. This assumption is unrealistic as the improvement from each acre is not likely uniform. To avoid overcounting, the study team used a conservative value for the benefit.

The Natural Capital metric used in this rescoped case study analysis was derived from a 2017 report, the *South Platte Watershed Natural Capital Resource Assessment* (Ecosystem Sciences Foundation, 2017). This report and accompanying decision support tool were a result of the collaborative, stakeholder-driven South Platte Urban Waters Partnership process led by USFS and USEPA. This extensive process engaged dozens of stakeholders to examine the natural capital of the entire South Platte watershed. As a whole, the South Platte Urban Waters Partnership process determined that the watershed provides approximately $7.4 billion per year in ecosystem services to the economy and people of the watershed.

The accompanying web-based decision support tool allows for more granular examination of parcels within and near the study area.[26] The current pre-project value for South Platte River parcels averages $605 per acre per year with an Ecosystem Services Valuation (ESV) rating of 3. The highest available value for the river in pre-project condition is $1,923 per acre per year with an ESV of 4. Because the NER Plan has not yet been constructed, it is not possible to calculate post-project ESV values using this tool; the study team determined that it was reasonable to assume that the mean post-project value would be the highest pre-project value of $1,923 per acre per year. Thus, the project natural capital benefits are conservatively calculated at $1,318 per acre per year ($1,923 minus the pre-project value of $605). These benefits may be undercounted; the study itself notes that investments in areas with low ESV value such as $100 per acre can increase their ESV to up to $3,000 per acre (Ecosystem Sciences Foundation, 2017).

7.5.2 Updated Benefits

Drawing on a natural capital assessment for the South Platte region from the USEPA the study team estimate the added annual benefit per acre to be $1,962. Across the 335.8 new and restored acres of habitat this sums to a total of $657,000 in annual benefits. The equation for the annual cash flow is:

$$C_{NC,t} = B_{NC} * A$$

Where $C_{ES,t}$ is the equivalent cash value of the total natural capital value for year t, B_{ES} is the natural capital value per acre and A is the number of acres associated with a plan.

Using the UDV methodology, the study team determined that Plan 12 would yield a total of $2,131,000 in annual recreation benefits compared with $1,864,000 as calculated in the original report. This is an increase in annual recreation benefits of $267,000. The equation for the annual cash flow is:

$$C_{UDV,t} = B_{UDV} * D$$

[26] The tool is available online at https://pg-cloud.com/NaturalCapital/.

Where $C_{UDV,t}$ is the equivalent cash value of the total unit day valuation for year t, B_{UDV} is the value generated per day and D is the number of days for the project area.

7.5.3 Updated Costs

No updates were made by the study team to the cost calculations outlined in the USACE feasibility study.

7.5.4 Benefit-Cost Comparisons

7.5.4.1 Planning Analysis

Table 7-5 contains a breakdown of the final AAEQ numbers used in the study team's analysis. Across all NED sections of the original study (the flood risk and recreation portions of the study), the original AAEQ benefit of $8,411,000, and AAEQ cost of $6,051,000 combine for a BCR of 1.4. However, this does not account for the NER aspects of the study associated with South Platte specifically. The NER component of the study is substantially more costly than the NED (additional AAEQ costs of $15,447,000), which lowers the BCR below 1.0 to 0.39 when NER benefits are not included in the calculation. Plan 12 has slightly larger NER costs and thus a slightly lower BCR of 0.36 when not accounting for NER benefits.

The additional NER benefits that were included in this analysis were approximately an order of magnitude below the calculated NER costs. Thus, they are not enough for either Plan 9 or Plan 12 to reach a BCR of 1.0 (0.42 and 0.40 respectively). Nor are the added benefits of Plan 12 enough to give it a higher BCR than Plan 9. While the new benefits calculated by the study team were not enough to overcome the relatively large NER costs of this study, it is important to note that the team was not able to quantify every source of benefit associated with the project. As little as $328,000 in additional NER benefits would have been enough to give Plan 12 a higher combined BCR than Plan 9, though it would have taken an additional $13.67 million in NER benefits for Plan 12 to have a BCR greater than 1.0.

Table 7-5. Table of AAEQ benefits and costs using planning analysis assumptions.

	Plan 9	**Plan 12**
Benefit/Cost Source	AAEQ (millions of dollars)	AAEQ (millions of dollars)
NED Benefit	$8.41	$8.41
NED Cost	$6.05	$6.05
NED BCR	1.4	1.4
NER Cost	$15.45	$16.96
Natural Capital	$0.66	$0.66
Additional Recreation	$-	$0.27
Combined BCR	0.42	0.40

Note: includes benefits, costs, and BCR calculations from both the original feasibility study and case study reanalysis. AAEQs are in millions of dollars.

7.5.4.2 OMB Process Analysis

Table 7-6 contains a breakdown of the final AAEQ numbers used in the study team's analysis with the OMB discount rate of 7%. The NED only BCR for Plan 9 drops to 0.67, well below 1.0. Adding the costs of the NER components of the study (inflated by the increased discount rate) along with meager monetized benefits results in very low overall BCRs. As under the planning analysis assumptions, not all benefits have been monetized but more benefits are required to achieve a BCR of 1.0.

Table 7-6. Table of AAEQ benefits and costs using OMB assumptions.

	Plan 9	Plan 12
Benefit/Cost Source	AAEQ (millions of dollars)	AAEQ (millions of dollars)
NED Benefit	$8.41	$8.41
NED Cost	$12.47	$12.47
NED BCR	0.67	0.67
NER Cost	$31.32	$37.05
Natural Capital	$0.66	$0.66
Additional Recreation	$-	$0.27
Combined BCR	0.21	0.19

Note: includes benefits, costs, and BCR calculations from both the original feasibility study and case study reanalysis. AAEQs are in millions of dollars.

7.6 PRIORITIZATION AND ALTERNATIVE SELECTION

The quantitative and qualitative ecosystem service benefits associated with Plans 9 and 12 are all positive, making the alternatives more desirable and beneficial across many stakeholder categories when compared to a FWOA alternative (Table 7-7). The study team applied a simple ranking system to compare these plans and benchmark the outcomes as part of a MODA (Table 7-8). In this assessment, the property value increases and flood risk reduction benefits of each of the plans is estimated to be high (ranked a 2) compared to the FWOA (ranked a 0), while the impacts to riparian and wetland habitat connectivity, river connectivity, and water quality are considered low (ranked a 1 compared to the FWOA ranked as 0).

Impacts of the plans on development within the WUI are assumed to be very low, so this benefit is ranked a 0 in all cases. The primary differences between the two plans are in the recreational use and natural capital value provided, with Plan 12 providing increased benefit (ranked a 2) when compared to Plan 9 (ranked a 1) and the FWOA (ranked a 0). These improvements come at a financial cost, however. This analysis suggests that the differential benefits for Plans 9 and 12 could be best distinguished through additional consideration of stakeholder preference and/or quantification of the expected benefits. In addition, tradeoffs of some of the expected outcomes (e.g., potential for property value increases to lead to exclusion of some home buyers) should be considered.

Table 7-7. Benefits likely to accrue from project implementation that were not calculated in this analysis.

Benefit	Certainty of impact	Magnitude of benefit	Tradeoffs to note
Increase in adjacent property values	High	High	Property value increases, over time, will exclude new homebuyers if wages do not keep pace.
Flood risk reduction	Medium	High	The stormwater capacity of the features may impair its recreational value or have other uncertain ecological costs.
Riparian and wetland habitat connectivity	High	Medium	
River connectivity	High	Medium	
Water quality improvements	High	Medium	
Discourage development in WUI	Low	Low	Without a growth boundary explicitly discouraging fringe growth, the certainty of this impact is low.

Note: Magnitude of benefit is not distinguished between Plan 9 and Plan 12 due to lack of supporting information (e.g., additional ecosystem acreage in Plan 12).

Table 7-8. Benefits and costs associated with alternatives considered in the South Platte River and Tributaries case study.

	Alternative		
	0. Future without Action	1. Plan 9	2. Plan 12
Recreation use	0	1	2
Natural capital improvements	0	1	2
Property values	0	2	2
Flood risk reduction	0	2	2
Riparian and wetland habitat connectivity	0	1	1
River connectivity	0	1	1
Water quality	0	1	1
Discourage development	0	0	0
Cost	2	-1	-2

Benefits identified for this case study, including recreation use, natural capital improvements, property value increases, flood risk reduction, riparian and wetland habitat connectivity, water quality improvements, discouraging development in the wildlife-urban interface, and cost. For each benefit, a numerical value is provided indicating the benefit provided by that alternative relative to the others on a scale of 0 (no benefit) to 2 (maximum benefit). A description of the measures included in each plan can be found in Table 7-2.

7.7 DISCUSSION

The rescoped BCA did not show the ecological restoration project as broadly beneficial in economic terms. The study team was not able to separate the impacts from this specific set of ecological restoration measures from the restoration that has occurred more broadly along the South Platte River in Denver over the past several decades, and so the metrics used in the rescoped analysis were conservative. All qualitative evidence, as well as high-level quantitative evidence that looks at the river's restoration more broadly, shows that these restoration projects are highly desired by residents and visitors, that they appreciate and are willing to pay for additional ecosystem services, and that the co-benefits are significant and likely outweigh the costs.

This disconnect between the broad desirability of the project—consider the coalition of governments, organizations, and businesses that have pushed not just for this project, but additional restoration along the corridor—and the low score of the BCA is instructive. Evaluating ecosystem restoration projects using a BCA is difficult, especially if they are part of a broader program or multi-decade effort. The USACE study used a cost-reasonableness analysis based on habitat units; this resulted in the selection of a plan that did not incorporate all the measures assessed but did include most of them. This analytical method essentially forced the assembly of smaller projects into one larger composite study, which was then assessed by cost reasonableness by habitat unit. The cost reasonableness method is not designed to consider additional benefits, either quantitative or qualitative, or to assess if a project's assembly of features will be able to achieve the overall project objectives. Some potential benefits were not quantifiable in this analysis, but could be areas of future study, including examining fiscal benefits of connecting wetland and riparian zones in dense urban areas, as well as the connectivity benefits for the river that result from the removal of infrastructure. However, quantifying these kinds of benefits would not impact the cost reasonableness method used in this case study.

Changing the project's assembly and evaluation process may have allowed for the additional quantification of benefits that were difficult in this project because it was one set of ecosystem improvements amid a larger multi-decade effort to improve the river. Setting an overall ecosystem function or restoration goal, delineating the ecosystem restoration outcomes they wanted to achieve and then designing a project that would meet those outcomes, would allow for a more holistic project analysis. Combined with some standard values for recreation benefits, water quality improvements, or other qualitative measures, this would make ecosystem restoration projects easier to value and opening up the BCA as a potential analytical tool to use rather than the cost-reasonableness approach. Additionally, with a broadly beneficial project designed to meet top level restoration outcomes, it may be easier to bring in other nonfederal sponsors to contribute to the project. In the case of South Platte, many other agencies and partners are interested and invested in this work; rather than designing additional restoration projects with the hope of them all working together as one system, a funding partner could be secured for a portion of the larger restoration project that was designed and evaluated as a whole.

8.0 JAMAICA BAY

8.1 OVERVIEW

Jamaica Bay is located the southwestern tip of Long Island, NY between Brooklyn (Kings County) and Queens County, with a small portion of the bay located in Nassau County. The bay is east of New York Bay, which it connects to through Rockaway Inlet. According to NYC DEP, "Jamaica Bay contains approximately 16,000 acres of surface waters" which are mostly shallow, and "3,000 acres of islands and marshes" (NYC Department of Environmental Protection, n.d.).

Jamaica Bay is known for being a complex urban ecosystem (USGS, 2021) that serves as protection from storms and home to both migratory and resident bird and fish species. The area also provides park and beach access to hundreds of thousands of New Yorkers each year, including several low-income census-block groups. Jamaica Bay is also home to a large portion of Gateway National Recreational Area, which was established when the enabling legislation was adopted in 1972, to "preserve a mosaic of coastal ecosystems and natural areas interwoven with historic coastal defense and maritime sites" (National Park Service, 2017).

After Hurricane Sandy made landfall on the Atlantic Coast of New York in 2012, Rockaway Inlet, Rockaway Peninsula, and Jamaica Bay experienced some of the most devastating impacts in the region, with over 1,000 structures damaged or destroyed and 10 fatalities. According to the USACE 2019 *Integrated Hurricane Sandy General Reevaluation Report* (HSGRR), in addition to significant storm surge damage, low-lying northern and central neighborhoods surrounding Jamaica Bay faced disproportionate devastation from flood waters. This area is characterized by narrow creeks and basins, which exacerbated flooding (USACE, 2019d).

In addition to structural damage to buildings, other impacts included disrupted transit service due to subway damage, widespread school closures, and habitat destruction for waterfowl and coastal waterbirds. According to the report, "High winds from storm-driven water moved masses of coastal sediments, changed barrier landscapes, and blew out dikes on impoundments managed specifically for migratory birds" (USACE, 2019d). The project area's low-lying elevation, dense population, and extensive development place it at particularly high risk for storm surge inundation because heavy urbanization has degraded coastal ecosystems and processes that historically provided a buffer against tidal flooding.

8.1.1 Project Goals

USACE conducted two feasibility studies in the area containing East Rockaway Inlet to Rockaway Inlet and Jamaica Bay after Hurricane Sandy: *The Integrated Hurricane Sandy General Reevaluation Report* (HSGRR) *and Environmental Impact Statement* (EIS), and the *Hudson-Raritan Estuary* (HRE) *Ecosystem Restoration Feasibility Study* (USACE, 2019d, 2020b). The study team considered NBS from both studies for this case study analysis.

8.1.1.1 Hurricane Sandy General Reevaluation Report and Environmental Impact Study

USACE initiated the 2019 HSGRR/EIS to build upon earlier USACE hurricane risk reduction efforts in the area that date back as far as 1965. The purpose of the 2019 HSGRR was to address CSRM needs and simultaneously "maximize contributions to [NED]" (USACE, 2019d). Project goals included reducing vulnerability, future flood risk, and economic costs of large-scale flood and storm events, supporting long-term sustainability of the coastal ecosystem, improving community resiliency, and enhancing natural storm surge barriers. Figure 8-1 shows the geographic area of focus and High Frequency Flood Risk Reduction Feature (HFFRRF) project sites identified in the recommended plan.

The stated objectives of the feasibility study include:

- Objective 1: Reduce vulnerability to coastal storm risks;
- Objective 2: Reduce future coastal storm risks in ways that will support the long-term sustainability of the coastal ecosystem and communities;
- Objective 3: Reduce the economic costs and risks associated with large-scale flood and storm events;
- Objective 4: Improve community resiliency, including infrastructure and service recovery from coastal storm events; and
- Objective 5: Improve coastal resilience and reduce the risk caused by frequent flooding.

Figure 8-1. Hurricane Sandy General Reevaluation Report/Environmental Impact Statement Recommended Plan for High Frequency Flood Risk Reduction Feature sites.

8.1.1.2 Hudson-Raritan Estuary Ecosystem Restoration Feasibility Study

The focus of the HRE Ecosystem Restoration Feasibility Study was to recommend a NER Plan that would "address long-term and large-scale degradation of aquatic habitats that support the overall HRE program goal," which includes the development of diverse habitats that provide renewed and increased benefits to society (USACE, 2020b).

The study objectives included the following:

- Objective 1: Restore the structure, function, and connectivity of estuarine habitat in the HRE;
- Objective 2: Restore the structure and function, and increase the extent of freshwater riverine habitat in the HRE;
- Objective 3: Restore the structure and function, and increase the extent of marsh island habitat in Jamaica Bay; and
- Objective 4: Increase the extent of oyster reefs in the HRE.

The HRE geographic scope covers a broad area of New York and New Jersey and includes both perimeter and marsh island sites located in Jamaica Bay (Figure 8-2). This case study draws specifically on the evaluation and site selection conducted for the Jamaica Bay estuarine habitat.

8.1.2 Alternative Formulation Process

8.1.2.1 HSGRR/EIS

For this project, the USACE PDT worked in consultation with the non-federal sponsor (the New York State Department of Environmental Conservation [NYSDEC]), the City of New York, and state and local agencies, among others, to form alternative plans for two separate planning reaches (see Figure 8-3). The Atlantic Ocean Shorefront Planning Reach centered around mitigating inundation, erosion, wave attack, and overtopping along the Rockaway Peninsula, while the Jamaica Bay Planning Reach addressed the storm surge that propagates in the bay after entering Rockaway Inlet and/or overtopping the Rockaway Peninsula and Coney Island.

With guidance from USACE, the study team identified the bay-side planning reach as most relevant for this case study and methodology review, with a specific focus on the HFFRRF alternatives formulated with NBS.

Figure 8-2. Hudson-Raritan Estuary restoration project sites.

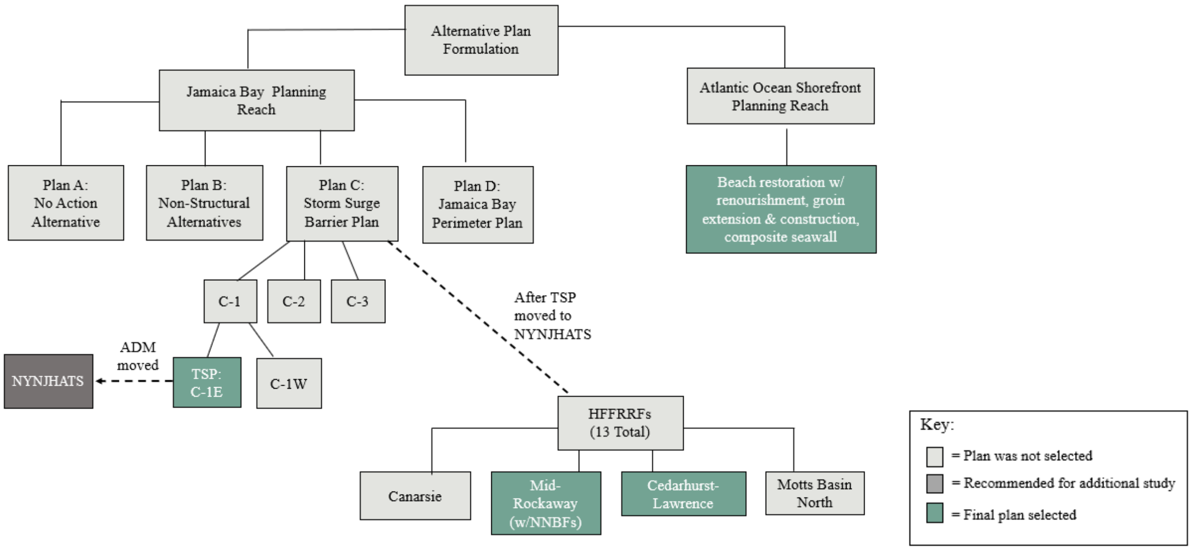


Figure 8-3. Hurricane Sandy General Reevaluation Report/Environmental Impact Statement alternative formulation and selection process.

8.1.3 Consideration of Nature-Based Solutions

The PDT established a goal of incorporating NBS components into the HFFRRFs at the outset of the project, and several NBS became crucial elements of the RP. After screening for cost effectiveness and feasibility, the PDT determined that including beach restoration and renourishment to enhance the Atlantic Ocean Shorefront Planning Reach's structural components would together provide the lowest annualized costs of the project's 50-year lifespan and provide recreational co-benefits (USACE, 2016a). After the Jamaica Bay Planning Reach Storm Surge Barrier Plan was moved to the New York and New Jersey Harbor and Tributaries (NYNJHAT) study, the PDT identified location-appropriate, standalone HFFRRFs that could be designed to both operate with an eventual barrier and function independently. Several of the proposed HFFRRFs included NBS components. The PDT ultimately found that NBS could enable "co-location with the flood risk reduction features in order to take advantage of their capacity to improve the function and resilience of the structural features" (USACE, 2016a). The final report notes that NBS are crucial for controlling erosion and are self-mitigating.

NBS sites (see Table 8-1) were identified using four criteria: high frequency flooding clusters (areas where NBS would mitigate risk for communities facing frequent coastal storms), existing bathymetry and lateral space, site suitability (sites were considered suitable if they contained less anthropogenic infrastructure), and wave attenuation and erosion control (USACE, 2019d).

Table 8-1. Hurricane Sandy General Reevaluation Report/Environmental Impact Statement alternative formulation and benefit-cost analysis.

Planning reach	Preliminary HFFRRF alternatives	NNBF component	Project phase		
			Prelim. HFFRRF screening (w/BCR)	Final HFFRRF screening (w/BCR)	Final Recommended Plan (w/BCR)
Jamaica Bay	Mid-Rockaway Arverne Site 1	High Berm + Limited Seaward Marsh Extension	1.8	1.4	1.1
	Mid-Rockaway Arverne Site 2	Low Berm + Limited Seaward Marsh Extension	1.8	1.4	1.1
	Mid-Rockaway Arverne Site 3	Low Berm + Full Seaward Marsh Extension	1.8	1.4	1.1
	Mid-Rockaway Edgemere Area	High Berm + Full Landward Marsh Extension	1.8	1.4	1.1
	Norton Basin	Shoreline Excavation for Phragmites Removal with Intertidal and High Marsh	<1		
	Bayswater	Shoreline Extension with Intertidal or High Marsh	<1		
	Motts Basin North (NNBF component)	Shoreline Extension with Intertidal or High Marsh	1.8*	*	*
	Motts Basin South	Shoreline Excavation for Phragmites Removal with Intertidal Marsh	<1		
Atlantic Ocean Shorefront	Atlantic Shorefront of Rockaway Peninsula (from Beach 9th St to Beach 149th St)				2.6

KEY

- (grey box) Measure was carried forward through this stage
- (white box) Measure was eliminated at or before this stage

**Note: The PDT screened the Motts Basin North (MBN) HFFRRF in Phase 2 (BCR 1.3), but the NBS component was eliminated in the preliminary screening, as the existing mudflat would be adversely impacted by conversion to intertidal marsh. The MBN HFFRRF was removed from the final plan due to a rise in construction costs and the corresponding BCR dropping to 0.8.*

8.1.3.1 HRE Ecosystem Restoration Feasibility Study

Grounded in the HRE Ecosystem Restoration Feasibility Study objectives, USACE developed target ecosystem characteristics (TECs) to tie restoration goals to specific actions. The TECs included wetlands; habitat for waterbirds; coastal and maritime forests; oyster reefs; shorelines and shallows; habitat for fish, crab, and lobsters; and tributary connections. The Comprehensive Restoration Plan (CRP) goals (both short-term and long-term) involve restoring, enhancing, and expanding habitats that provide secondary CSRM benefits such as wave attenuation, shoreline stability, shoreline resiliency, and improved water quality and storage (USACE, 2020b). The RP in the Jamaica Bay Planning Region included marsh restoration for two perimeter sites (Dead Horse Bay and Fresh Creek) and five marsh island sites (Duck Point, Stony Creek, Pumpkin Patch East, Pumpkin Patch West, and Elders Center). The plan also included an oyster reef restoration project at the Head of Jamaica Bay.

8.1.4 Outcome of Chief's Reports

8.1.4.1 HSGRR/EIS

The Chief's Report was signed August 22, 2019. According to the Chief's Report, "Based on a 2.875-percent discount rate and a 50-year period of analysis, the total equivalent average annual costs of the project are estimated to be $10,737,000, including monitoring and OMRR&R. All project costs are allocated to the authorized purpose of storm damage reduction and shoreline protection."[27] Additionally, the average annual benefits of the RP are $11,851,000, with a BCR of 1.1 (USACE, 2019a).

8.1.4.2 HRE Ecosystem Restoration Feasibility Study

The Chief's Report recommends a series of ecosystem restoration projects that will restore nearly 200 acres of habitat in the Jamaica Bay Planning Region (throughout both perimeter sites and marsh island sites) and reduce long-term and large-scale degradation in HRE. The report was signed in May 2020 and received congressional authorization in December 2020. The RP includes several geographies within HRE. The plan includes restoration at 20 locations, including five marsh island sites, two perimeter sites, and one site for oyster restoration at the Head of Jamaica Bay. The total first cost of the project was $180,574,177 and the fully funded cost (escalated to mid-point of construction) was $267,340,000 (FY21 price level; USACE, 2020a).

8.2 CASE STUDY REANALYSIS: STUDY SCOPE

The purpose of this case study analysis was to consider an integrated nature-based approach to meet multiple planning goals in Jamaica Bay. The re-scoping process involved defining systems of interest and hypotheses based on available data, and the study team determined that the best approach would be to draw from several parallel USACE planning studies that included NBS but were directed towards different mission areas and goals.

[27] OMRR&R stands for Operation, Maintenance, Repair, Replacement, and Rehabilitation.

To determine the geographic areas of interest, the study team identified actions with overlapping or common geographies interior to Jamaica Bay from both the HSGRR/EIS and the HRE Ecosystem Restoration Study (Table 8-1 and Table 8-2) to consider through the remainder of this analysis. Sponsor guidance led the study team to exclude NBS actions for the Atlantic shorefront focused on beach restoration and renourishment, as these are the most common NBS project types funded and constructed by USACE at present, and as such were of less interest for further investigation. The surge barrier concept was also excluded for this analysis, as it was moved out of the final HSGRR/EIS study and did not include NBS options or alternatives.

Table 8-2. Hudson-Raritan Estuary alternative formulation for actions of interest with common geography identified for this analysis. (cy = cubic yards)

Study	Site	Action	Project cover	BCR		
				Prelim. Screen	Final Screen	Rec. Plan
Hudson-Raritan Estuary Ecosystem (HRE) Restoration Feasibility Study (Perimeter)	Dead Horse Bay	Marsh creation	30.6 acres	BCR not calculated for ER projects		
		Tidal channel/creek restoration	2.31 acres			
	Fresh Creek	Marsh Creation	24.1 acres			
		Tidal channel/creek restoration	45.08 acres			
		Maritime Forest	10.7 acres			
Hudson-Raritan Estuary Ecosystem (HRE) Restoration Feasibility Study (Marsh Island)	Duck Point	Marsh Creation	38.6 acres			
		Sand fill	213,776 cy			
		Tidal channel/creek restoration	1.03 acres			
		Shallows	7.57 acres			
	Stony Creek	Marsh creation	51.5 acres			
		Sand fill	151,360 cy			
	Pumpkin Patch West	Marsh creation	23.2 acres			
	Pumpkin Patch East	Marsh creation	28.8 acres			
		Sand fill	351,952 cy			
	Elders Point Center	Marsh creation	27.5 acres			
		Sand fill	284,891 cy			
	Head of Bay	Oyster Reef Expansion	10.1 acres 340 gabions 30 castles 470 trays			

8.3 ALTERNATIVE FORMULATION

The study team developed new project groupings (suites) from the actions identified in Table 8-3 to compete in the reanalysis and valuation process. Each suite contains different combinations of actions from both original studies, with generally larger investments and broader range of targeted geographies moving towards the higher-numbered suites. This process was patterned in part on an independent study that evaluated integrated CSRM and restoration features for multiple benefits conducted in parallel to the HSGRR effort after Hurricane Sandy (Fischbach et al., 2018).

The study team included some project locations that were identified earlier in the HSGRR screening process but were removed in the Final RP for a variety of reasons, including low preliminary BCR calculations. The study team did this to allow for the consideration of a more robust suite of possibilities and to analyze how including the NBS at these sites, even if considered not economically efficient on an individual basis, might have impacted the final BCR.

Table 8-3. New suites of project sites identified for reanalysis.

Study	Site	Action	Suite 0	Suite 1	Suite 2	Suite 3	Suite 4	Suite 5
Hurricane Sandy General Reevaluation Report (HSGRR)	Arverne	Marsh creation	X	X	X	X		X
	Edgemere	Marsh creation	X	X	X	X		X
	Norton Basin	Marsh creation	X					
	Bayswater	Marsh creation	X					
	Motts Basin North		X					
	Motts Basin South	Marsh creation	X					
Hudson-Raritan Estuary Ecosystem (HRE) Restoration Feasibility Study	Dead Horse Bay	Marsh Creation & tidal channel/ creek restoration			X		X	X
	Fresh Creek	Tidal channel/ creek restoration & maritime forest			X		X	X
	Duck Point	Marsh creation, sand fill, tidal channel/creek restoration, & shallows				X	X	X
	Stony Creek	Marsh creation & sand fill				X	X	X
	Pumpkin Patch West	Marsh creation				X	X	X
	Pumpkin Patch East	Marsh creation & sand fill				X	X	X
	Elders Point	Marsh creation & sand fill				X	X	X
	Head of Bay	Oyster reef expansion				X	X	X

For Suite 0, the study team re-calculated HFFRRF benefits using the most up to date BCRs established by the USACE PDT in the HSGRR/EIS. For Suites 1–5, the study team re-calculated benefits using the final BCRs from the same report. Because it was an Ecosystem Restoration project, there were no BCAs conducted for projects in the original HRE Restoration Feasibility Study.

8.4 NON-MONETIZED OUTCOME EVALUATION

The study team identified a tractable set of metrics that could either be monetized or used to demonstrate non-monetary value through tradeoff analyses. Using the process outlined in Chapter 2 and in (Fischbach et al., 2023), the team compiled the proposed actions in a table to identify ecological indicators, estimated potential changes to the biophysical system, and retained a subset of those biophysical changes to help identify ecosystem services for quantification. These were further filtered based on the existing data available for ecosystem service valuation to arrive at a monetized subset of outcomes for the BCA reanalysis.

To estimate changes to the biophysical system and develop a list of potential ecosystem services, the study team conducted reviews of related literature, collected supplemental information about the study area, and utilized expert judgment in both coastal restoration and flood risk reduction to fill in any remaining gaps. The main action approaches that were considered in the rescoping of this project included marsh creation/tidal channel restoration, maritime buffer forest restoration, and oyster reef expansion. Through this funneling process, the study team identified links to beneficial use related to different types of recreation, fish catchability, and water quality. Once the study team explored monetization opportunities, it became apparent that willingness to pay for recreational activities (using USACE Visitor UDVs) was the most reliable monetization approach requiring the fewest assumptions. Table 8-4 summarizes the results of this process.

8.4.1.1 Assessing the Potential Value of Fish Habitat Using AQUATOX

AQUATOX is an open source, peer reviewed, ecosystem model that is used and distributed by the USEPA (Clough, 2014). The model can be applied to rivers, lakes, and estuaries and traces nutrients, sediments, and organic chemicals in water bodies to model potential impacts on living organisms (encompassing multiple trophic levels from phytoplankton up through higher level nekton such as fish). It was applied in the Deepwater Horizon Natural Resource Damage Assessment framework (DWH NRDA) to assess damages to coastal marshes in the northern Gulf of Mexico as differences in Discount Service Acre Years (DSAYs) or Net Productivity (D-kg, g m^{-2} yr^{-1}) of different trophic levels (Clough, 2014). An additional application of the AQUATOX model has been the comparison of different marsh creation designs in terms of the potential net productivity of various trophic levels that could potentially be supported (Blancher et al., 2017; Blancher & Goecker, 2016). These comparisons are based on the physical structure of the marsh, including the relative complexity and length of marsh edge (calculated as a fractal measure of marsh morphology) and water volume.

The study team applied the model to one of the marsh creation projects, Dubos Point, indicating that this approach may have potential utility for future assessments. The level of effort for new analysis with AQUATOX for all actions considered, however, was determined to be out of scope of the current study and was not pursued further. The case study analysis presented here instead utilized previously calculated assessment components. However, this report returns to the opportunity presented by AQUATOX and similar numerical models for future USACE studies in Chapter 9.0.

Table 8-4. Ecosystem services and associated benefit-relevant indicators considered in the Jamaica Bay case study.

Study	Action / approach	Primary metric	Quantifiable (units and method)	Sensitivity of change relative to project	Direct links to beneficial use	Quantification metric of beneficial use	Approach to monetize this change	PR&G goal(s)
HSGRR & HRE	Marsh creation/Tidal Channel Restoration	Marsh extent	Area (acres/ha)	At local spatial scales (100s of m to kms), project will result in measurable change	Recreation Bird watching	Change in number of people bird watching (e.g., people birdwatching per year)	Park entrance fees to access bird watching. Proportion of revenue supporting local businesses	Sustainable Economic Development
					Recreation Kayaking	Change in number of people kayaking (e.g., people kayaking per year)	Applying quality adjustments to recreation day values (USACE Visitor UDVs) to represent the WTP for a recreation trip	Sustainable Economic Development
					Recreation Viewshed from shoreline	Change in number of people visiting for the viewshed (# people per year) Change in number of people picnicking in the adjacent shoreline park areas (# people per year)	Applying quality adjustments to recreation day values (USACE Visitor UDVs) to represent the WTP for a recreation trip	Sustainable Economic Development
		Marsh habitat value for fauna	Edge to area ratio and volume	Within project area (created marsh) Measurable change with implementation	Recreation Fishing catchability (edge ratio directly impacts value)	Change in number of people fishing. Change in recreational fish catch from area or launch site	Support to local businesses Boat ramp launch fees	Sustainable Economic Development

Study	Action / approach	Primary metric	Quantifiable (units and method)	Sensitivity of change relative to project	Direct links to beneficial use	Quantification metric of beneficial use	Approach to monetize this change	PR&G goal(s)
HRE	Maritime Buffer Forest Restoration	Forest extent	Area (Acres)	At local spatial scales (100s of m to kms), project will result in measurable change	Recreation Wildlife viewing	Change in number of people viewing wildlife (e.g., people wildlife viewing per year)	Revenue from park visitation and apportioned revenue from those visitors to the surrounding businesses	Healthy and Resilient Ecosystems
HRE	Oyster Reef Expansion	Water quality	Using AQUATOX model	At local spatial scales (100s of m), project will result in measurable change.	Water quality			Healthy and Resilient Ecosystems
		Habitat value for fauna	Edge to area ratio and volume	At local spatial scales (100s of m), project will result in measurable change.	Recreation Fishing catchability	Change in number of people fishing. Change in recreational fish catch from area or launch site	Support to local businesses Boat ramp launch fees	Sustainable Economic Development

8.4.2 Biophysical Outcomes

8.4.2.1 Arverne, Edgemere, Motts Basin South, and Norton Basin Marsh Creation

The sites are currently dangerous with abundant trash, abandoned cars, and derelict buildings. After the project, the sites would have basic facilities, be safe, and the condition would not detract from recreational activities. Finally, the environmental quality of the sites is currently poor with derelict buildings and vehicles, this would become above average for the neighborhoods, recognizing that high quality viewsheds may still need to be selected carefully.

8.4.2.2 Bayswater and Motts Basin North Marsh Creation

Recreational opportunities at the sites include fishing, walking, cycling, and picnicking. High quality walking is expected to be provided after implementation of each project. In addition, the current average aesthetic quality is expected to increase to above average aesthetic quality for the area with improved marsh edge with project implementation.

8.4.2.3 Duck Point, Stony Creek, Pumpkin Patch West, Pumpkin Patch East, and Elders Point Marsh Island Restoration

These marsh islands are currently in a degraded state, so there are several other sites within one hour of travel time. Once restored, there would be no equivalent habitats within less than a two-hour travel time. Currently the sites have average aesthetic quality since these are degraded marshes and therefore mostly open water. After implementation of the project, the sites would have outstanding aesthetic quality of marshes with creeks and edge features.

8.4.3 Benefit-Relevant Indicators

8.4.3.1 Environmental

8.4.3.1.1 Bird Watching

Jamaica Bay and the surrounding area (Gateway National Recreation Area) is composed of marshes and island habitats that support several bird species. This area is located along the Atlantic Flyway and is important for migrating, breeding, and foraging birds. Bird abundance is a potentially useful metric to use for valuation, however, there are several factors to consider. Habitat area alone should not be used as a reliable indicator of bird abundance (Benoit & Askins, 2002; Rehm & Baldassarre, 2007).

Bird abundance is influenced by factors such as hydrology, prey availability, predators, and disturbance. An important food resource for birds in this area includes benthic organisms and small fish (Davis et al., 2017). The presence of these and other prey organisms can be indicative of bird abundance. Additionally, the presence and management of manmade areas in the vicinity such as landfills and airports have also been shown to influence the numbers of certain bird species in the area, such as Herring Gulls and Laughing Gulls (Brown et al., 2001). There are also seasonal variations in bird abundance to consider, with higher numbers of certain species recorded during fall and winter (Davis et al., 2017).

The presence of birds in and around Jamaica Bay attracts many bird watchers to the area. Bird watching was considered as a metric for valuation, but this statistic also proved challenging. The National Park

Service statistics reports for the area [28] do not break down recreational visits by birdwatchers. Don Riepe, co-chair of the Jamaica Bay Ecowatchers estimates that about 35,000 people go to the refuge annually to see and enjoy birds (personal communication, May 2021).

However, as noted above, since habitat creation is not necessarily correlated to bird abundance, it should be noted that the number of bird watchers in the area is unlikely to be influenced by habitat creation alone. The presence of bird watchers will predominately depend on the availability and quality of bird watching areas. It should also be noted that there are no entrance fees to the refuge, however it may be possible to quantify the average distance traveled by each visitor and money spent on travel.

8.4.3.1.2 Kayaking

Visitation to the Jamaica Bay area for kayaking was also considered as a potential metric. A kayaking trail map is available through the National Park Service [29] in which kayak launch points and access areas are identified. The National Park Service statistics reports for the area[30] do not break down recreational visits by kayakers. Kayaking permits are $15 and required by the state of New York, however permits are not location-specific, so could not be used as a meaningful measure of the quantity of kayaking recreation.

Using census data and estimated walking times, the study team calculated that there are a total of 4,275 residents who live within walking distance of one of the kayak launches (see Appendix A, Section A.4). 3,250 of these residents live near Canarsie Pier. However, once again, this only provides potential users and could not confidently be connected to the number of kayakers actually using the natural resource areas.

8.4.3.1.3 Fishing

The study team considered the potential improvement in fishing via a catchability metric. This was explored using the AQUATOX model as discussed in the previous section. Shallow vegetated marsh habitats are known for their high abundance of juvenile fishes and other species of nekton (Castellanos & Rozas, 2001). The productivity of these marshes is partly due to the complex mosaic of marsh edge. These habitats provide refugia and resources to a wide variety of nekton including juvenile fishes (Baltz et al., 1993; Minello & Rozas, 2002). Despite the connection between fish abundance and marsh edge, these habitats have undergone frequent anthropogenic disturbances resulting in a reduction in habitat heterogeneity and a loss ecosystem services (Chesney et al., 2000). To ensure the continued production of these habitats a myriad of restoration efforts have been undertaken to restore habitat function. Overall, the creation of new marsh habitat has preceded the recolonization of fish assemblages in restored marshes (Able et al., 2004; Herbold et al., 2014).

[28] https://irma.nps.gov/STATS/Reports/Park/GATE

[29] https://www.nps.gov/gate/planyourvisit/images/Kayaking_Trail_Map_2011.jpg

[30] https://irma.nps.gov/STATS/Reports/Park/GATE

The AQUATOX model was successfully tested to inform this assessment, but this approach was not pursued further in the current analysis given the level of effort required to apply to all project sites.

8.4.3.2 Economic

8.4.3.2.1 Arverne, Edgemere, Motts Basin South, and Norton Basin Marsh Creation

The sites currently have limited access which would improve to fair access via roads and paths to the sites and within each site. The UDV was calculated to increase from $5.35 up to $9.57 with implementation of each project. Recreational experience was considered likely to increase. In addition to fishing, the marsh creation would support additional recreational opportunities such as walking, cycling, and picnicking.

8.4.3.2.2 Bayswater and Motts Basin North Marsh Creation

The UDV was calculated to increase from $6.75 up to $9.57 with implementation of the project. Each site currently has basic facilities to conduct activities, these would improve to adequate facilities that would not detract from the experience. The currently fair access with fair roads to each site would be improved to good access with good roads to each site.

8.4.3.2.3 Duck Point, Stony Creek, Pumpkin Patch West, Pumpkin Patch East, and Elders Point Marsh Island Restoration

The UDV was calculated to increase from $8.44 up to $12.94 with implementation of each project. Recreational experience was considered likely to increase, hiking is expected to be possible in addition to the current high-quality kayaking, fishing, picnicking, and bird watching. Currently the sites have basic, degraded, facilities to carry out recreation activities, these would be improved to ideal facilities for the recreational activities. The sites have and would continue to have good access and good roads to the (launch) sites.

The study team explored the possibility of further monetizing benefits through park entrance fees and changes in revenue for local businesses (e.g., kayak rentals/launches), but ultimately concluded that this approach was both out of scope for the study and required too many assumptions for USACE and their partners to be able to replicate in future project formulation methods.

8.4.4 Additional Quantitative or Qualitative Outcomes of Interest

8.4.4.1 Environmental

Additional benefit-relevant environmental outcomes of interest that are not easily monetized included maritime buffer forest restoration (with its impact on habitat quality and connectivity) and oyster reef expansion, both of which have potential to improve water quality and aquatic habitat.

Maritime forests have always been an integral part of the bay, as they have historically enhanced the value of both wetland and aquatic habitats by “providing cover, alternate food sources and breeding habitats” to species that exist in adjacent habitats (USACE, 2019e). Restoration of these areas has the potential to increase the quality of recreation opportunities (e.g., wildlife viewing), but was not easily monetized considering the scope of this study.

For oyster reef expansion, the scale of the proposed oyster reef installation was not large enough to significantly impact water quality or habitat improvement throughout the project area.

8.4.4.2 Social

According to the 2019 HSGRR/EIS, the Jamaica Bay planning reach contains several Potential Environmental Justice Areas (PEJAs), which are census block groups that meet one or more of the following criteria developed by NYSDEC:

- 51.1% or more of the population are members of minority groups in an urban area,
- 33.8% or more of the population are members of minority groups in a rural area, or
- 23.59% or more of the population in an urban or rural area have incomes below the federal poverty level (USACE, 2019d).

Consideration of these PEJAs will be critical in the next phase of this analysis, as the study team explores the relationship between increased vulnerability of resident populations within the study area and potential added benefits.

8.5 MONETIZED VALUATION

8.5.1 Valuation Methods and Key Assumptions

During the rescoping process and after careful consideration, the study team decided to measure additional potential benefits of general recreation activities in and around Jamaica Bay using the UDV method, which was also applied in several other case studies (e.g., South Platte River, South San Francisco Bay). The Jamaica Bay analysis used Recreation UDVs for FY22. According to USACE Economic Guidance Memorandum 22-03 (USACE, 2021a), "General" recreation days represent activities that attract "the majority of outdoor users" and involve developing and maintaining access and facilities. "Specialized" recreation days are characterized by activities that require a high degree of skill and knowledge. Specialized activities are often limited in opportunity and intensity of use and were not included as part of this analysis.

The UDV method involves assigning point ratings to recreational activities based on measurement standards for five discrete criteria: recreation experience, availability of opportunity, carrying capacity, accessibility, and environmental quality (USACE, 2021a). The method requires "expert or informed opinion and judgement" in order to find the "average willingness to pay of users of federal or federally assisted recreation resources" (USACE, 2021a).

To measure accessibility for the perimeter sites identified in both studies, the study team performed a buffer analysis in GIS (see Appendix A, Section A.4) and calculated the population within a 10-minute walking distance from each project site. To account for accessibility among the marsh island sites, the study team aggregated annual fishing visit numbers from the Jamaica Bay Wildlife Refuge portion of the Gateway National Recreation Area by averaging the total number of visits between 2017 and 2021 (National Park Service, 2017). The study team decided to exclude pre-2017 visitation data due to the disruptive impacts of Hurricane Sandy on park access and infrastructure for several years post-storm (2013–2016).

Table 8-5 and Table 8-6 below summarize the UDV calculations performed for sites on the perimeter of Jamaica Bay and the marsh island, respectively. The changes in total annual unit day between with and without project conditions were calculated using the following equation:

$$\Delta C_{UDV} = B_{UDV,n} * D_n - B_{UDV,o} * D_o$$

where ΔC_{UDV} is the change in the cash equivalent of the total annual UDV caused by the project, $B_{UDV,o}$ is the UDV without the project, $B_{UDV,n}$ is the UDV with the project, D_o is the without project number of uses per year, and D_n is the with-project number of uses per year. The total annual without project, with project, and change in UDV are summarized by suite in Table 8-7.

Table 8-5. Unit Day Values for perimeter sites.

Site	Action	Project cover	Population with access	Change in total annual UDVs
Arverne	Marsh creation	12,300 ft	20,490	$169,339
Edgemere	Marsh creation	6,300 ft	11,950	$98,311
Norton Basin	Marsh creation	2,400 ft	5,770	$47,193
Bayswater	Marsh creation	1,500 ft	3,568	$17,270
Motts Basin North	Marsh Creation	28 acres	1,017	$6,357
Motts Basin South	Marsh creation	N/A	11,486	$96,546
Dead Horse Bay	Marsh creation	30.6 acres	0[31]	$0
	Tidal channel/creek restoration	2.31 acres	-	-
Fresh Creek	Tidal channel/creek restoration	45.08 acres	34,069	$292,290
	Maritime Forest	10.7 acres	-	-

[31] Radioactive contamination was found at Dead Horse Bay (adjacent to Floyd Bennett Field) in 2020 and has since been closed to visitors. Since the feasibility study was also completed in 2020, the study team determined that it would not be possible to estimate UDV benefits for this site.

Table 8-6. Unit Day Values for marsh island sites.

Site	Action	Project cover	Average annual fishing visits to Jamaica Bay Wildlife Refuge (2017–2021)	Change in total annual UDVs
Duck Point	Marsh Creation	38.6 acres	636,022[32]	$8,225,904
	Sand fill	213,776 cy		
	Tidal channel/creek restoration	1.03 acres		
	Shallows	7.57 acres		
Stony Creek	Marsh creation	51.5 acres		
	Sand fill	151,360 cy		
Pumpkin Patch West	Marsh creation	23.2 acres		
Pumpkin Patch East	Marsh creation	28.8 acres		
	Sand fill	351,952 cy		
Elders Point	Marsh creation	27.5 acres		
	Sand fill	284,891cy		
Head of Bay	Oyster Reef Expansion	10.1 acres	No access points identified	N/A

Table 8-7. Total Unit Day Values for Jamaica Bay project suites.

Suite	Total annual UDVs without project	Total annual UDVs with project	Change in total annual UDVs
Suite 0	$84,450	$519,469	$435,019
Suite 1	$42,800	$310,450	$267,650
Suite 2	$363,650	$923,591	$559,941
Suite 3	$47,020	$8,540,575	$8,493,555
Suite 4	$320,570	$8,843,265	$8,518,195
Suite 5	$688,720	$9,766,856	$9,078,136

8.5.2 Updated Benefits

Updated benefits were derived from the UDV method described above, with the AAEQ benefit in each year from a project suite being the change in total annual UDVs for the suite reported in Table 8-7. The new benefit AAEQs calculated using this method are included in the benefit calculation in Table 8-8.

8.5.3 Updated Costs

No updates were made to the cost calculations for the included project site.

[32] The study team applied this number once to account for annual visitation among all marsh island sites.

8.5.4 Benefit-Cost Comparisons

8.5.4.1 Planning Analysis

Table 8-8 first presents the benefit, cost, and resulting BCR taken directly from the original report (first three rows). Benefits include flood risk reduction (NED) estimates from the HSGRR/EIS only, because monetized benefits were not estimated for the HRE-derived actions in the original NER study. Costs, by contrast, represent the sum of costs from the HSGRR/EIS and HRE studies. AAEQ costs were calculated as $3.8 and $5.0 million for the perimeter and marsh island sites, respectively, and included in the total cost estimate in the table below. Without the addition of UDV benefits, only Suite 1 (which has no NER elements) has a BCR greater than 1.0, indicating the NED-only benefits of this suite outweigh the combined NED/NER costs.

However, the addition of benefits from recreational usage, especially for suites that include the HRE projects which had no NED values associated with them, does influence the analysis. Notably, the BCR of Suite 0 rises to 0.98, indicating that UDV benefits were almost enough to put the unfunded HFFRRF projects above the threshold to receive funding. Specifically, as little as an additional $170,000 in NER benefits would have been sufficient to raise the BCR above 1.0.

Table 8-8. Table of AAEQ of the benefits and costs of the Jamaica Bay project using the USACE Planning Analysis Assumptions.

	Suite 0	Suite 1	Suite 2	Suite 3	Suite 4	Suite 5
Benefit/Cost Source	AAEQ (millions of dollars)	AAEQ (millions of dollars)	AAEQ (millions of dollars)	AAEQ (millions of dollars)	AAEQ (millions of dollars)	AAEQ (millions of dollars)
NED Benefit	$12.31	$11.85	$11.85	$11.85	$-	$11.85
Combined NED/NER Cost	$12.92	$10.74	$14.54	$15.71	$8.77	$19.50
Combined BCR	0.95	1.10	0.81	0.75	-	0.61
UDV Benefit	$0.44	$0.27	$0.56	$8.49	$8.52	$8.79
Updated BCR	0.98	1.13	0.85	1.29	0.97	1.06

Suite 3's BCR rose from 0.75 to 1.29 with UDV benefits included. Note that the large NER benefits of the marsh island projects estimated for this suite are driven more by the assumed change in annual usage rather than the increase in UDV. The study team assumed that in the absence of new marsh island restoration investments, annual usage would drop to a few hundred due to the site becoming open water. By contrast, implementing the suite of projects would maintain the annual usage in the hundreds of thousands reflecting the current annual visits to the park. If the current annual visits to the park number were used for both with and without project annual usage, the change in total annual UDV from without project to with project would drop from $8.49 million to $3.33 million. This would lower the BCR to 0.96. Suite 5, which also contains the marsh island projects, would have a BCR of 0.79 under this assumption.

Suite 4, containing just the HRE projects, had a BCR of 0.97 indicating that the usage benefits from these projects almost paid for themselves (considering the marsh island sites alone, the BCR was greater than 1.0, again due to the large population they are assumed to be able to serve). Finally, Suite 5 combining the funded HFFRR projects and the HRE projects had a BCR greater than 1.0 and thus could have been considered for funding on NED terms alone.

8.5.4.2 OMB Process Analysis

Table 8-9 contains the cost, benefit, and BCR numbers for the analysis using the OMB discount rate of 7%. Again, no non-UDV AAEQ benefits were calculated for the HRE sites, but AAEQ costs were calculated as $6.8 and $9.1 million dollars for the perimeter and marsh islands, respectively. Additionally, not enough information was available to provide AAEQ costs under the 7% discount rate for Suite 0 projects, so they are omitted.

Notably none of the projects (including the funded Suite 1) have BCRs above 1.0 either with or without UDV benefits included. Further the substantial increase in AAEQ costs means that the addition of UDV benefits had minimal impact except on suites which included the marsh island sites. Even the large UDV benefits from the marsh island sites were not enough to put any of the BCRs close to 1.0.

Table 8-9. Table of AAEQ of the benefits and costs of the Jamaica Bay project using OMB assumptions.

	Suite 1	Suite 2	Suite 3	Suite 4	Suite 5
Benefit/Cost Source	AAEQ (millions of dollars)	AAEQ (millions of dollars)	AAEQ (millions of dollars)	AAEQ (millions of dollars)	AAEQ (millions of dollars)
NED Benefit	$11.85	$11.85	$11.85	$-	$11.85
Combined NED/NER Cost	$25.81	$32.62	$32.92	$15.93	$41.74
Combined BCR	0.46	0.36	0.33	-	0.28
UDV Benefit	$0.27	$0.56	$8.49	$8.51	$8.79
Updated BCR	0.47	0.38	0.58	0.53	0.49

Note: Suite 0 is omitted from this table because there was insufficient information in the original USACE reporting to update the costs for Suite 0 using the higher OMB discount rate.

8.6 PRIORITIZATION AND ALTERNATIVE SELECTION

As was done for several of the other case studies, the study team applied a simple ranking scheme as part of applying MODA to the evaluation of the Jamaica Bay case study (Table 8-10). This assessment identified some clear distinctions between suites of alternatives. One of the large influences in overall scores was related to the suites containing projects along the perimeter of the Bay and those containing projects restoring marsh island sites. Suites 3–5 included multiple marsh island sites and therefore had potential for large improvements in recreation and access, marsh extent, habitat value for fauna, and localized improvement in water quality. The cost of these suites was correspondingly high. In addition, due to the location (away from residential neighborhoods in the middle of the Bay), there is expected to be limited to no reduction in tidal flood risk.

Suites 1 and 2 focused on smaller projects along the perimeter of the Bay and therefore were lower in cost, with moderate potential for improvements in recreation and access as well as moderate decline in tidal flood risk. Only one project included maritime forest (Fresh Creek) which is reflected in scores for Suites 2, 4, and 5.

Table 8-10. Comparison of benefits and costs for suites of alternatives evaluated as part of reanalysis of the Jamaica Bay Feasibility Study.

Suite	Benefits and Costs							
	Tidal Flood Risk Reduction	Recreation and Access	Marsh Extent	Marsh Habitat Value for Fauna	Forest Extent	Water Quality	Habitat Value	Cost
FWOA	-2	-1	-2	-2	0	-2	-2	2
0	1	1	-2	-1	0	1	-1	0
1	-1	0	-2	-1	0	0	-1	1
2	-1	1	-1	-1	1	1	-1	-1
3	-1	2	1	1	0	2	1	-1
4	-2	2	2	2	1	2	2	-2
5	-1	2	2	2	1	2	2	-2

8.7 DISCUSSION

This case study helps demonstrate how several separate USACE studies conducted under different authorities could have been merged into a single, multi-objective integrated analysis. The study team sought to highlight the innovative, purposely formulated NBS approaches to tidal flood risk reduction along the interior of Rockaway Peninsula included as part of the overall CSRM study. Although modest in size, these projects have potential to provide multiple co-benefits and are located in disadvantaged neighborhoods that could benefit from new, high-quality green space and access/viewpoints along the perimeter of the bay.

This case study also provides a novel assessment of the potential ecosystem service benefits from the larger scale restoration projects recommended in the separate HRE study. Ecosystem service benefits from restoration in Jamaica Bay could be significant given the size and location of this natural resource, a unique estuarine environment located within the city limits of New York City that has the potential to serve thousands to millions of residents and visitors. This analysis showed that the proposed HRE restoration, especially the marsh islands, could yield significant economic benefits even with limited and conservative assumptions regarding environmental quality improvements to support use values for fishing and kayaking. The HRE recommended plan alone nearly pays for itself (Suite 4), and the combined perimeter, marsh island, and HFF projects show positive net benefits when all considered economic benefits and costs are combined (Suite 5).

Rather than individually considering coastal storm risk reduction, high-frequency flood mitigation, and ecosystem and park improvements for this unique resource, this case study highlights how a joint study across multiple PR&G objectives might lead to a more integrated strategy with potential to build and sustain broader benefits and co-benefits. This is especially the case if only one or a portion of one of the studies received appropriations for engineering, design, and construction, while other elements remained on the recommended list but were not carried through to implementation. For example, if only the storm surge barrier identified in the CSRM study was funded initially, a suite of the most beneficial supporting ecosystem-based actions could be recommended for additional funding through other mechanisms. It is useful to contrast, for example, the multi-mission approach detailed in South San Francisco Bay (Chapter 5.0) to the separately authorized studies overlapping Jamaica Bay, the earliest of which dates back to the 1960s, while the latest of which remains ongoing as of this writing.

Jamaica Bay, however, presents specific challenges in terms of estimating both biophysical change and ecosystem services to local communities and visitors. As a barrier island and coastal estuarine ecosystem, Jamaica Bay is highly dynamic and has additionally been substantially altered by the development of the New York urban environment over multiple centuries. As a result, even though substantial progress has been made on numerical modeling of the Bay in recent years (Fischbach et al., 2018; Sanderson et al., 2016), USACE would need access to integrated biophysical, hydrodynamic, and water quality modeling tools to be able to jointly consider landscape and habitat, flood risk, and water quality changes in a future without action or resulting from new NBS interventions. Although the demonstration analysis with AQUATOX showed promise to assess benefits of catch effort for recreational fish, additional work is needed to capture potential water quality changes and translate these to BRIs. Another example is monetized assessment of benefits to migratory birds as well as the recreational benefits to bird watchers, assessment of these benefits and associated BRIs was critically limited by lack of data. In addition, the highly urbanized land uses adjacent to the Bay, densely populated and dynamically changing neighborhoods on the perimeter, and pressure of sea level rise, add additional uncertainty that may require use of methods such as DMDU.

This case study analysis also had several other limitations of note. First, the modest increase in monetized HFF benefits is due to the relatively small scale of projects coupled with conservative assumptions about the population benefitting from new or improved green space. Given the population density in Rockaway neighborhoods, even modest adjustments in the radius served by each project could lead to larger changes in monetized benefit. In addition, when considering overall monetized benefits, the study team notes that UDV is itself a conservative and limited approach and likely provides a lower bound for ecosystem service benefits. Even slightly larger numbers for ecosystem service benefits would have been enough to move both Suite 0 and Suite 4 past the threshold of paying for themselves. Moreover, some categories of ecosystem service benefit, particularly water quality improvement, were not quantified or monetized due to current model and data limitations. Finally, as noted earlier in the chapter, the UDV estimates in this case study reanalysis are particularly sensitive to assumptions about the number of active users and change in active users with projects implemented given the scale and location of Jamaica Bay. This challenge and associated uncertainty could complicate other ecosystem service valuation approaches when applied to Jamaica Bay or other large urban ecosystem improvements.

9.0 CROSS-CUTTING THEMES FROM CASE STUDY ANALYSIS

9.1 OVERVIEW

The case studies conducted by the study team (Chapters 3–8) were deliberately selected to vary in their geographic location, USACE Mission Area focus, and scale (see Section 2.3 for more information on the case study selection process). This diversity enabled the study team to identify commonalities and key themes that are likely representative of a wide range of USACE Feasibility Studies.

9.2 STUDY SCOPE

From the initial inventory of completed planning studies developed for this study (Section 2.3), scoring by USACE subject matter experts indicated that approximately 85% of the studies that could be evaluated considered NBS during their initial phases. However, only 53% of the studies evaluated NBS in the final array of alternatives, and many of those were focused exclusively on environmental restoration. Overall, less than a third (29%) of the studies included in the inventory considered NBS options and evaluated those options across multiple objectives (for example, both flood risk management and ecosystem restoration). Evaluation of the six case studies reflected a similar trend of NBS being excluded early in the planning process or evaluated independently of non-NBS measures based solely on advancing environmental restoration objectives. In the following sections, case study authorizations and objectives are reviewed to identify potential drivers of that outcome and determine how study scoping can be executed to provide greater consideration of NBS.

9.2.1 Study Authorization and Purpose

Of the six case studies (Table 9-1), two were authorized within a single USACE mission area: navigation for Jacksonville Harbor Mile Point and flood risk management for West Sacramento. In the West Sacramento study, objectives articulated during the scoping process focused exclusively on flood risk mitigation, even though alternatives were ultimately formulated that included setback levees allowing for wetland habitat along the river. Similarly, the articulated objectives for Jacksonville Harbor Mile Point were focused on reduction of crosscurrents in the river in support of navigation. Marsh creation using dredged sediment was not initially considered as part of alternative formulation, and the costs and benefits of this NBS were only benchmarked against the planned upland dredge disposal cost as part of a VE study conducted later in the planning process. These examples suggest that studies authorized under a single Mission Area may still include unstated or secondary objectives outside of their primary goal. Scoping studies from the onset to include these objectives may increase the number of studies where NBS are considered given that they often provide multi-objective benefits.

Table 9-1. Summary of study authorizations for the six case studies evaluated by the study team.

Study	Single authorization, single purpose	Multiple separate authorizations	Single authorization, multiple purposes
Jacksonville Harbor	X		
Southwest Coastal Louisiana		X	
South San Francisco Bay			X
West Sacramento	X		
South Platte River and Tributaries			X
Jamaica Bay		X	

Two other case studies, Jamaica Bay and Southwest Coastal Louisiana, did consider multiple objectives under separate authorizations for each mission area. Inclusion of multiple objectives allowed USACE to consider the ecosystem benefits from NBS. However, independent authorizations led to separate formulation of alternatives and the development of ecosystem restoration plans that were not necessarily well-integrated with flood risk mitigation.

In the case of the Jamaica Bay study, two separate Feasibility Studies were conducted within the same geographic region, with the Hurricane Sandy General Reevaluation Report focused on coastal storm risk management and the Hudson Raritan Estuary Study focused on environmental restoration. Although the coastal storm risk management study did ultimately include NBS to help manage tidal flooding, it was only for a small handful of sites along Rockaway Peninsula. In Southwest Coastal Louisiana, an integrated feasibility study was conducted, but analyses were independently conducted for flood risk management and ecosystem restoration. As in the case of Jamaica Bay, this led to the separation of flood risk mitigation alternatives from those for ecosystem restoration. This was captured within distinct NED and NER plans.

The two remaining case studies, South Platte River and Tributaries and South San Francisco Bay, did consider multiple objectives under a single overarching project authorization. In both of these cases, NBS were included as part of the final recommendations. For South Platte, a combined NED/NER Plan was developed with different geographic portions of the study area designated as NER versus NED; however, NBS were considered throughout the study domain. The South San Francisco Bay study was conducted under a single authorization that explicitly identified multiple objectives, including those related to flood risk mitigation and ecosystem restoration. This study, which was also a multi-agency collaboration with close coordination across multiple federal, state, and local agencies, led to the development and recommendation of a combined NED/NER Plan for a multi-objective project.

Taken together, the six case studies illustrate that the underlying authorization associated with Feasibility Studies can drive the scoping process and lead to objectives being framed within single Mission Area and/or environmental restoration objectives being considered independently from other objectives (i.e., located at different sites and or targeted toward different goals, rather than considered alongside structural alternatives as part of an integrated approach to advancing multiple objectives). However, the identification and use of NBS—even in the case of sole-purpose authorizations such as West Sacramento and Jacksonville Harbor Mile Point—illustrate that NBS can have broad applicability regardless of authorization.

9.2.2 Study Goals

The primary objective of five of the case studies was coastal or inland flood risk mitigation. The case study team only considered one authorized navigation project: Jacksonville Harbor Mile Point. All six of the studies considered environmental benefits at some point in the planning process. For the coastal studies, ecosystem connectivity and function were explicitly included as part of stated project objectives (Table 9-2). The two riverine studies (Jacksonville Harbor Mile Point and West Sacramento) did not include stated objectives of ecosystem restoration, which is consistent with the study team's prior evaluation of USACE planning studies that determined it is difficult to find multi-objective riverine studies that consider NBS (Windhoffer et al., 2022).

However, environmental benefits (and/or avoidance of harm) were considered in the riverine case studies despite ecosystem function not being included as a project objective. For example, a setback levee that provides wetland habitat adjacent to the river was ultimately selected as the preferred implementation plan for the West Sacramento study, even though the stated project objectives were focused exclusively on flood risk mitigation. This commonality across the case studies is partially driven by the process the study team used for selection, given that studies that did not include any consideration of environmental impacts were likely to be excluded from consideration based on insufficient underlying information for reanalysis. However, this outcome does indicate that USACE planning studies that are authorized for a single purpose or a limited set of objectives may ultimately consider environmental benefits at some point in the planning process.

Table 9-2. Summary of planning study goals for the six case studies evaluated by the study team.

Planning Study Goal	Jacksonville Harbor Mile Point	Southwest Coastal Louisiana	South San Francisco Bay	West Sacramento	South Platte River and Tributaries	Jamaica Bay
Improve navigation	X					
Reduce risk and damage from flooding		X	X	X	X	X
Improve water quality		X				
Increase habitat quantity		X	X			X
Improve ecosystem connectivity and function		X	X		X	X
Reduce shoreline erosion		X				X
Improve public access and recreation			X	X		
Encourage wise use of the floodplain					X	

**Note that although Jacksonville Harbor Mile Point did not include improving ecosystem connectivity as an explicit goal, impacts of the alternatives on water quality and habitat were considered during alternative finalization. Similarly, setback levees that allowed for riverside marsh habitat were part of the recommended alternative for West Sacramento.*

9.2.3 Key Findings: Study Scope

One of the findings from the case study analysis is that flood risk mitigation and navigation studies may implicitly be multi-objective (based on selected alternatives) regardless of authorized purpose and articulated objectives. This finding suggests unrealized opportunities for NBS implementation, given that less than a third of studies in the project inventory evaluated NBS as part of multi-objective analysis. In addition, NBS alternatives that result in environmental benefits should be formulated and analyzed in conjunction with infrastructure solutions to allow identification of integrated solutions for addressing multiple objectives simultaneously.

Studies can be scoped to include greater consideration of NBS, however, and doing so will better align them with the PR&G. The South San Francisco Bay case study provides an example of a study authorization and scoping process that supports multi-objective alternative formulation. Co-equal objectives were established that included flood risk mitigation and environmental restoration, and integrated solutions were identified and evaluated that could simultaneously advance those multiple goals.

This approach is consistent with the PR&G, which establishes healthy ecosystems as a co-equal goal alongside floodplain management, sustainable economic development, public safety, environmental justice, and a watershed-based approach. Comparison of the case study goals (Table 9-2) with the PR&G guiding principles (Table 9-3) reveals that many studies have objectives spanning the guiding principles and therefore a multi-objective study scoping process would provide greater consistency with the PR&G.

Table 9-3. Cross-linking of planning study goals (Table 9-2) with guiding principles identified in the 2014 USACE PR&G (described in more detail in Chapter 1).

Planning Study Goal	Healthy and resilient ecosystems	Sustainable economic development	Floodplain management	Public safety	Environmental justice	Watershed approach
Improve navigation		X		X		
Reduce risk and damage from flooding		X	X	X	X	
Improve water quality	X	X			X	
Increase habitat quantity	X	X	X			
Improve ecosystem connectivity and function	X	X	X			
Reduce shoreline erosion	X	X		X		
Improve public access and recreation		X	X		X	
Encourage wise use of floodplain	X	X	X	X	X	X

9.3 ALTERNATIVE FORMULATION

Another stage of planning studies that can lead to early exclusion of NBS is alternative formulation. In this section, the guiding assumptions and screening processes used for alternative formulation in the case studies are reviewed. The outcomes are then compared to identify factors that can lead to inclusion (or exclusion) of NBS within the evaluated alternatives.

9.3.1 Guiding Assumptions for Formulation

Four of the case studies considered were formulated as multi-objective projects through either a single multi-purpose authorization or through dual authorizations (Section 9.2, Table 9-1). The underlying assumptions and alternative formulation process varied considerably across these studies, however, leading to different outcomes for potential NBS solutions. Alternatives for Southwest Coastal Louisiana were independently formulated, for example, and the associated measures were targeted to different geographies with limited consideration of NBS or other measures that could simultaneously advance multiple objectives. Measures developed for Jamaica Bay and South Platte River and Tributaries similarly targeted measures for advancing different objectives at different sites within the geographic area of the study, rather than considering alternatives that include NBS and structural solutions as part of an integrated, system-wide approach to advancing objectives. These outcomes suggest that alternatives tend to be independently formulated with USACE mission areas even in the case of studies framed as multi-objective.

Another factor that impacted NBS consideration in alternative formulation was how NBS were developed and considered alongside structural approaches to flood risk management. In the case of Southwest Coastal Louisiana, NBS solutions that provided environmental benefits were included within the NER Plan, while flood risk mitigation measures were included within the separate NED Plan. In the West Sacramento study, formulated alternatives initially included structural and nonstructural plans, with the latter screened out early. Developing structural and nonstructural solutions independently inherently competes NBS against structural alternatives, rather than supporting development of comprehensive alternatives that include both structural and nonstructural elements to advance multiple objectives simultaneously.

In contrast, alternative formulation for South San Francisco Bay built upon the multi-objective study scoping process to develop integrated alternatives. Flood risk management and ecosystem restoration options were first developed and screened independently, then the final array of alternatives drew across those measures to develop holistic solutions that considered natural system feedbacks and impacts to study objectives. This case study illustrates that an alternative formulation process that considers multiple types of measures, including NBS, can be effective in identifying approaches that advance multiple objectives.

9.3.2 Site or Project Screening with Benefit-Cost Analysis

In addition to assumptions made in formulating alternatives, application of the BCA during early screening of potential alternatives can lead to the exclusion of NBS. For example, BCA was used as a tool early in the planning process for Jamaica Bay to screen potential sites for NBS measures to reduce high-frequency (tidal) flooding in the eastern portion of Rockaway Peninsula (see Section 8.3). This preliminary BCA screening reduced the number of potential sites, and thus neighborhoods benefiting from these interventions, from six to two. This process limited the number of sites where NBS could be applied given that—when taken individually rather than as part of a holistic approach to systemwide benefit—the economic benefits derived from site-specific NBS measures were limited.

9.3.3 Key Findings: Alternative Formulation

Analysis of the case studies reveal that the process and assumptions used as part of alternative formulation play an important role in determining if NBS are eliminated from consideration. Formulation and assessment of alternatives through the lens of a single objective tends to favor structural solutions and exclude NBS that generally provide multi-objective benefit. Impediments include separate formulation of alternatives by goal or mission area; development of single objective-orientated measures that are not combined into comprehensive alternatives; independent consideration of structural and nonstructural measures that are competed rather than integrated; and the early screening of alternatives based on site- and objective-specific BCA. In contrast, NBS or combined NBS/structural alternatives receive greater consideration through alternative formulation processes that broadly consider multi-objective benefits on a systemwide scale.

9.4 NON-MONETIZED OUTCOME EVALUATION

After a study is scoped and alternatives are formulated, a robust and comprehensive analysis process can be used to evaluate alternatives against study objectives. Apart from environmental restoration projects, this process is typically conducted at USACE through application of BCA, which precludes consideration of NBS ecosystem services that cannot be monetized and thereby effectively (and inaccurately) assigns them zero benefit. As part of reanalyzing the case studies, the study team began by broadly considering potential benefits associated with potential NBS for each of the case studies. A "funnel" approach (Fischbach et al., 2023) was then applied in which non-monetized metrics of ecosystem service value (i.e., BRIs) were identified across the potential benefits. This section reviews commonalities across the case studies in ecosystem service benefits that were identified, then discusses non-monetized metrics and associated calculation methods.

9.4.1 Environmental, Economic, and Social Benefits

The geographic and site variability of the case studies was reflected in a similar diversity of NBS, which can be broadly categorized as: habitat or land cover change (creation of marsh/wetland, terraces, hard-bottom habitat, oyster reefs, chenier ridge, riparian habitat, etc.); hydrologic improvements (flow improvement channels, water control structures, etc.); and shoreline protection (ecotone levee, stone aggregate to prevent erosion, etc.). The most common NBS considered across the case studies was creation of fresh or saltwater marsh/wetland, which was included in all case studies except for West Sacramento (where NBS did include a setback levee that could allow for natural marsh propagation).

The ecosystem services of these NBS included environmental, economic, and social benefits (Table 9-4), with NBS generally associated with increases in the quantity or quality of habitat that was desirable for residents or visitors and/or through increasing habitat for targeted species (e.g., associated with commercial or recreational fisheries, having protected status, etc.). Benefits were identified that accrued locally (e.g., through recreational use of created habitat) and regionally (e.g., marsh providing wave attenuation and associated protection of coastal infrastructure).

Table 9-4. Categories of NBS ecosystem services benefits identified for the six case studies reviewed by the study team along with example metric(s) of quantification.

Category	Socioeconomic benefit	Example metric(s)
Ecosystem restoration (habitat and associated species, human use, non-use value)	Consumptive (recreational and charter fishing, water supply, etc.) and non-consumptive use (hiking, kayaking, camping, bird watching, boating, etc.) Non-use existence values	Habitat acreage Habitat quality (e.g., number and or diversity of target fauna and/or flora in habitat, Index of Benthic integrity) Metrics of pressure on ecosystem (stressors e.g., impervious surface, air quality) Number of recreational users per day Special status species abundance Indicator species abundance
Quality of life and/or property value improvements for residents	Water quality and/or clarity	Total suspended solids Nitrogen and phosphorous discharge Dissolved Oxygen Toxicants including heavy metals Water clarity
	Waterway access	Number or residences with river access Mean drive time to site from target communities Quality of roads and boat ramps Presence of boat ramps
	Investment in restoration benefiting economically disadvantaged communities	Infrastructure investment Area of high value habitat Presence of high quality and/or rare natural experience
Regional / system scale benefits	Flood risk mitigation (storm surge, tidal flooding, riverine flooding, etc.) and/or wave attenuation	Wave height or energy Stage versus flooding extent (cost or number of houses impacted etc.)
	Sediment trapping (reductions in navigation channel dredging, land-building, etc.)	Dredged volume Deposition in a setback area or natural shoreline (where deposition is intentional)
	Erosion control	Shoreline erosion rate Survival and condition of shoreline vegetation
	Carbon sequestration	Carbon sequestered Carbon stored in soil Accretion rate Plant biomass
Resource preservation	Preservation of capacity at upland dredge disposal sites Extension of infrastructure useful service life	Sediment volume Recapitalization cost

Note that there are multiple potential metrics for each benefit that vary depending on the specific NBS and study parameters. For example, nitrogen and phosphorous discharge was considered as a metric of water quality for South San Francisco Bay, whereas total suspended solids was considered for Jacksonville Harbor Mile Point.

One benefit was also identified that did not directly derive from habitat creation or ecosystem restoration: resource preservation associated with beneficial use of dredge material whereby sediment placed for marsh creation preserved capacity at an upland disposal site for future use. More details on the NBS associated with each case study and the identified environmental, economic, and social benefits can be found in Chapters 3.0–8.0.

9.4.2 Non-Monetized Metrics of Ecosystem Services

After benefits were identified for each case study, the study team determined what metrics, data, and calculation methods could be used to quantify the associated ecosystem services benefits (Table 9-4). There were multiple potential metrics including some that could be directly calculated from NBS features (e.g., acres of habitat created) and others that required ancillary data or models to calculate (e.g., quantification of wave height attenuation associated with marsh creation).

Metrics that could be directly calculated from NBS parameters, such as acres of habitat created, were generally associated with indicators of ecosystem function (Figure 2-5), whereas capturing economic or social benefits directly requires ancillary information. Potential metrics for quantifying the same ecosystem service varied depending on the NBS and site-specific considerations. For example, total suspended solids was identified as a potential metric for Jacksonville Harbor Mile Point, where a primary consideration was water clarity, whereas nitrogen and phosphorous discharge was identified for South San Francisco Bay, where the primary concern was non-point source pollution to waterways.

In some cases, it was difficult to identify an appropriate metric for a known benefit. For example, demographic information for the West Sacramento study indicated spatial variability in population vulnerability that would be an important factor to consider when considering environmental justice under the PR&G principles. Because expert elicitation and ranked impact scales can be used as part of MODA (see Section 9.6.2), it is not necessary to identify a quantifiable metric for each benefit. However, this finding suggests that there is an opportunity for USACE to support practitioners by developing guidance on the identification and calculation of quantified metrics for social and environmental impacts.

The study team next evaluated ancillary data and models that could be used to calculate ecosystem services metrics. In some cases, analyses or data collected by USACE as part of the Feasibility Study or by other entities for an overlapping geography could be used. For example, data within the Southwest Coastal Louisiana Feasibility Study and Louisiana Coastal Master Plan could be used to calculate acres of wetland that would be restored or maintained through project implementation, as well as the carbon sequestration potential of those wetlands.

In other cases, the study team was able to use publicly available data to calculate metrics. For the Jacksonville Harbor Mile Point study, for example, the study team used Google Earth© imagery to determine the number of homes that would gain waterway access to the St. John's River through creation of a flow improvement channel, whereas for Jamaica Bay the study team piloted an approach using the AQUATOX model to quantify the potential value of fish habitat over a portion of the study domain.

In many cases, however, the lack of available data or underlying models was a limiting factor for calculating metrics to quantify ecosystem services identified for NBS. Study data was limited by a lack of data or models that could be used to quantify or predict NBS impacts to water quality for some case studies; changes in habitat at sufficient spatial resolution to determine impacts to species, particularly those with special status (i.e., threatened or endangered); wave attenuation or shoreline erosion prevention potential; and sediment retention within freshwater marsh adjacent to rivers and associated benefit in reducing navigation channel dredging. Although this gap does not preclude MODA from being conducted (see Section 9.6.2), this finding also suggests that there is an opportunity for USACE to expand the potential for robust evaluation of ecosystem services through the development of databases and tools that can support metric calculation.

9.4.3 Key Findings: Non-Monetized Metrics of Ecosystem Services

The study team identified a range of possible benefits associated with NBS that are often not considered as part of flood risk mitigation or navigation studies, including creation of habitat that is desirable for human use or for species of interest; improvements to quality of life for residents or increases to property values; regional-scale benefits outside of project footprints, such as wave attenuation and shoreline protection; and preservation of resources, such as preserving disposal site capacity through beneficial use of dredge. Some biophysical metrics and BRIs can be calculated using available USACE data and tools, which can also be augmented using information from sources (research studies, data, etc.) that cover the same geographic region. However, the availability of data and models to quantify ecosystem service benefits (environmental and social) is still limited in many cases and beyond the scope of Feasibility Studies to develop or collect. For this reason, the study team estimates that there would be value in the development of databases and tools that can support USACE practitioners in identifying ecosystem service benefits and calculating associated metrics. In cases where metrics cannot be calculated, however, expert judgment and ranked scales can be used to consider benefits (as described in Section 2.4.1).

9.5 MONETIZED VALUATION

As part of executing a ‘funnel’ approach to evaluation, the study team next considered which metrics and outcomes identified for each case study could be monetized. In the next sections, valuation methods and metrics are described along with challenges that limited case study application and opportunities for expanding the types of valuation metrics used for BCA. In addition, the results of applying those metrics to recalculate a BCA are reviewed.

9.5.1 Methods Applied for Reanalysis

The study team identified multiple ecosystem service benefits (Table 9-4) that could be quantified through valuation methods (Table 9-5) and included in an updated BCA. Two of these methods were applied by USACE within one or more case studies and/or relied exclusively on USACE data. Specifically, the study team applied UDVs to quantify recreational use following an approach that USACE incorporated for the South Platte River and Tributaries and South San Francisco Bay studies. The study team recalculated the values for South Platte based on additional research and applied the same method to Jamaica Bay. The monetary value of preserved capacity at an upland dredge disposal area was calculated for Jacksonville Harbor Mile Point using existing USACE data on the capacity of the disposal site, the fill rate based on local dredge disposal needs for navigation channel maintenance, and the relative cost of alternate dredge disposal options if the capacity of the site were to be exceeded.

Table 9-5. Monetized metrics calculated or applied for each of the six case studies as part of the BCA reanalysis.

Benefit	Method of calculation and source information	Study (or studies)
Property value increase due to water quality improvement	Hedonic pricing model: methods from independent research in the study geography combined with study team analysis of publicly available data	Jacksonville Harbor Mile Point
Property value increase due to waterway access	Hedonic pricing model: methods from independent research in the study geography combined with study team analysis of publicly available data	Jacksonville Harbor Mile Point
Future cost savings by preserving dredge disposal site capacity	Calculated future cost savings based on data from USACE Feasibility Studies and dredge management plans	Jacksonville Harbor Mile Point
Aggregate habitat / land cover change value across all uses	Benefit transfer: determination of aggregate value per acre from multiple independent studies conducted in the study geography	Southwest Coastal Louisiana West Sacramento
Social cost of atmospheric GHG saved through carbon sequestration	Benefit transfer: determination of value per acre from independent study conducted in the study geography	Southwest Coastal Louisiana
Value for recreational use	USACE standard UDV methodology: value of use/acre, applied or updated based on information from feasibility studies and/or independent sources	South Platte River and Tributaries Jamaica Bay South San Francisco Bay
Natural capital value	Benefit transfer: use of per-acre values from an independent study conducted in the study geography	South Platte River and Tributaries

Note: Additional details on each approach can be found in the chapter describing the details of the associated study.

Several other ecosystem services could be monetized through benefit transfer approaches, that is, when secondary data are used to estimate nonmarket economic value at a given site. These approaches required use of data or models that were conducted within the geographic area of the USACE Feasibility Studies by outside entities. Key categories of newly monetized benefit included aggregate land cover value; social cost of GHG reduction through carbon sequestration by wetlands; and natural capital value of created habitats (Table 9-5).

Lastly, a hedonic pricing model (i.e., estimation of property value increase based on desirable features) was used for the Jacksonville Harbor Mile Point study. This calculation leveraged a study that had been conducted in the case study geographic region along with publicly available Google Earth data used to determine the number of properties impacted by implementation of a flow improvement channel.

9.5.2 Challenges and Opportunities in Valuation Methods

The study team identified several valuation metrics and methods that were not used to update the BCA of the case studies for two primary reasons (Table 9-6): 1) scientifically robust methods for calculating the biophysical impact of the NBS and/or monetizing its ecosystems service benefit were unavailable, or 2) methods to calculate the benefits required site-specific data or models that could not be attained. These metrics are described here and may be applicable to other Feasibilities Studies where there is available data.

Table 9-6. Monetized metrics that were identified for each of the six case studies as part of the BCA reanalysis, but that were not included for the reason given.

Benefit	Reason for exclusion	Study (or studies) where benefit was identified but not monetized
Reduced costs of navigation channel maintenance	Applicable methods not available	Jacksonville Harbor Mile Point
Increased recreational or commercial fishing	Applicable methods not available	Jacksonville Harbor Mile Point West Sacramento
*Future cost savings by preserving dredge disposal site capacity	Site-specific data and/or models not available	Southwest Coastal Louisiana
Carbon sequestration by open water habitats	Applicable methods not available	Southwest Coastal Louisiana
* Aggregate habitat / land cover change value for recreational or other use	Site-specific data and/or models not available	Jacksonville Harbor Mile Point Southwest Coastal Louisiana South San Francisco South Platte River and Tributaries Jamaica Bay
Flood risk reduction / shoreline protection	Applicable methods not available	Southwest Coastal Louisiana South San Francisco South Platte River and Tributaries
Species benefits from habitat quantity/quality, particularly connectivity	Applicable methods not available	South San Francisco West Sacramento South Platte River and Tributaries
*Property value increase due to aesthetic improvements	Site-specific data and/or models not available	South Platte River and Tributaries
*Property value or other quality of life improvements based on water quality	Site-specific data and/or models not available	South Platte River and Tributaries Jamaica Bay

Asterisks (*) indicate benefits that were calculated for another case study (Table 9-5) or for some (but not all) NBS or habitat types within a study. Additional details on each approach can be found in the chapter describing the details of the associated study.

Data for some valuation approaches applied in the case study analysis were of varying quality. For example, the UDV method used to estimate recreational benefits applied in the South Platte River, Jamaica Bay, and South San Francisco Bay case studies requires both estimating the monetary value of a single use day and determining the number of annual use days. While it is relatively easy to estimate the former using established USACE methods, the latter may be difficult to estimate with accuracy, especially when trying to estimate the change in usage with one or more projects in place. This estimation challenge is further complicated by the potential for undercounts of potential users if the geographic study scope is defined too narrowly.

In four cases, methods that the study team identified and applied for one case study could not be applied to NBS that provide similar benefits at another site. For Southwest Coastal Louisiana, for example, marsh restoration sites were located near a maintained shipping channel. The beneficial use of dredged sediment for marsh building could thus provide value in preserving sediment disposal area capacity elsewhere, akin to a benefit quantified for Jacksonville Harbor. However, insufficient data were available to estimate future dredge disposal volume and associated cost savings.

Underlying data were also unavailable for estimating the increase in property values associated with aesthetic improvements to the South Platte River. Similarly, habitat / land cover change value could not be estimated for all created habitat types for five of the six case studies. Ecosystem services could be valued for some habitat types and not others within a single study in some cases, such as for Jamaica Bay, where the recreational use value of marsh restoration sites could be quantified but underlying data were unavailable to assign value to maritime forests.

Lastly, data and models were unavailable for robustly predicting or valuing water quality improvements for South Platte River and Tributaries and for Jamaica Bay, whereas a hedonics study conducted in the geographic region of Jacksonville Harbor Mile Point enabled estimation of property value increases associated with water quality improvements. The applicability of the identified methods to some case studies, while being limited due to data availability in others, suggests there is an opportunity to create guidance and/or databases providing parameter ranges to use for NBS valuation depending on the type and geographic location. These resources could support alternative evaluation and benchmark the uncertainty associated with excluding potential benefits altogether (i.e., excluding the benefit and thereby assuming it is zero).

When quantified valuation metrics could not be calculated, the study team was in some cases able to use best professional judgement or elicit input from experts to estimate the magnitude of the ecosystem service benefit relative to other factors considered in the BCA. For example, the monetized recreational benefit of the 53 acres of marsh created through beneficial use of dredge material for Jacksonville Harbor Mile Point is expected to be small given that users can experience similar habitat throughout the 46,000 acres of the adjacent TNEHP. Similarly, the wave attenuation benefits from an ecotone levee for South San Francisco Bay were expected to be minimal given the low-energy wave climate of the area, and the impacts of oyster reefs on water quality for Jamaica Bay were expected to be minimal based on the overall condition of the site.

The process used by the case study team illustrates that expert judgement can be used to identify the relative value of benefits compared to other components of the BCA to either put those benefits in context within a MODA process (see Section 9.6.2), or to focus effort on identifying data sources and valuation methodologies.

9.5.3 Case Study Reanalysis: Benefit Cost Analysis and Alternative Ranking

The valuation metrics identified by the study team were used to recalculate a BCR for each of the case studies to benchmark the impact of including a wider suite of benefits within a BCA (Table 9-7). Valuation of ecosystem services costs and benefits increased the BCR for three of the case studies. For Jacksonville Harbor Mile Point, beneficial use of dredge was cheaper than use of an upland disposal area, and in addition the associated benefits of created marsh and a flow improvement channel exceeded their cost. As a result, inclusion of NBS increased the BCR. The inclusion of ecosystem services benefits similarly led to a modest increase in the BCR for Jamaica Bay. The NBS alternatives for West Sacramento had a higher BCR than those without and, when using OMB discount rates, the BCR surpassed the breakeven threshold of 1.0 for one plan (increasing from 0.92 to 1.08) based on inclusion of NBS and associated ecosystem services value.

Conversely, however, the BCR for the remaining three case studies (South San Francisco Bay, South Platte River and Tributaries, and Southwest Coastal Louisiana) decreased when comparing alternatives with NBS solutions to structural or nonstructural alternatives developed for flood risk management. The original Feasibility Studies at these locations analyzed NED alternatives separately from NER and NBS alternatives. In these cases, the added costs of NBS exceeded the calculated benefits even with added consideration of ecosystem services, thereby leading to the more targeted risk reduction alternatives included in the NED having a higher BCR than alternatives that included both NED and NER elements.

Table 9-7. Results of reconducting a BCA for the six case studies including valuation metrics identified by the study team.

Study	NBS considered in valuation	BCR reanalysis outcome	Key factors
Jacksonville Harbor Mile Point	Marsh creation and flow improvement channel	• Reanalysis considered NBS that were originally added with VE study. • Each measure improved the BCR, therefore alternative with all NBS included would rank highest. • BCR improved from 1.4 to 2.3 with inclusion of all benefits	• Beneficial use of dredge had lower costs than upland disposal in addition to providing benefits. • Improved waterway access, water quality, and preserved dredge disposal capacity all improved BCR
Southwest Coastal Louisiana	Multiple including marsh, barrier island, ridge, and hydrologic restoration	• Reanalysis combined NED and NER, while original BCA considered NED alternatives only. • BCR for combined NED/NER Plan decreased from 5.65 to 2.67 for NED	• BCR for NED/NER exceeded 1.0, showing benefits exceeded costs. • Lower BCR than for flood risk protection alone, noting that some benefits could not be quantified

Study	NBS considered in valuation	BCR reanalysis outcome	Key factors
South San Francisco Bay	Restoration of historic tidal march and construction of ecotone levee	• Reanalysis evaluated unified BCR across multiple accounts (NED or LPP, NER, and recreation) • BCR decreased when including NER and recreation from 10.62 to 7.46	• Insufficient data were available to quantify any new benefits or costs. • BCR well exceeded 1.0 when including NER and recreation (ranging from 2.29–7.46)
West Sacramento	Setback levee and weir/bypass widening	• Reanalysis compared two alternatives with NBS to one without • BCR for alternatives with NBS improved from 2.21 to 2.62 and 2.56 to 2.67 and • Inclusion of environmental costs/benefits led to NBS alternatives ranking equal to or higher than non-NBS alternative	• Inclusion of ecosystem services valuation had modest impact on BCR but changed alternative ranking. • Inclusion of ecosystem services valuation increased the BCR using OMB discount rate from below (0.9) to just above (1.08) the breakeven threshold
South Platte River and Tributaries	Multiple including wetland/habitat restoration and improvement, river widening, etc.	• Reanalysis compared the NER Plan, a more expansive NER Plan that was not chosen, and the BCR of the NED Plan. • BCR considered NED/NER together dropped from 1.4 to 0.42 and 0.67 to 0.21 when NBS costs, benefits included.	• Insufficient data for valuation limited benefit assessment, particularly in terms of natural capital
Jamaica Bay	Marsh, tidal creek, and maritime forest restoration, sand fill, oyster reefs	• Reanalysis considered a new suite of alternatives with NBS measures. • BCR of alternatives with more NBS increased (e.g., from 0.75 to 1.29), surpassing selected alternative that increased from 0.95 to 0.98	• Inclusion of ecosystem services valuation had modest impact on BCR but did change alternative ranking. • Most alternatives (including the one selected) had BCRs below 1.0 without including day use values

Note: BCRs given use study-specific USACE discount rates and assume the higher (or highest) BCR if uncertainty ranges were included in the reanalysis. Also given are key factors driving underlying these results.

There were, however, several reanalysis limitations that should be considered when interpreting this result. First, the study team was also only able to consider NBS alternatives drawn from measures already included with the original Feasibility Studies to have sufficient information (e.g., costing data) to recalculate the BCR. This limitation prohibited consideration of a full suite of NBS, including holistic alternatives that more directly integrate NBS with structural measures.

In addition, each case study had benefits that could not be monetized due to lack of available data and/or methods (Table 9-6). The potential value of these benefits was potentially high in some cases; for example, an independent study focused on the downtown Denver area estimated that South Platte River improvements could have led to an increase in property values of $18 billion, but the fraction of this value attributable to the USACE project could not be accounted for in the reanalysis.

Finally, the study team notes that the BCA reanalysis results are sensitive to key assumptions, notably 1) the discount rate applied and 2) the assumed period of performance for the alternatives considered. In terms of discount rate, sensitivity analysis results from the various case studies clearly demonstrated that an assumed 7% discount rate can dramatically reduce the BCR for proposed NBS investments when compared with the lower discount rates applied during different time periods to inform the various USACE planning analyses.

An assumed 50-year period of performance may also limit the ability to capture NBS benefits. This is both because 1) the benefits from nature-based approaches may take time to accrue and extend beyond a 50-year planning horizon, and 2) it can be difficult to capture the value associated with NBS solutions that can extend the useful service life of traditional infrastructure (e.g., the resilience value associated with a longer foreshore for the ecotone levee that was evaluated in the South San Francisco Bay study).

9.5.4 Key Findings: Monetized Valuation

Based on the analysis of the case studies, the study team determined that existing USACE tools in use for some feasibility studies (e.g., recreational UDV) can be applied more broadly to expand the type of benefits used in BCR calculation. Similarly, existing USACE data and information can be used to quantify a wider range of benefits for projects than is typically evaluated in the BCR. For example, the preservation of capacity at dredge disposal areas and the associated future cost savings should be included as a benefit of BUD, which can be calculated using available USACE dredge management plans.

In addition, co-located research conducted separately from USACE planning studies and benefit transfer approaches can be used to estimate alternative benefits in cases where USACE data and/or methodologies are not available. Expert judgement can be used as a filter to determine the relative magnitude of potential benefits and to focus effort on identifying data and information that can be used to monetize benefits expected to provide the greatest impact on the BCA. Development of guidance and/or databases that provide geographic-specific parameters for use in these methods could also support their application within Feasibility Studies.

9.6 PRIORITIZATION AND ALTERNATIVE SELECTION

Although including a wider range of benefits into BCA can support more comprehensive analysis of NBS, analysis of the case studies suggests that the measures and alternatives considered provide benefits that cannot be effectively monetized due to lack of data or appropriate methodologies (Section 9.5). In addition, the co-equal principles established by the PR&G include consideration of project impacts that may be difficult or impossible to quantify through monetization regardless of supporting information (e.g., environmental justice considerations). However, MODA techniques provide an opportunity to evaluate these costs and benefits more effectively and can be used in conjunction with BCA for more comprehensive alternative evaluation. In the following sections, case studies are considered in the context of the co-equal principles of the PR&G and the results of applying MODA to evaluate alternatives in reviewed. An approach to incorporating BCA in conjunction with multi-objective analysis is then presented.

9.6.1 Alternative Evaluation and Prioritization: PR&G Context

All benefits identified for NBS within the case studies have the potential to advance one or more of the co-equal principles identified in the PR&G (Table 9-8). However, only two of the identified benefits (waterway access and carbon sequestration) could be monetized for every case study and NBS where it was potentially applicable. In addition, monetization of benefits in some cases produced a result that, if used without careful consideration, would potentially have negative impacts on one or more of the PR&G principles.

For example, water quality improvements and waterway access were monetized for Jacksonville Harbor Mile Point using a hedonics model for predicting property value improvements, which is inconsistent with environmental justice considerations if the BCA is used exclusively for alternative evaluation. The BCR will improve more for communities with high property values than those with low property values, thereby exacerbating existing disparities by ranking alternatives that benefit economically disadvantaged communities lower. A similar outcome would result in any method that considers property and infrastructure value within the BCR, such as valuation of storm surge and wave attenuation for flood risk mitigation. For Southwest Coastal Louisiana, South San Francisco Bay, West Sacramento, and Jamaica Bay, the study team identified that potentially affected communities were lower income and/or were demographically weighted toward minority groups, and therefore environmental justice considerations may need to be evaluated through targeted MODA to avoid a BCA favoring alternatives based on existing economic disparities.

Incorporating equity and justice into BCA or other quantified evaluation approaches is currently an area of active research. These could include different weighting schemas or the application of participatory methods like Social Return on Investment, which was introduced and described in (Fischbach et al., 2023). A detailed consideration of these approaches was out of scope for this study and report, but a follow-up analysis to be conducted by the study team will explore and test such methods using the same six case studies selected for this analysis.

Table 9-8. Cross-linking of benefits identified for the case studies (Table 9-4) with guiding principles identified in the PR&G.

Category	Benefits	Healthy and resilient ecosystems	Sustainable economic development	Floodplain management	Public safety	Environmental justice
Ecosystem Restoration (habitat and associated species, human use, non-use value)	Consumptive (recreational and charter fishing, water supply, etc.) and non-consumptive use (hiking, kayaking, camping, bird watching, boating, etc.) *		X			X
	Enhancement of habitat and benefits to species*	X				
Quality of life and/or property value improvements for residents	Water quality and/or clarity*	X	X			X
	Waterway access		X			X
	Investment in restoration benefiting economically disadvantaged communities*					X
Regional / system scale benefits	Flood risk mitigation (storm surge, tidal flooding, riverine flooding, etc.) and/or wave attenuation*		X	X	X	X
	Sediment trapping (reductions in navigation channel dredging, land-building, etc.)*		X		X	
	Erosion control*	X	X			X
	Carbon sequestration	X	X			
Resource preservation	Preservation of capacity at upland dredge disposal sites*		X			

Note: Also added is a benefit direct benefit of ecosystem restoration to species and habitats, which was only considered in the case studies through the lens of socioeconomic outcomes. Evaluation of all these benefits supports the sixth co-equal principal to take a watershed approach that identifies that best means possible to achieve multiple goals.

**Benefit that was identified for one or more cases studies but excluded from the associated updated BCA due to lack of available data or appropriate methodologies for quantifying socioeconomic benefit.*

Another PR&G principle that is likely to receive more appropriate consideration under a MODA than BCA is ecosystem protection and restoration. Ecosystem services may be difficult to monetize even where they are known to exist; in every case study considered (Table 9-6), there were potential ecosystem, habitat, or species benefits identified that could not be effectively valuated.

Beyond the limits of calculation methods, however, valuation does not consider impacts to the health and resiliency of habitats and associated species that do not provide direct anthropogenic benefit. This gap inhibits consideration of cascading and long-term project impacts to local and regional ecosystems, which may also ultimately affect ecosystem services. For example, an alternative may negatively impact a keystone species (i.e., a species that has a disproportionate impact on an ecosystem and other species, such that the entire ecosystem is impacted by its presence or absence). The costs of that impact would not be included in BCA if the species is not of commercial or recreational value and/or if the supporting habitat cannot be otherwise valuated; however, the long-term costs associated with the resulting impacts to the ecosystem and other species could be substantial.

Lastly, the PR&G explicitly promotes a watershed approach to planning and use of policies that "facilitate evaluation of a more complete range of potential solutions and is more likely to identify the best means to achieve multiple goals over the entire watershed" (CEQ, 2013, pp. 4–6). In addition to the other PR&G principles that cannot be effectively monetized for appropriate consideration within a BCA, the team identified multiple benefits that could not be assigned an economic value due to lack of data or calculation methods (Table 9-6). A MODA approach is more consistent with comprehensive evaluation of project alternatives based on multiple goals than an approach that assigns zero cost and benefits to outcomes that cannot be monetized.

9.6.2 Multi-Objective Decision Analysis: Case Study Results

An alternate approach to exclusive use of BCA for evaluating alternatives is through MODA. This method does not require that all benefits and costs be put in a common currency of dollars and can therefore consider outcomes and impacts to objectives—including those consistent with the PR&G principles—that could otherwise be partially or totally unaccounted for. For the case studies in which multiple alternatives were reevaluated and there were significant potential benefits that could not be monetized in BCA, the study team applied a method wherein each benefit and cost of alternatives are ranked on a normalized and unitless scale of -2 to 2. For example, the cheapest alternative is ranked a 2 while the most expensive is ranked a -2, and alternatives with intermediate costs are scaled appropriated; an alternative that has the greatest improvement to water quality is ranked a 2 and one with negative impacts is ranked a -2; and so forth.

This approach allowed alternatives that could not be robustly characterized by BCA to be evaluated. For example, an alternative that incorporated CSUs was not evaluated in an updated BCA for Jacksonville Harbor Mile Point because the ecosystem services benefits (i.e., impacts to oysters and other benthic species and resulting benefit to recreational fishing) could not be monetized. The multi-objective analysis captured this benefit while also reflecting that the cost of an alternative including this measure was still lower than an alternative using stone for stabilization rather than CSUs. Similarly, benefits such as restoration of ecological function and improvements to water quality that could not be monetized for South San Francisco Bay led to the LPP, which included multiple NBS, being ranked highest among the alternatives across every factor except cost.

The relative ranking approach that was applied within the case studies is modular and adaptable to virtually any type of system, given that expert elicitation informed by analysis of both monetized and non-monetized metrics (e.g., acres of habitat created) forms the basis of this methodology. In cases where the spatial extent of a Feasibility Study is small and/or there are a targeted number of focused objectives, MODA can rely more heavily on BCA (e.g., the approach used by the study team for West Sacramento). MODA also allows tradeoffs to be explicitly identified and considered (i.e., a deliberate determination of benefits against the associated monetary cost, such as might occur in a USACE VE study).

One limitation of this approach is that it does not result in a single metric that can be used to rank alternatives, which may be a desired outcome of alternative evaluation. The method is readily adaptable to achieve this result, however. The ranked scores for each benefit and cost can be weighted based on the relative importance of associated objectives identified through stakeholder input and/or USACE determination and then summed to calculate a final score for each alternative. The suite of quantitative metrics used for MODA, particularly when weighted and combined for scoring and ranking alternatives, should be developed such that each metric characterizes unique benefits and costs to avoid double counting. Alternately, BCA and/or evaluation of calculated metrics (such as acres of habitat created and/or social impact metrics capturing environmental justice considerations) can be used as screening tools or constraints as part of multi-objective analysis, as described in the next section.

9.6.3 Integration of BCA into Multi-Objective Alternative Evaluation

One of the key results of the case study reanalysis is that BCA discounts or excludes both benefits and costs that are relevant to study objectives (see Sections 9.4 and 9.5), and may therefore be difficult to apply to alternative evaluation in a way that is consistent with the principles established by the PR&G. Reanalysis of the case studies suggests that MODA (see Section 9.6.2), which allows consideration of both monetized and non-monetized costs and benefits, could provide more comprehensive alternative evaluation and greater consider of NBS. However, this approach does not preclude use of BCA.

USACE must comply with OMB efficiency requirements as stewards of public funds, a need that can be addressed through application of BCA. For consistency with that requirement, BCA could be conducted and applied to a suite of alternatives that integrates structural and nonstructural alternatives, including NBS (see Section 9.3). This analysis should include ecosystem services valuation wherever possible to ensure that relevant costs and benefits are not implicitly assumed to be zero through exclusion. This analysis could be used to screen out alternatives that do not achieve a breakeven threshold of 1.0 (or other minimum level of economic performance determined to be appropriate), while not eliminating alternatives solely based on monetized costs and benefits.

The suite of alternatives that pass the identified threshold could then be evaluated based on multi-objective analysis such as described in Section 9.6.2. This multi-objective analysis could be used to identify alternatives providing maximal benefit across all objectives in several ways. Alternatives could be ranked through a sum of weighted metrics identified for each objective, and/or methods like those used in VE studies could be applied directly as part of alternative evaluation to determine the incremental benefit additional investment would provide across objectives.

9.6.4 Key Findings: Prioritization and Alternative Selection

The inherent limitations of BCA in valuing costs and benefits of ecosystem services suggests that MODA approaches that are adaptable to use of non-monetized metrics and expert judgement of relative benefit can more completely evaluate study alternatives, including those incorporating NBS. Reanalysis of the case studies indicates that multi-objective analysis can change the ranking of alternatives, specifically NBS that typically provide a wide range of co-benefits. This type of approach can, however, be used in conjunction with a BCA to ensure OMB efficiency requirements are addressed: BCA that incorporates ecosystem services valuation can be used as a screening step to exclude alternatives that do not meet a minimum threshold, then the suite of alternatives that meet the specified threshold can be comprehensively evaluated through multi-objective analysis. This approach is consistent with the principles established by the PR&G, which specifies equal consideration of factors that are particularly difficult to monetize within a BCA (e.g., environmental justice considerations and ecosystem impacts).

10.0 CONCLUSIONS

The results of the case study analysis described in Chapters 2–9were synthesized along with findings from a review of USACE evaluation approaches over time (Ehrenwerth et al., 2022); an investigation into where and how NBS were considered in planning studies from 2005–2020 (Windhoffer et al., 2023) and a review of relevant planning and valuation methods that could be applied to improve NBS evaluation (Fischbach et al., 2023). This synthesis led to the identification of opportunities for enhancing the evaluation of NBS and USACE projects that is presented in this chapter.

10.1 SUMMARY OF FINDINGS

This chapter summarizes the key findings that emerged from the cross-cutting analysis of the six studies and identifies opportunities for USACE to enhance the Feasibility Study evaluation process based on the results. These opportunities may support USACE in developing and applying forward-looking and practical approaches for formulating, evaluating, and developing water resources projects in a way that integrates and considers the multiple benefits NBS may provide, as required by the updated PR&G.

The key findings and opportunities are organized around stages of a planning analysis (Table 10-1) and are discussed in more detail in the sections that follow.

Table 10-1. Summary of key findings and opportunities organized by planning stage.

Planning stage	Key finding	Opportunity
Study Scope	Scoping within separate mission areas limits NBS opportunities	Use an integrated, multi-objective approach to scope planning studies
Alternative Formulation	NBS options are often excluded during alternative formulation	Formulate integrated alternatives designed to provide benefits or co-benefits across all PR&G guiding principles and to different communities of interest
Evaluation of Non-Monetized Outcomes	Existing tools can support non-monetary benefit estimation	Evaluate alternatives using metrics for all PR&G guiding principles and communities of interest
Ecosystem Service Valuation	A range of existing methods may be applied to enable more comprehensive valuation	Develop USACE guidance, resources, and tools for monetizing a broader range of benefits
Prioritization and Alternative Selection	• Monetizing ecosystem service benefits improved BCA analysis but was generally insufficient to change alternative rankings due to decisions made during scoping, screening, and alternative formulation. • Multi-objective analysis is necessary to capture all benefits	Apply transparent multi-criteria decision analysis as the primary approach for alternative ranking and selection

10.2 STUDY SCOPING

10.2.1 Key Findings

From the initial inventory of completed planning studies evaluated for this research, scoring by USACE subject matter experts indicated that approximately 85% of those that could be scored started out considering NBS in some way. However, only about half of the studies evaluated NBS in the final array of alternatives. Many of these remaining studies were focused solely on environmental restoration, leaving less than a third of the studies that considered NBS options and evaluated them across multiple objectives together (for example, both flood risk management and ecosystem restoration).

Although all but one of the six evaluated planning studies identified multiple goals that could be addressed through integrated NBS, most studies formulated and evaluated these goals separately by mission area rather than holistically.

As a result, a key finding is that **the process of study scoping within specific mission areas can limit the ability to capture synergistic and cross-mission area benefit and, therefore, limit consideration of NBS**. In many cases, NBS options are excluded early in the planning process, in large part due to study scoping that emphasizes a single or limited set of study objectives.

10.2.2 Opportunities

A scoping approach that could broaden consideration of NBS is to **use an integrated, multi-objective study scope as the default to begin future studies**. Under this approach, beneficial outcomes and associated objectives identified by USACE and stakeholders would be considered at the start of the study, and would consider benefits that span mission areas and the co-equal principles established of the PR&G.

Implementation of this opportunity could be supported by:

- Eliciting and incorporating input from non-federal sponsor(s) and stakeholders to inform the objectives that the study will address,
- Considering the potential for benefits across all PR&G principles, and
- Ensuring that all alternatives would address the authorized project purpose(s), and otherwise consider all PR&G principles when ranking alternatives.

10.3 ALTERNATIVE FORMULATION

10.3.1 Key Findings

The process and assumptions that undergird alternative formulation play an essential role in considering or excluding integrated NBS. **Most of the case studies reviewed did not identify or excluded integrated alternatives with NBS that could support primary study objectives or that could provide ancillary benefits**.

The lack of NBS in the formulated alternatives resulted from:

- Separate formulation of alternatives for each mission area,

- Use of fundamentally different approaches (e.g., structural vs. nonstructural risk reduction) in alternative formulation, and/or
- Preliminary analysis screening out integrated approaches in favor of more narrowly tailored options that are economically justifiable in isolation.

10.3.2 Opportunities

An approach to alternative formulation that can support more widespread consideration of NBS is for studies to **deliberately identify integrated alternatives designed to meet multiple objectives**.

Implementation of this opportunity could be supported by:

- Formulating integrated alternatives designed to provide benefits or co-benefits across all PR&G mission areas and to different communities of interest,
- Explicitly considering NBS in alternative formulation for all relevant studies, and
- Focusing initial screening on feasibility and cost rather than economic performance, reserving BCA as a minimum threshold for economic performance as part of a multi-criteria analysis of complete, integrated alternatives.

10.4 NON-MONETIZED OUTCOME EVALUATION

10.4.1 Key Findings

Full consideration of the co-equal principles established by the updated PR&G requires consideration of a wide suite of benefits and costs, including those that cannot be effectively monetized through BCA (e.g., environmental justice considerations and environmental benefits that may not be directly associated with ecosystem services).

The study team found that **some environmental/social/non-economic metrics may be estimated with existing USACE tools, while others will require additional modeling or analysis not typically incorporated into a planning study**. That said, NBS evaluation across multiple objectives could be augmented with relevant science developed independently of the study, expert knowledge, and local and community knowledge.

10.4.2 Opportunities

There is an opportunity to broaden the benefits and costs included in alternative evaluation by **using metrics from all relevant PR&G guiding principles and communities of interest with a stake in study outcomes**. There are challenges to this approach, however, given that it is likely unfamiliar to many USACE practitioners and because identifying and utilizing available tools from other USACE Districts and/or that can be found in the literature may be beyond the scope of most Feasibility Studies.

Implementation of this opportunity could therefore be supported by:

- Expanding the USACE-certified modeling toolkit to support alternatives evaluation for multiple outcomes, and

- Developing updated guidance for using multiple lines of evidence regarding project benefits and costs including BRIs or metrics for each PR&G principle, and use of peer-reviewed science, expert input, and traditional and community knowledge to augment study analysis.

10.5 MONETIZED VALUATION

10.5.1 Key Findings

Although there are ecosystem services benefits that cannot be monetized, analysis of the case studies indicates that **there are opportunities to make BCA more comprehensive through ecosystem service valuation**. The study team identified a variety of existing methods that could be used to improve estimation of monetized benefits, thereby valuing outcomes that are often excluded and thereby (inaccurately) assumed to be zero.

Methods are available to estimate monetized benefits from ecosystem services, including some already in use by USACE (e.g., application of recreational use-day values) or that rely exclusively on USACE data and methods (e.g., quantifying the cost savings associated with beneficial use of dredge preserving capacity in disposal areas). In addition, methods such as benefit transfer, which rely on using appropriate valuation parameters established outside of the case study, would allow for broader valuation of NBS in BCA analysis.

The study team also considered how incorporation of ecosystem service benefits impacted the BCR. **Although the ratio of benefits to costs increased in some case studies, it decreased the ratio in others due to increased costs associated with NBS implementation**. Additionally, incorporating additional ecosystem service benefits did not change alternatives ranking in most cases based on BCA alone. This finding is tempered by the fact that decisions made during study scoping, screening, and alternative formulation limited the number and diversity of NBS and integrated NBS-structural alternatives that could be evaluated in the reanalysis. However, the change in BCR identified for some of the case studies suggests that incremental improvements can be made reducing the uncounted costs and benefits of BCA by building on existing methods and new tools and providing guidance on use to USACE practitioners.

10.5.2 Opportunities

The case study analysis indicates there are additional ecosystem services that can be monetized and included in BCA analysis beyond what USACE typically applies. However, methods to monetize these services typically rely on data and models that may be beyond the scope of a feasibility study to generate and/or for Districts to have in-house expertise in application. An opportunity therefore exists to support more comprehensive BCA through **development of additional guidance and resources for monetizing environmental and social benefits**.

Implementation of this opportunity could be supported by:

- Updated guidance to raise awareness and capacity across Districts to use existing USACE methods, such as recreational UDVs or dredge disposal cost estimation, and

- Development of a benefit transfer database and/or decision support tool(s) to support ecosystem valuation in BCA analysis. This could build on similar efforts by other agencies, such as USEPA and NOAA.

10.6 PRIORITIZATION AND ALTERNATIVE SELECTION

10.6.1 Key Findings

One of the key determinations of the case study reanalysis is that **NBS alternatives tend to provide benefits that are difficult to robustly monetize**. There are multiple reasons driving this outcome. First, there is still the challenge of lack of data and/or appropriate methods for some key sources of benefit. More broadly, though, even with improved approaches **monetized valuation alone cannot fully represent the PR&G principles, values, and associated benefits from the water resources case studies considered**.

The study team did determine, however, that MODA provides an opportunity to consider a broader range of benefits and costs consistent with the PR&G principles, including those where ecosystem service valuation is limited by data availability or impossible due to the inherently non-monetary nature of a desired outcome.

10.6.2 Opportunities

The opportunity identified by the study team that is likely to have the most widespread impact on Feasibility Study outcomes is to **adopt transparent, multi-objective decision analysis as the primary approach for alternative ranking and selection**. Under this approach, BCA can be used as an initial screening criterion to address cost-efficiency considerations, such as by excluding those alternatives that do not achieve a breakeven threshold of one even with the inclusion of ecosystem services benefits of the types identified in the case study review.

MODA techniques that rely on monetized and non-monetized benefits, and which can be augmented by expert judgement in cases where insufficient data exist to robustly characterize outcomes, can then support final prioritization of alternatives. This approach also allows for explicit tradeoffs to be considered directly in the alternative evaluation process; for example, using approaches taken in VE studies where the benefit per unit cost is considered in addition to the total values.

Use of BCA as a screening rather than prioritization tool would follow related efforts by FEMA to combine monetized valuation and MODA in its grant programs. For instance, FEMA released guidance for the 2022 Building Resilient Infrastructure and Communities and Flood Mitigation Assistance grant competitions specifying that "A mitigation project may be considered cost-effective if, when using the 7% discount rate, the BCR is at least 0.75 or greater, and if at the 3% discount rate the BCR is at least 1.0 or greater" (FEMA, 2022a). To use this alternate approach, the project must also meet other criteria, including providing difficult to quantify benefits and benefitting disadvantaged communities.

This approach would allow for incremental improvement to valuation to incorporate where appropriate while still removing other impediments to the broader consideration of NBS.

Implementation of this opportunity could be supported by:

- Guidance for practitioners on use of multi-objective decision analysis to consider economic and non-economic quantitative outputs,
- Augmenting quantitative assessment with qualitative information, such as local knowledge and values, along with expert input, and
- Prioritizing alternatives that provide balanced benefits across all PR&G guiding principles rather than optimizing for a single mission.

10.7 NEXT STEPS

The initial phase of this effort identified MODA, supported in part by BCA that incorporates a wider range of ecosystem services than are typically included, as a method for greater consideration of NBS to address the co-equal principles of the PR&G. The study also determined, however, that there are non-monetized (and non-monetizable) social outcomes and equity considerations that could potentially be quantified through additional study. Going forward, the same set of six case studies presented in this report will be analyzed to specifically consider social outcomes and equity as part of the overall study process and BCA analysis. In addition, updated guidance and tools can support USACE in implementation of multi-objective analysis and expanded BCA in future planning studies.

11.0 REFERENCES

Able, K. W., Nemerson, D. M., & Grothues, T. M. (2004). Evaluating salt marsh restoration in Delaware Bay: Analysis of Fish response at former salt hay farms. *Estuaries*, *27*(1), 58–69. https://doi.org/10/b8vft4

Baltz, D. M., Rakocinski, C., & Fleeger, J. W. (1993). Microhabitat use by marsh-edge fishes in a Louisiana estuary. *Environmental Biology of Fishes*, *36*(2), 109–126. https://doi.org/10/d2f78p

Bane, C. (2021, August 24). *In landlocked Denver, river surfing rides a wave of popularity*. Westword. https://www.westword.com/news/river-surfing-rides-a-wave-of-popularity-in-landlocked-denver-12184999

Baptist, M. J., Gerkema, T., van Prooijen, B. C., van Maren, D. S., van Regteren, M., Schulz, K., Colosimo, I., Vroom, J., van Kessel, T., Grasmeijer, B., Willemsen, P., Elschot, K., de Groot, A. V., Cleveringa, J., van Eekelen, E. M. M., Schuurman, F., de Lange, H. J., & van Puijenbroek, M. E. B. (2019). Beneficial use of dredged sediment to enhance salt marsh development by applying a 'Mud Motor.' *Ecological Engineering*, *127*, 312–323. https://doi.org/10.1016/j.ecoleng.2018.11.019

Barnes, S., Bond, C., Burger, N., Anania, K., Strong, A., Weilant, S., & Virgets, S. (2015). *Economic evaluation of coastal land loss in Louisiana* (p. 119). Louisiana State University, Economics & Policy Research Group; The RAND Corporation. https://www.rand.org/pubs/external_publications/EP67228.html

Barnes, S. R., Bond, C. A., Burger, N., Anania, K., Strong, A., Weilant, S., & Virgets, S. (2017). Economic evaluation of coastal land loss in Louisiana. *Journal of Ocean and Coastal Economics*, *4*(1). https://doi.org/10.15351/2373-8456.1062

Batker, D., de la Torre, I., Costanza, R., Swedeen, P., Day, J., Boumans, R., & Bagstad, K. J. (2010). *Gaining ground: Wetlands, hurricanes, and the economy: The value of restoring the Mississippi River Delta* [Earth Economics Project Report]. Environmental Law Institute.

Baustian, M. M., Liu, B., Moss, L., & Wang, Y. (2022). *Estimating changes of net greenhouse gas sinks and sources in Louisiana's coastal area from implementation of the state's 2017 Coastal Master Plan* [Prepared for Coastal Protection and Restoration Authority and Governor's Office of Coastal Activities and funded by the Coastal Protection and Restoration Authority via Task Order 83 through the Gulf Coast Ecosystem Restoration Council].

Beagle, J., Lowe, J., McKnight, K., Safran, S., Tam, L., & Szambelan, S. J. (2019). *San Francisco Bay Shoreline adaptation atlas: Working with nature to plan for sea level rise using operational landscape units*. San Francisco Estuary Institute & SPUR.

Benoit, L. K., & Askins, R. A. (2002). Relationship between habitat area and the distribution of tidal marsh birds. *The Wilson Bulletin*, *114*(3), 314–323. https://doi.org/10.1676/0043-5643(2002)114[0314:RBHAAT]2.0.CO;2

Blancher, E. C., & Goecker, M. (2016, December). *Using Aquatox 3.1 NME to maximize restoration priorities for natural resources injured by the Deepwater Horizon oil release*.

Blancher, E. C., Park, R. A., Clough, J. S., Milroy, S. P., Graham, M. W., Rakocinski, C. F., Hendon, J. R., Wiggert, J. D., & Leaf, R. (2017). Establishing nearshore marine secondary productivity baseline estimates for multiple habitats in coastal Mississippi and Alabama using AQUATOX 3.1 NME for use in the Deepwater Horizon natural resource damage assessment. *Ecological Modelling*, *359*, 49–68. http://dx.doi.org/10.1016/j.ecolmodel.2017.05.004

Bridges, T. S., Wagner, P. W., Burks-Copes, K. A., Bates, M. E., Collier, Z. A., Fischenich, C. J., Gailani, J. Z., Leuck, L. D., Piercy, C. D., Rosati, J. D., Russo, E. J., Shafer, D. J., Suedel, B. C., Vuxton, E. A., & Wamsley, T. V. (2015). *Use of natural and nature-based features (NNBF) for coastal resilience* (Final Report ERDC SR-15-1; p. 479). U.S. Army Corps of Engineers, Engineer Research and Development Center.

Brown, K. M., Tims, J. L., Erwin, R. M., & Richmond, M. E. (2001). Changes in the nesting populations of colonial waterbirds in Jamaica Bay Wildlife Refuge, New York, 1974-1998. *Northeastern Naturalist*, 19.

Calder, R. S. D., Shi, C., Mason, S. A., Olander, L. P., & Borsuk, M. E. (2019). Forecasting ecosystem services to guide coastal wetland rehabilitation decisions. *Ecosystem Services*, *39*, 101007. https://doi.org/10.1016/j.ecoser.2019.101007

Castellanos, D. L., & Rozas, L. P. (2001). Nekton use of submerged aquatic vegetation, marsh, and shallow unvegetated bottom in the Atchafalaya River Delta, a Louisiana tidal freshwater ecosystem. *Estuaries*, *24*(2), 184. https://doi.org/10/btp3d4

Cecchetti, A. R., Stiegler, A. N., Graham, K. E., & Sedlack, D. L. (2020). The Horizontal Levee: A multi-benefit nature-based treatment system that improves water quality and protects coastal levees from the effects of sea level rise. *Water Research X*. https://doi.org/10.1016/j.wroa.2020.100052

CEQ. (2013). *Principles and requirements for federal investments in water resources*. Council on Environmental Quality. https://obamawhitehouse.archives.gov/sites/default/files/final_principles_and_requirements_march_2013.pdf

Chesney, E. J., Baltz, D. M., & Thomas, R. G. (2000). Louisiana estuarine and coastal fisheries and habitats: Perspectives from a fish's eye view. *Ecological Applications*, *10*(2), 350–366. https://doi.org/10/cp73rf

Clough, J. S. (2014). Aquatox (Release 3.1 Plus): Modeling environmental fate and ecological effects in aquatic systems. *U.S. Environmental Protection Agency Office of Water*, *1*.

Collins, J. N., & Grossinger, R. M. (2004). *South Bay Salt Pond Restoration Project: Syntheses of scientific knowledge for maintaining and improving functioning of the South Bay ecosystem and restoring tidal salt marsh and associated habitats over the next 50 years at pond and pond-complex scale* (No. 308). San Francisco Estuary Institute.

Colorado Department of Local Affairs, State Demography Office. (2022). *Demographic summary January 2022*. SDO Population Resource Page. https://demography.dola.colorado.gov/assets/html/population.html

Council on Environmental Quality. (2013). *Economic and environmental principles and requirements for water and related land resources implementation studies: Final* (78 Fed. Reg. 18562).

Council on Environmental Quality. (2014). *Economic and environmental principles and guidelines for water and related land resources implementation studies, final interagency guidelines* (79 Fed. Reg. 77460).

Couvillion, B. R., Beck, H., Schoolmaster, D., & Fischer, M. (2017). *Land area change in coastal Louisiana from 1932 to 2016* (U.S. Geological Survey Scientific Investigations Map No. 3381; p. 16). U.S. Geological Survey. https://doi.org/10.3133/sim3381

CPRA. (2012). *Louisiana's Comprehensive Master Plan for a Sustainable Coast* (p. 186). Coastal Protection and Restoration Authority.

CPRA. (2017a). *Louisiana's Comprehensive Master Plan for a Sustainable Coast* (p. 184). Coastal Protection and Restoration Authority of Louisiana. http://coastal.la.gov/wp-content/uploads/2017/04/2017-Coastal-Master-Plan_Web-Single-Page_CFinal-with-Effective-Date-06092017.pdf

CPRA. (2017b). *Louisiana's Comprehensive Master Plan for a Sustainable Coast: Committed to our Coast* (p. 392). Coastal Protection and Restoration Authority. http://www.icevirtuallibrary.com/doi/abs/10.1680/cmsb.41301.0034

CPRA. (2017c). *Louisiana's Comprehensive Master Plan for a Sustainable Coast: Committed to our Coast. Appendix C: Modeling, Attachment C4-11.2: Social vulnerability index.* http://coastal.la.gov/wp-content/uploads/2017/04/Attachment-C4-11.2_FINAL_030817.pdf

CPRA. (2020). *Southwest Coastal Louisiana project nonstructural coastal storm damage risk reduction preconstruction, engineering, and design*. Coastal Protection and Restoration Authority. https://cims.coastal.louisiana.gov/outreach/Projects/SWCoastal

Davies-Colley, R., & Smith, D. (2001). Turbidity, suspended sediment, and water clarity: A review. *Journal of the American Water Resources Association*, *35*(5), 1085–1101.

Davis, D., Weppler, P., Rafferty, P., Clarke, D., & Yazoo, D. (2017). *Elders Point East Marsh Island restoration monitoring data analysis* (ERDC/EL CR-17-1). USACE. https://doi.org/10.21079/11681/23952

de Groot, R., Brander, L., van der Ploeg, S., Costanza, R., Bernard, F., Braat, L., Christie, M., Crossman, N., Ghermandi, A., Hein, L., Hussain, S., Kumar, P., McVittie, A., Portela, R., Rodriguez, L. C., ten Brink, P., & van Beukering, P. (2012). Global estimates of the value of ecosystems and their services in monetary units. *Ecosystem Services*, *1*(1), 50–61. https://doi.org/10.1016/j.ecoser.2012.07.005

Doedderlein, J., & Binnings, T. (2017). *The economic impacts of transforming Denver's South Platte River and Cherry Creek: 1965-present*. https://doi.org/10.13140/RG.2.2.33525.60642

Ecosystem Sciences Foundation. (2017). *South Platte Watershed natural capital resource assessment*. 85.

Ehrenwerth, J. R., Jones, B., Morris, D., Windhoffer, E., Fischbach, J. R., Hughes, S., Hughes, T., Pippin, S., Shudtz, M., & Jones, S. (2022). *Evolution of benefits evaluation and prioritization of water* *resources projects* (Enhancing Benefits Evaluation for Water Resources Projects: Towards a More Comprehensive Approach for Nature-Based Solutions). The Water Institute of the Gulf.

Farber, S. (1996). Welfare loss of wetlands disintegration: A Louisiana study. *Contemporary Economic Policy*, *14*(1), 92–106. https://doi.org/10.1111/j.1465-7287.1996.tb00606.x

FEMA. (2022a). *Alternative cost-effectiveness methodology for fiscal year 2022 BRIC and FMA application cycle* [Memorandum]. Federal Emergency Management Agency.

FEMA. (2022b). *Declared disasters*. FEMA Disasters & Assistance. https://www.fema.gov/disaster/declarations

Fischbach, J. R., Bond, C. A., Carruthers, T., Dalyander, S., & Hemmerling, S. (2023). *Planning and valuation methods for case study analysis* (Enhancing Benefits Evaluation for Water Resources Projects: Towards a More Comprehensive Approach for Nature-Based Solutions, p. 64). The Water Institute of the Gulf. Funded by the U.S. Army Corps of Engineers Engineer Research and Development Center.

Fischbach, J. R., Knopman, D., Smith, H., Orton, P., Sanderson, E., Fisher, K., Moray, N., Friedberg, A., & Parris, A. (2018). *Building resilience in an urban coastal environment: Integrated, science-based planning in Jamaica Bay, New York*. RAND Corporation. https://doi.org/10.7249/RR2193

Frittelli, J. (2019). Harbor dredging: Issues and historical funding. *Congressional Research Service*, 5. https://crsreports.congress.gov/product/pdf/IN/IN11133

GAO. (2019). *Consideration of project costs and benefits in using natural coastal infrastructure and associated challenges* (Report to Congressional Requesters GAO-19-319; p. 31). United States Government Accountability Office.

Guerry, A. D., Silver, J., Beagle, J., Wyatt, K., Arkema, K., Lowe, J., Hamel, P., Griffin, R., Wolny, S., Plane, E., Griswold, M., Papendick, H., & Sharma, J. (2022). Protection and restoration of coastal habitats yield multiple benefits for urban residents as sea levels rise. *Npj Urban Sustainability*, *2*(1), Article 1. https://doi.org/10.1038/s42949-022-00056-y

Hackney, C. T. (2011). Introduction to an economic study of the St. Johns River. In C. T. Hackney (Ed.), *St. Johns River Economic Study* (p. 284). University of North Florida.

Harris, K. (2021). Here's how the River Mile, a massive 15,000-resident Denver development, will rise along the flood-prone South Platte River banks. *Denverite*. https://denverite.com/2021/11/12/heres-how-the-river-mile-a-massive-15000-resident-denver-development-will-rise-along-the-flood-prone-south-platte-river-banks/

Herbold, B., USEPA, Baltz, D. M., Lousiana State University, Brown, L., U.S. Geological Survey, Grossinger, R., San Francisco Estuary Institute, Kimmerer, W., San Francisco State University, Lehman, P., California Department of Water Resources, Moyle, P. B., University of California, Davis, Nobriga, M., U.S. Fish and Wildlife Service, Simenstad, C. A., & University of Washington. (2014). The role of tidal marsh restoration in fish management in the San Francisco Estuary. *San Francisco Estuary and Watershed Science*, *12*(1). https://doi.org/10/ggc9gk

Iglesias, V., Braswell, A. E., Rossi, M. W., Joseph, M. B., McShane, C., Cattau, M., Koontz, M. J., McGlinchy, J., Nagy, R. C., Balch, J., Leyk, S., & Travis, W. R. (2021). Risky development:

Increasing exposure to natural hazards in the United States. *Earth's Future*, *9*(7), e2020EF001795. https://doi.org/10.1029/2020EF001795

Interagency Working Group on Social Cost of Greenhouse Gases. (2021). *Technical support document: Social cost of carbon, methane, and nitrous oxide interim estimates under Executive Order 13990*. 48.

Jacksonville Harbor begins Mile Point project ahead of port deepening. (2015, September 25). *The Waterways Journal*. https://www.waterwaysjournal.net/2015/09/25/jacksonville-harbor-begins-mile-point-project-ahead-of-port-deepening/

JaxGIS Duval Maps. (n.d.). *Duval property map*. Retrieved May 19, 2022, from https://www.maps.coj.net/DuvalProperty/default.aspx

Kim, T.-G., & Petrolia, D. R. (2013). Public perceptions of wetland restoration benefits in Louisiana. *ICES Journal of Marine Science*, *70*(5), 1045–1054. https://doi.org/10.1093/icesjms/fst026

Li, G., & Fang, C. (2014). Global mapping and estimation of ecosystem services values and gross domestic product: A spatially explicit integration of national 'green GDP' accounting. *Ecological Indicators*, *46*, 293–314. https://doi.org/10.1016/j.ecolind.2014.05.020

Linkov, I., Satterstrom, F. K., Kiker, G., Batchelor, C., Bridges, T., & Ferguson, E. (2006). From comparative risk assessment to multi-criteria decision analysis and adaptive management: Recent developments and applications. *Environment International*, *32*(8), 1072–1093. https://doi.org/10.1016/j.envint.2006.06.013

Linkov, I., Satterstrom, F. K., Kiker, G., Seager, T. P., Bridges, T., Gardner, K. H., Rogers, S. H., Belluck, D. A., & Meyer, A. (2006). Multicriteria decision analysis: A comprehensive decision approach for management of contaminated sediments. *Risk Analysis*, *26*(1), 61–78. https://doi.org/10.1111/j.1539-6924.2006.00713.x

Loomis, J., Kent, P., Strange, L., Fausch, K., & Covich, A. (2000). Measuring the total economic value of restoring ecosystem services in an impaired river basin: Results from a contingent valuation survey. *Ecological Economics*, *33*(1), 103–117. https://doi.org/10.1016/S0921-8009(99)00131-7

Lowe, J., Battalio, B., Brennan, M., Crooks, S., Holmes, T., Niemi, E., & Toms, C. (2013). *Analysis of the costs and benefits of using tidal marsh restoration as a sea level rise adaptation strategy in San Francisco Bay*.

Manson Construction Co. (2022). *Mile Point Training Wall reconfiguration*. What We Do: Marine Construction. https://www.mansonconstruction.com/what-we-do/marine-construction/mile-point-training-wall-reconfiguration

McGonagle, M. P., & Swallow, S. K. (2005). Open space and public access: A contingent choice application to coastal preservation. *Land Economics*, *81*(4), 477–495.

Meselhe, E., White, E. D., & Wang, Y. (2017). *2017 Coastal master plan: Attachment C3-24: Integrated compartment model uncertainty analysis* (2017 Coastal Master Plan, p. 68). Coastal Protection and Restoration Authority. http://coastal.la.gov/wp-content/uploads/2017/04/Attachment-C3-24_FINAL_04.03.2017.pdf

Metro Water Recovery. (n.d.). *South Platte River improvements*. Metro Water Recovery. Retrieved January 9, 2023, from https://www.metrowaterrecovery.com/innovations/south-platte-river-improvements/

Minello, T. J., & Rozas, L. P. (2002). Nekton in Gulf Coast wetlands: Fine-scale distributions, landscape patterns, and restoration implications. *Ecological Applications*, *12*(2), 441–455. https://doi.org/10/dshqt9

Monroe Hazard Mitigation Steering Committee. (2010). *City of Monroe multi-hazard mitigation plan – 2010 update*. https://monroela.us/sites/default/files/Hazard-Risk-Assessment-Report.pdf

National Park Service. (2016). *State of the park report for Timucuan Ecological and Historic Preserve and Fort Caroline National Memorial.* 69. http://www.npshistory.com/publications/state-of-the-park/timu-2016.pdf

National Park Service. (2017, 2021). *Gateway NRA recreation visits by month*. Irma.Nps.Gov. https://irma.nps.gov/STATS/SSRSReports/Park%20Specific%20Reports/Park%20YTD%20Version%201?Park=GATE

NYC Department of Environmental Protection. (n.d.). *Jamaica Bay*. Www1.Nyc.Gov. Retrieved October 26, 2022, from https://www1.nyc.gov/site/dep/water/jamaica-bay.page#:~:text=Jamaica%20Bay%20is%20a%20shallow,acres%20of%20islands%20and%20marshes.

Office of Management and Budget. (2012). *OMB determination* [Government].

Olander, L. P., Johnston, R. J., Tallis, H., Kagan, J., Maguire, L. A., Polasky, S., Urban, D., Boyd, J., Wainger, L., & Palmer, M. (2018). Benefit relevant indicators: Ecosystem services measures that link ecological and social outcomes. *Ecological Indicators*, *85*, 1262–1272. https://doi.org/10.1016/j.ecolind.2017.12.001

Palmquist, R. B., & Smith, V. K. (2003). The use of hedonic property value techniques for policy and litigation. *International Yearbook of Environmental and Research Economics*, *VI*, 115–164.

Plane, E., & Iknayan, K. (2021). *Ecotone levees and wildlife connectivity: A technical update to the adaptation atlas*. San Francisco Estuary Institute.

Preisendorfer, R. (1986). Secchi disk science: Visual optics of natural waters. *Limnology and Oceanography*, *31*(5), 909–926.

Rehm, E. M., & Baldassarre, G. A. (2007). The influence of interspersion on marsh bird abundance in New York. *The Wilson Journal of Ornithology*, *119*(4), 648–654. https://doi.org/10.1676/06-060.1

Robinson, W. (2017, August 6). *Mile Point project paying off*. Jacksonville Business Journal. https://www.bizjournals.com/jacksonville/news/2017/08/16/shippers-seeing-mile-point-benefits.html

Roy, K. (2006). *Wetland Value Assessment Methodology Procedure Manual*. Coastal Wetlands Planning, Protection and Restoration Act. https://lacoast.gov/reports/wva/WVA%20Procedural%20Manual.pdf

Sanderson, E. W., Orton, P., Fischbach, J. R., Knopman, D., Roberts, H., Solecki, W. D., & Wilson, R. (2016). Computational modeling of the Jamaica Bay system. In E. W. Sanderson, W. D. Solecki, J. R. Waldman, & A. S. Parris (Eds.), *Prospects for Resilience: Insights from New York City's Jamaica Bay* (pp. 167–191). Island Press/Center for Resource Economics. https://doi.org/10.5822/978-1-61091-734-6_8

Seidel, V., Diamond, C., Yacobellis, P., Barker, A., & Cortez, C. (2016). The economic impact of the St. Johns River water quality on property values. *Water E-Journal*, 1–12. https://doi.org/10.21139/wej.2016.028

Simpson, K. (2018, October 1). *South Platte River: After years of regarding it as little more than a sewer, is metro Denver ready to love its river?* The Colorado Sun. https://coloradosun.com/2018/10/01/denver-embrace-south-platte-river/

Smith, M. (2022, March 25). *Hurricane-hit southwest Louisiana's population drop among steepest in nation*. The Advocate. https://www.theadvocate.com/lake_charles/article_44d67698-abb4-11ec-9763-a70b7b6adfc4.html

Sommer, L. (2016, June 8). San Francisco Bay restoration measure clears two-thirds hurdle. *KQED*.

Spicer, A. (2015, April 6). *Army Corps closes Little Jetties park for 2 years*. WJXT. https://www.news4jax.com/news/2015/04/06/army-corps-closes-little-jetties-park-for-2-years/

Suedel, B. C., McQueen, A. D., Wilkens, J. L., Saltus, C. L., Bourne, S. G., Gailani, J. Z., King, J. K., & Corbino, J. M. (2021). Beneficial use of dredged sediment as a sustainable practice for restoring coastal marsh habitat. *Integrated Environmental Assessment and Management*, ieam.4501. https://doi.org/10.1002/ieam.4501

Tallis, H., Goldman, R., Uhl, M., & Brosi, B. (2009). Integrating conservation and development in the field: Implementing ecosystem service projects. *Frontiers in Ecology and the Environment*, *7*(1), 12–20. https://doi.org/10.1890/080012

Talton, T. (2018, December 4). *Corps puts limits on dredged sand disposal*. Coastal Review. https://coastalreview.org/2018/12/corps-puts-limits-on-dredged-sand-disposal/

The River Mile. (n.d.). Retrieved May 20, 2022, from https://rivermiledenver.com/

The Water Institute of the Gulf. (2022). *Partnership for Our Working Coast: A Community-Informed Transdisciplinary Approach to Maximizing Benefits of Dredged Sediment for Wetland Restoration Planning at Port Fourchon, Louisiana.* Prepared for and funded by The National Fish and Wildlife Foundation, Shell, Chevron, Danos, and the Greater Lafourche Port Commission.

Townsend, K., Maglio, C., Thomas, R., Thornton, D., Miller, J., Campbell, T., Lin, L., Willey, S., & Wood, E. (2014). *Reducing shoaling in the Texas GIWW and erosion of barrier islands along West Galveston Bay*. 10.

U.S. Census Bureau. (2020). *Decennial census, Calcasieu Parish, LA population, P1: Race.* https://data.census.gov/table?q=population+calcasieu+parish+louisiana+2020&tid=DECENNIALPL2020.P1

USACE. (n.d.). *Southwest Coastal Louisiana feasibility study project status*. Retrieved June 2, 2022, from https://www.mvn.usace.army.mil/About/Projects/Southwest-Coastal/

USACE. (2010). *Final Calcasieu River and pass, Louisiana dredged material management plan and supplemental environmental impact statement* (Volume I). https://www.mvn.usace.army.mil/Portals/56/docs/PD/Projects/CalcasieuDMMP/DMMP_SEIS%20Main%20Report-November%2022%202010.pdf

USACE. (2012a). *Jacksonville Harbor (Mile Point) Navigation Study, Duval County, Florida: Final Integrated Feasibility Report and Environmental Assessment*. Jacksonville District.

USACE. (2012b). *Jacksonville Harbor (Mile Point) Navigation Study, Duval County, Florida: Final Integrated Feasibility Report and Environmental Assessment, Appendices*. USACE.

USACE. (2014a). *Jacksonville Harbor navigation study, Duval County, Florida: Final integrated general reevaluation report II and supplemental environmental impact statement* (p. 310). USACE.

USACE. (2014b). *West Sacramento general reevaluation report: Economic appendix* (Appendix G; p. 96). U.S. Army Corps of Engineers.

USACE. (2015a). *Project partnership agreement*. https://www.saj.usace.army.mil/Portals/44/docs/Navigation/MilePointPPA20150130.pdf

USACE. (2015b). *South San Francisco Bay phase I study: Appendix D-hydrology and hydraulics*. U.S. Army Corps of Engineers.

USACE. (2015c). *South San Francisco Bay Shoreline: Chief's report*.

USACE. (2015d). *South San Francisco Bay Shoreline phase I study: Appendix B-supporting planning and environmental documentation and information*. U.S. Army Corps of Engineers.

USACE. (2015e). *South San Francisco Bay Shoreline phase I study: Appendix C-economics appendix*. U.S. Army Corps of Engineers.

USACE. (2015f). *South San Francisco Bay Shoreline Phase I study: Final interim feasibility study with environmental impact statement/environmental impact report*. San Francisco District.

USACE. (2015g). *West Sacramento project, post authorization change report*.

USACE. (2016a). *Atlantic Coast of New York, East Rockaway Inlet to Rockaway Inlet and Jamaica Bay draft integrated Hurricane Sandy general reevaluation report and environmental impact statement*.

USACE. (2016b). *Southwest Coastal Louisiana: Integrated final feasibility report and environmental impact statement*. Mississippi Valley Division, New Orleans District.

USACE. (2016c). *West Sacramento chief's report* [Chief's Report]. U.S. Army Corps of Engineers.

USACE. (2016d). *West Sacramento project general reevaluation report* (p. 212).

USACE. (2018). *Section 1135 ecosystem restoration study, integrated feasibility report and environmental assessment, Southern Platte Valley Denver, Colorado*. Omaha District.

USACE. (2019a). *Chief's report: East Rockaway Inlet to Rockaway Inlet and Jamaica Bay reformation, Atlantic Cost of New York*. U.S. Army Corps of Engineers.

USACE. (2019b). *Final integrated feasibility report and environmental impact statement, Adams and Denver Counties, Colorado, general investigation study*. https://usace.contentdm.oclc.org/digital/collection/p16021coll7/id/7366

USACE. (2019c). *Final integrated feasibility report and environmental impact statement, Adams and Denver Counties, Colorado, general investigation study: Appendix C economics*.

USACE. (2019d). *Hurricane Sandy general reevaluation report and environmental impact statement*.

USACE. (2019e). *Integrated Hurricane Sandy general reevaluation report and environmental impact statement: Atlantic Coast of New York, East Rockaway Inlet to Rockaway Inlet and Jamaica Bay*.

USACE. (2020a). *Chief's report: Hudson-Raritan Estuary (HRE) ecosystem restoration, New York and New Jersey*. U.S. Army Corps of Engineers.

USACE. (2020b). *Hudson-Raritan Estuary ecosystem restoration feasibility study: Final integrated feasibility report & environmental assessment*. U.S. Army Corps of Engineers.

USACE. (2021a). *Economic guidance memorandum, 22-03, unit day values for recreation for fiscal year 2022*.

USACE. (2021b). *Jacksonville Harbor Duval County, FL dredged material management long-term assessment*.

USACE. (2021c). *Solicitation np: W912HZ21R0007: Review and analysis of completed USACE planning studies to advance the prioritization and selection of alternative designs that feature natural infrastructure and Engineering With Nature® Projects*. U.S. Army Corps of Engineers.

USACE. (2016, July 29). *Subject: Southwest coastal Louisiana* [Personal communication].

USACE. (2019, July 29). *Subject: South Platte River and tributaries, Adams and Denver Counties, Colorado* [Personal communication].

USACE. (2021d, September). *South San Francisco Bay Shoreline phase I construction*. https://www.spn.usace.army.mil/Missions/Projects-and-Programs/Current-Projects/South-San-Francisco-Bay-Shoreline-Study/

USACE. (2021e, November). *Unit day values for recreation, fiscal year 2022*.

USACE Omaha District. (2022, April 1). *USACE Omaha district to partner with city of Denver on $350M waterway restoration, flood mitigation project*. Omaha District. https://www.nwo.usace.army.mil/Media/News-Releases/Article/2986454/usace-omaha-district-to-partner-with-city-of-denver-on-350m-waterway-restoratio/

USGS. (2021, May). *Jamaica Bay UVVR*. Usgs.Gov. https://www.usgs.gov/media/images/jamaica-bay-uvvr

Vela, V. (2018). *When The Rockies moved to LoDo, the team and the neighborhood grew together*. Colorado Public Radio. https://www.cpr.org/2018/06/22/when-the-rockies-moved-to-lodo-the-team-and-the-neighborhood-grew-together/

Villa, F., Bagstad, K. J., Voigt, B., Johnson, G. W., Portela, R., Honzák, M., & Batker, D. (2014). A methodology for adaptable and robust ecosystem services assessment. *PLOS ONE*, *9*(3), e91001. https://doi.org/10.1371/journal.pone.0091001

Water Resources Council. (1982). *Economic and environmental principles and guidelines for water and related land resources implementation studies: Request for comment* [47 Fed. Reg. 12297].

Water Resources Council. (1983). *Economic and environmental principles and guidelines for water and related land resources implementation studies* (p. 147). Water Resources Council.

Water Resources Development Act of 2007, no. 110–114 (2007).

Wenk Associates Inc. (2013). *Confluence Park: A plan for the future of Denver's gathering place*. https://www.denvergov.org/content/dam/denvergov/Portals/747/documents/planning/master_plans/Confluence/2013-05-01_DRAFT%20MASTER%20PLAN.pdf

White, E. D., Meselhe, E. A., McCorquodale, J. A., Couvillion, B. R., Dong, Z., Duke-Sylvester, S. M., & Wang, Y. (2017). *2017 Coastal Master Plan: Attachment C3-22: Integrated Compartment Model (ICM) Development* (Louisiana's Comprehensive Master Plan for a Sustainable Coast, pp. 1–49) [Version Final]. Coastal Protection and Restoration Authority. http://coastal.la.gov/our-plan/2017-coastal-master-plan/

Windhoffer, E., Hughes, S., Hughes, T., Grismore, A., Littman, A., Haertling, A., & Fischbach, J. R. (2022). *Enhancing benefits evaluation for water resources projects: Towards a more comprehensive approach for nature-based solutions*. The Water Institute of the Gulf. Funded by the U.S. Army Corps of Engineers Engineer Research and Development Center.

Windhoffer, E., Hughes, S., Hughes, T., Grismore, A., Littman, A., Haertling, A., & Fischbach, J. R. (2023). *Inventory and selection of completed USACE planning studies for case study analysis* (Enhancing Benefits Evaluation for Water Resources Projects: Towards a More Comprehensive Review of Nature-Based Solutions, p. 76).

APPENDICES

APPENDIX A. ADDITIONAL TECHNICAL INFORMATION FOR CASE STUDIES

This appendix includes additional tables, figures, and technical documentation to support the technical analyses described in the case study chapters of this report. Specifically, additional information is provided for the Southwest Coastal Louisiana, West Sacramento, and Jamaica Bay case studies.

A.1 SOUTHWEST COASTAL LOUISIANA

Table A-1. Nature-based solutions considered during alternative plan formulation. Abbreviations are as follows: MC = marsh creation, T = terracing, SP = shoreline protection, HR = hydrologic restoration, RR = ridge restoration, OR = oyster reef, NWR = National Wildlife Refuge

ID	NBS Alternatives identified (from first screening of over 200 features)	Project Type	Project Area (in acres)	Project Length (in LF)	Estimated net benefit in AAHUs (in acres)	In Final Plan?
3a1	Black Lake marsh restoration. Beneficial use of dredged material from Calcasieu Ship Channel.	MC	599		191	Y
3c	Marsh creation at East Calcasieu Lake. Beneficial use of dredged material from Calcasieu Ship Channel. *(Partially on USFWS land; recommended for independent Congressional authorization & appropriation for construction by USFWS)*	MC	2,081		607	Y
3c2	Cameron-Creole marsh restoration	MC	1,137			N
47a1	Marsh restoration using dredged material south of Hwy 82, east of Grand Chenier	MC	1,021		272	Y
47a2	Marsh restoration using dredged material south of Hwy 82, east of Grand Chenier, immediately south of 47a1	MC	1,423		381	Y
47c1	Marsh restoration using dredged material south of Hwy 82, east of Grand Chenier	MC	1,308		353	Y

ID	NBS Alternatives identified (from first screening of over 200 features)	Project Type	Project Area (in acres)	Project Length (in LF)	Estimated net benefit in AAHUs (in acres)	In Final Plan?
47f	Marsh restoration using dredged material south of Hwy 82	MC		Measures 47f & h were dropped to select MC measures that would best reinforce critical landscape features, with emphasis on areas exposed to saltwater, tidal & wave action. Measures 47f & h are not exposed to as high salinities as other MC areas selected.		
47f	Marsh creation at South Pecan Island	MC				
47f	Terracing south of Hwy 82	T	809			
47h	Marsh restoration using dredged material south of Hwy 82	MC				
47h	Marsh creation at South Pecan Island	MC				
47h	Terracing south of Hwy 82	T	1,520			
124c	Marsh creation/restoration at Mud Lake (adjacent to Hwy 27 and has synergy with measure 5a)	MC	2,658 (Appendix K, p. K-20 reports 1,785 acres)		500	Y
124d	Mud Lake marsh restoration (reinforces West Cove lake rim; within or adjacent to Sabine NWR) **Recommended for independent Congressional authorization and appropriation for construction by USFWS*	MC	623 (Appendix K, p. K-23 reports 607 acres)		4	Y
127c3	Marsh restoration at East Pecan Island on west side of Freshwater Bayou	MC	894		241	Y
135a	Marsh creation at Sweet Lake	MC		Measure 135a is not located in a critical area for MC (salinities are relatively low in this location).		
135a	Sweet/Willow Lake marsh restoration	MC	1,620			

ID	NBS Alternatives identified (from first screening of over 200 features)	Project Type	Project Area (in acres)	Project Length (in LF)	Estimated net benefit in AAHUs (in acres)	In Final Plan?
135b	Sweet/Willow Lake marsh restoration	MC	2,146	The depth near 135b is likely > 2 ft. Terracing projects in this area have failed in the past because of high subsidence rates; dropped due to sustainability issues.		
306a1	Rainey Marsh Restoration - Southwest Portion (Christian Marsh)	MC	2,089 (Appendix K reports 1,896; p K-29)		151	Y
306b	Rainey Marsh Restoration. Restore marsh at Marsh Island south shoreline and Rainey Marsh via dedicated dredging.	MC		Measure 306b was screened out because the adjacent portion of Freshwater Bayou bank is relatively solid and protected by rock.		
5a	Holly Beach Shoreline Stabilization - Breakwaters	SP		39,445 (Appendix K-30 states 8.7 miles and 46,014 ft)	56	Y
6b1	Gulf shoreline of Rockefeller NWR; Gulf Shoreline Restoration: Calcasieu River to Freshwater Bayou	SP	Protects 2,141 acres	58,707 (Appendix K-33: 11 mi; K-35: 58,293 ft)	625	Y
6b2	Gulf shoreline of Rockefeller NWR; Gulf Shoreline Restoration: Calcasieu River to Freshwater Bayou	SP	Protects 1,583 acres	42,805 (Appendix K-36: 8.1 mi; K-38: 42,883 ft)	466	Y
6b3	Gulf shoreline of Rockefeller NWR	SP	Protects 1,098 acres	37,911 (Appendix K-39: 6.3 mi; K-41: 33,355 ft)	312	Y
16b	Fortify spoil banks of GIWW and Freshwater Bayou. Three measure reaches: 16bNE (approx. 2.9 miles), 16bSE (approx. 7.7 miles), and 16bW (approx. 2.8 miles)	SP	Protects 1,288 acres	13.4 mi	279	Y
26	Bankline protection for GIWW (via Rock Dike)	SP		Measure 26 was screened out because it was not cost effective to rock the entire length of the GIWW.		
49b1	Stabilize Calcasieu Lake Shoreline; Shoreline protection for Calcasieu Lake/Cameron-Creole levee	SP		82,282	Measure 49b1 was screened out because	

ID	NBS Alternatives identified (from first screening of over 200 features)	Project Type	Project Area (in acres)	Project Length (in LF)	Estimated net benefit in AAHUs (in acres)	In Final Plan?
					benefits are mostly limited to levee protection.	
49b2	Calcasieu Lake Shoreline protection	SP		151,249	Measure 49b2 was labeled "not efficient," as its cost/net acre was 3x the average.	
99a	Gulf shoreline protection in front of Cheniere Au Tigre ridge	SP	86	9,235		N
113b2	Stabilize Vermilion Bay shoreline: Southwest section	SP	282	42,473		N
21a	Salinity control structures/Hydraulic improvements in Mermentau Basin @ Hwys 82 & 27 (via hydraulic improvement structures): E of Calcasieu Lake	HR		Measure 21a was screened out because a structure was already constructed in this location under CWPPRA authority.		
21b	Salinity control structures at Hwy 82	HR		Measure 21b was screened out due to size (<500 acres).		
21b	Hydraulic improvements in Mermentau Basin @ Hwys 82 & 27 (via hydraulic improvement structures): S of Grand Lake (Little Pecan Bayou Hydrologic Restoration)	HR				
21b	Freshwater introduction at South Grand Chenier	HR				
21b	South of White and Grand Lakes (Flap-gate culverts)	HR				
21c	Salinity control structures at Hwy 82.	HR		Measure 21c was screened out due to size (<500 acres).		
21c	Hydraulic improvements in Mermentau Basin @ Hwys 82 & 27 (via hydraulic improvement	HR				

ID	NBS Alternatives identified (from first screening of over 200 features)	Project Type	Project Area (in acres)	Project Length (in LF)	Estimated net benefit in AAHUs (in acres)	In Final Plan?
	structures): S of White Lake (S Pecan Freshwater Introduction)					
21c	Freshwater introduction at Pecan Island	HR				
21c	South of White and Grand Lakes (Flap-gate culverts)	HR				
7	Salinity control structures in Calcasieu Ship Channel near Ferry/at the Gulf of Mexico	HR				N
13	Freshwater introduction/retention structure or sill on Little Pecan Bayou	HR				N
17a	Salinity control structure on Alkali Ditch	HR				N
17b	Salinity control structure on Crab Gully	HR				N
17c	Salinity control structure on Black Lake Bayou near Hackberry (Kelso Bayou)	HR				N
48	Salinity control structure at Sabine Pass (works w/ 7 as a unit for exterior perimeter control and preclude the need for Alkali Ditch/Crab Gully/Kelso Bayou, GIWW at Gum Cove Ridge (407), and E Calcasieu Lake (74a)	HR				N
74a	*Cameron: need spillway structures at East Calcasieu Lake - moved to a different study. See p. 2-37*	*HR*		*Moved to a different study*		
74b	Cameron: need spillway structures at Humble Canal	HR		Screened out <500 acres		
74c	Cameron: need spillway structures North of Deep Lake	HR		Screened out <500 acres		
304a	Southwest Pass Sills (screened out <500 acres)	HR		Screened out <500 acres		

ID	NBS Alternatives identified (from first screening of over 200 features)	Project Type	Project Area (in acres)	Project Length (in LF)	Estimated net benefit in AAHUs (in acres)	In Final Plan?
304b	Southwest Pass Sills (screened out <500 acres)	HR		Screened out <500 acres		
407	Structure on GIWW at Gum Cove Ridge.	HR				N
507	Abbeville: Consider artificial reef creation; Navy ships could be used as reefs by sinking them; old oil platforms or sheet pile could be used	HR		Screened out because (1) the Louisiana State Master Plan showed only modest benefits for these measures; (2) the measures are outside the study area; (3) these measures may be constructed with Oil Spill Restoration funds.		
507	Reef like feature from Dead Cypress point (near Cypremort Point) to Near Bayou Michael (NW corner of Marsh Island) to replace historic reefs (screened out because LA SMP showed modest benefits, measures outside study area, and measures may be constructed with Oil Spill Restoration funds)	HR				
508	Abbeville: Consider artificial reef creation; Navy ships could be used as reefs by sinking them; old oil platforms or sheet pile could be used	HR		Same as 507 above		
508	Reef like feature from Maroon Point or Point No Point to Lake Point (Marsh Island) to replace historic reefs	HR				
602	Modify existing Cameron-Creole Watershed Control Structure. Operational changes to existing structures (not on map).	HR				N
603	Control structure at Tom's Bayou (screened out <500 acres)	HR		Screened out <500 acres		
416	Restore Chenier Forests	RR				Y
416	Grand Chenier ridges (Restore ridges and upland forests on prominent ridges)	RR				Y

ID	NBS Alternatives identified (from first screening of over 200 features)	Project Type	Project Area (in acres)	Project Length (in LF)	Estimated net benefit in AAHUs (in acres)	In Final Plan?
416	Grand Chenier Ridge (eastern 6 mi of measure do not encompass large swaths of suitable elevation. Of the remainder, nine tracts totaling approx. 252 ac identified)	RR	252			Y
509	Restore Chenier Forests	RR				Y
509a	Restore/sustain Chenier ridges and upland forests on prominent ridges in Vermilion Parish	RR		Screened out because Pecan Island ridge is densely developed with no large tracts (>5 acres) available for reforestation		
509c	Restore/sustain Chenier ridges and upland forests on prominent ridges in Vermilion Parish	RR				Y
509c	Bill Ridge - 3 tracts identified that encompass approximately 9 acres of the northern ridge, and roughly 7 and 6 acres of the southern ridge. Middle section of southern ridge excluded due to insufficient elevation	RR				Y
509d	Restore/sustain Chenier ridges and upland forests on prominent ridges in Vermilion Parish	RR				Y
509d	Cheniere Au Tigre - Majority of this chenier is currently forested with exception of 8-acre tract on western end. The eastern part of the measure along the Gulf shoreline was screened out due to concerns about sustainability of tree plantings in these exposed areas.	RR				Y
510	Restore Chenier Forests	RR				Y
510a	Hackberry and Blue Buck Ridges (Restore ridges and upland forests on prominent ridges)	RR				Y

ID	NBS Alternatives identified (from first screening of over 200 features)	Project Type	Project Area (in acres)	Project Length (in LF)	Estimated net benefit in AAHUs (in acres)	In Final Plan?
510a	Chenier Ridges in Cameron Parish (restore/sustain ridges and upland forests on prominent ridges)	RR				Y
510a	Blue Buck Ridge - 8 tracts totaling approximately 524 acres were identified	RR	524			Y
510b	Hackberry and Blue Buck Ridges - restore ridges and upland forests on prominent ridges	RR				Y
510b	Chenier Ridges in Cameron Parish - restore/sustain ridges and upland forests on prominent ridges	RR				Y
510b	Hackberry Ridge - 3 tracts totaling approximately 149 acres were identified. The western 2 mi (including the 63-acre tract) of this measure have been identified by LA Natural Heritage Program as "Remnant Chenier Forest," but appear to have been damaged by recent hurricanes.	RR	149			Y
510d	Chenier Ridges in Cameron Parish - restore/sustain ridges and upland forests on prominent ridges	RR				Y
510d	Front Ridge - eastern 3 mi of this measure do not encompass large swaths of suitable elevation. Of the remainder, 11 tracts totaling approximately 459 acres were identified.	RR	459			Y
604	Preservation of Sabine Historic Oyster Reefs	OR				N

A.2 WEST SACRAMENTO

Table A-2. Summary of alternative plans by river reach.

	Alternative number											
	0.5A	0.5B	0.5C	0.5D	1	2	3	4	5	6	7	8
	Alternative name											
	Preliminary BCR											
	3.2	1.2	1.8	0.8	2.5	2.2	2.1	1.8	2.9	1.7	0.8	0.5
	Final BCR											
					2.4		2.0		2.6			
Reach	Actions											
Sacramento River North Levee	slurry wall waterside armoring bank protection Raise levee in place		slurry wall waterside armoring bank protection Raise levee in place	slurry wall waterside armoring bank protection Raise levee in place	slurry wall waterside armoring bank protection Raise levee in place	slurry wall waterside armoring bank protection Sacramento Weir and Bypass widening	slurry wall waterside armoring bank protection Raise levee in place	slurry wall waterside armoring bank protection Sacramento Weir and Bypass widening	slurry wall waterside armoring bank protection Raise levee in place	slurry wall waterside armoring bank protection Raise levee in place	slurry wall waterside armoring bank protection Raise levee in place	slurry wall waterside armoring bank protection Raise levee in place
Sacramento River South Levee		slurry wall and seepage berm waterside armoring bank protection raise levee in place		slurry wall or seepage berm waterside armoring bank protection raise levee in place	slurry wall & seepage berm waterside armoring bank protection raise levee in place	slurry wall & seepage berm waterside armoring bank protection Sacramento Weir and Bypass widening	slurry wall & seepage berm waterside armoring bank protection raise levee in place	slurry wall & seepage berm waterside armoring bank protection Sacramento Weir and Bypass widening	setback levee with slurry wall & seepage berm waterside armoring bank protection new setback levee		slurry wall & seepage berm waterside armoring bank protection Sacramento Weir and Bypass widening	I Street Diversion Structure and Cutoff Wall Bank protection Sacramento Bypass and Weir Widening
Port North			flood wall or raise levee in place	flood wall or raise levee in place	flood wall or raise levee in place	flood wall or raise levee in place		DWSC Closure structure	flood wall or raise levee in place	flood wall or raise levee in place	flood wall or raise levee in place	flood wall or raise levee in place

	Alternative number											
	0.5A	0.5B	0.5C	0.5D	1	2	3	4	5	6	7	8
	Alternative name											
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Preliminary BCR											
	3.2	1.2	1.8	0.8	2.5	2.2	2.1	1.8	2.9	1.7	0.8	0.5
	Final BCR											
					2.4		2.0		2.6			
Reach	**Actions**											
Yolo Bypass Levee	slurry wall		slurry wall	slurry wall		slurry wall	slurry wall	slurry wall	slurry wall	slurry wall	slurry wall	slurry wall
Sacramento Bypass Training Levee		waterside armoring bank protection	waterside armoring bank protection	waterside armoring bank protection	waterside armoring bank protection	waterside armoring bank protection	waterside armoring bank protection	waterside armoring bank protection	waterside armoring bank protection	waterside armoring bank protection	waterside armoring bank protection	waterside armoring bank protection
South Cross Levee		relief wells stability berm raise levee in place		relief wells stability berm raise levee in place	relief wells stability berm raise levee in place	relief wells stability berm raise levee in place	relief wells stability berm raise levee in place	relief wells stability berm raise levee in place	relief wells stability berm raise levee in place	relief wells stability berm raise levee in place	relief wells stability berm raise levee in place	relief wells stability berm raise levee in place
Mid-Cross Levee			slurry wall new levee waterside armoring bank protection									
Deep Water Ship Channel East Levee		slurry wall raise levee in place	slurry wall raise levee in place	slurry wall raise levee in place	slurry wall raise levee in place	slurry wall raise levee in place	slurry wall raise levee in place	slurry wall raise levee in place	slurry wall raise levee in place	slurry wall raise levee in place	slurry wall raise levee in place	slurry wall raise levee in place
Port South Levee	slurry wall or seepage berm waterside armoring bank	slurry wall waterside armoring bank protection	cutoff wall or seepage berm slurry wall waterside	slurry wall waterside armoring bank protection	slurry wall waterside armoring bank protection	slurry wall waterside armoring bank protection	slurry wall waterside armoring bank protection	slurry wall waterside armoring bank protection	slurry wall waterside armoring bank protection	slurry wall waterside armoring bank protection	slurry wall waterside armoring bank protection	slurry wall waterside armoring bank protection

	Alternative number											
	0.5A	0.5B	0.5C	0.5D	1	2	3	4	5	6	7	8
	Alternative name											
	Preliminary BCR											
	3.2	1.2	1.8	0.8	2.5	2.2	2.1	1.8	2.9	1.7	0.8	0.5
	Final BCR											
					2.4		2.0		2.6			
Reach	Actions											
	protection Raise levee in place	raise levee in place	armoring bank protection raise levee in place	raise levee in place	raise levee in place	raise levee in place	raise levee in place	levee raise	raise levee in place	raise levee in place	raise levee in place	raise levee in place

Table A-3. West Sacramento pre-project Land Use Land Cover.

Reach	Action	Pre-project Land Use Land Cover (LULC; Acres)								
		Barren Lands	Cropland	Temperate or sub-polar broadleaf deciduous forest	Temperate or sub-polar grassland	Urban	Water	Wetland	Other	Total area (acres)
Sacramento River North Levee	Raise levee in place	0.0	0.3	0.0	2.7	71.4	39.8	1.4	0.0	**115.6**
Sacramento River North Levee	Sacramento Weird and Bypass Widening	0.0	449.8	0.0	0.0	44.9	0.0	0.0	0.0	**494.7**
Port North	DWSC Closure Structure	0.0	0.8	0.0	0.0	4.6	1.6	0.0	0.0	**7.0**
Port North	Flood wall or raise levee in place	0.0	5.9	0.0	0.2	21.2	0.0	1.1	0.0	**28.4**
Yolo Bypass Levee	-									**0.0**

Reach	Action	Pre-project Land Use Land Cover (LULC; Acres)								
		Barren Lands	Cropland	Temperate or sub-polar broadleaf deciduous forest	Temperate or sub-polar grassland	Urban	Water	Wetland	Other	Total area (acres)
Sacramento Bypass Training Levee	-	-	-	-	-	-	-	-	-	**0.0**
Sacramento River South Levee	New setback levee	1.0	185.6	0.0	2.6	62.6	8.3	2.0	0.0	**262.1**
Sacramento River South Levee	Raise levee in place	1.6	7.8	0.0	0.0	27.0	2.8	0.4	0.0	**39.6**
South Cross Levee	Raise levee in place	0.0	24.6	0.0	0.0	0.1	0.0	0.7	0.0	**25.4**
Mid-Cross Levee	New levee	-	-	-	-	-	-	-	-	**0.0**
DWSC East Levee	Raise levee in place	2.2	30.2	0.0	5.8	26.1	0.0	0.4	0.0	**64.7**
DWSC West Levee	Raise levee in place	1.1	22.9	0.0	3.0	0.1	2.9	0.2	0.0	**30.2**
Port South Levee	Raise levee in place	0.0	27.4	0.0	5.8	12.1	3.5	0.0	0.0	**48.8**
Port South Levee	DWSC Closure Structure	-	-	-	-	-	-	-	-	**0.0**

Table A-4. West Sacramento land use change values. DWSC = Deep Water Ship Channel

	Land Use Change Values											
	Reach											
	Sacramento River North Levee		Port North Levee	Sacramento River South Levee		South Cross Levee	Mid-Cross Levee	DWSC East Levee	DWSC West Levee	Port South Levee		Port North Levee
	Plan 1	Plan 2	Plan 3	Plan 4	Plan 5	Plan 7	Plan 8	Plan 9	Plan 10	Plan 11	Plan 12	Plan 13
	Raise levee in place	Sacramento Weir and Bypass widening	Flood wall or raise levee in place	Raise levee in place	New setback levee	Raise levee in place	New levee	Raise levee in place	Raise levee in place	Raise levee in place	DWSC Closure Structure	Flood wall or raise levee in place
De Groot Median	$ (93,341)	$ (63,181)	$ (11,077)	$ (3,529)	$ 182,702	$ (19,715)	$ -	$ (24,194)	$ (23,023)	$ (26,898)	$ -	$ (3,735)
De Groot Mean	$ (299,710)	$ 27,317	$ (120,883)	$ (42,145)	$ 2,890,308	$ (88,171)	$ -	$ (67,624)	$ (51,241)	$ (34,258)	$ -	$ (6,491)
Li & Fang	$ (151,960)	$ 857,142	$ (121,716)	$ (46,417)	$ 3,032,761	$ (88,530)	$ -	$ (78,110)	$ (45,600)	$ (31,194)	$ -	$ (497)

A.3 SOUTH PLATTE RIVER AND TRIBUTARIES

Table A-5. Ecosystem restoration measures identified by reach and plan.

	Ecosystem Restoration Measures	Plan 0, No Action	Plan 1	Plan 2	Plan 3	Plan 4	Plan 5	Plan 6	Plan 7	Plan 8	Plan 9	Plan 10	Plan 11	Plan 12
Reach 1	• Relocate Burlington Canal and Platte River Interceptor Sewer to east. • Regrade east bank to widen river and connect existing wetland and riparian area to river corridor. • Regrade west bank to address bank erosion and stability. • Add wetland benches to narrow the low flow channel and jetties to restore aquatic habitat. • Remove invasive species and replace with native vegetation.			•	•	•	•	•	•	•	•	•	•	•
Reach 2	• Relocate sanitary sewers to the east to allow for extensive widening on east bank. • Remove wetlands channel at 51st Ave storm outfall. • Add wetland benches and jetties to restore aquatic habitat. • Regrade and vegetate approximately 28 acres of habitat through Heron Pond Natural Area and restore approximately 10 acres of upland area. • Remove invasive species and replace with native vegetation. • Remove existing concrete ditch and modify storm outfalls. • Relocate sanitary sewers on west bank. • Create riparian connection between this riparian area and the South Platte River corridor riparian areas. • Widen through Northside Park to add wetland and riparian area.					•	•	•	•	•	•	•	•	•
Reach 3	• Relocate the Globeville Park Pedestrian Bridge with deck above the 100 year water surface elevation. • 4' retaining wall for compensatory conveyance area. • Add wetland benches and jetties to restore aquatic habitat. • Widen into RTD parking lot on west bank and at CDOT parcel on east bank. • Add wetland bench and jetties in area of widening. • Remove invasive species and replace with native vegetation.							•	•	•	•	•	•	•
Reach 4	• Remove invasive species and replace with native vegetation. • Convert some existing riparian areas to wetlands. • Add jetties to restore aquatic habitat.								•	•				
	○ PLUS: Widening into Cuernavaca Park on west bank to increase riparian area. ○ Modification of large storm outfall to support new wetlands channel. ○ Additional wetland benches and jetties.										•	•		
	○ PLUS: Remove drop downstream of 16th St/Highlands Bridge. ○ Regrade and vegetate at 3101 Huron property on east bank to increase riparian and wetland area around storm outfall.												•	
	○ PLUS: Remove drop structures under 19th and 20th Sts and replace with riffles and drops designed for restored aquatic habitat.													•
Reach 5	• Replace existing Confluence Park Dam with flashboard gates and excavate upstream channel to address sedimentation and restore aquatic habitat. • Add wetland benches to narrow low flow channel. • Riprap invert and submerged banks of the channel to accommodate deep thalweg. • Remove invasive species and replace with native vegetation. • Two 2' drop structures with fish passage downstream of the RTD drop to tie into existing invert. • Add freeboard levees where the top of bank freeboard for the 100-year event is less than 1 foot. • Relocate Trolley tracks away from river and widen west bank into Fishback Park and Crescent Park. • Add new section of riffles and drops at upstream end of channel excavation between Colfax Ave and the RTD bridge.									•	•	•	•	•
Reach 6	• Remove upland vegetation and replace with native riparian vegetation along existing banks. • Add jetties to restore aquatic habitat.		•	•										
	○ PLUS: Lower bench on east bank at Phil Milstein to restore wetland and riparian area within the river corridor. ○ Install jetties to restore aquatic habitat and protect wetland benches.				•	•								
	○ PLUS: Widen east bank to restore wetland and riparian area within the river corridor. ○ Vegetate existing sand bar to increase wetland area. ○ Install jetties to restore aquatic habitat and protect wetland benches.						•	•	•	•	•			
	○ PLUS: Replace existing drop structure at 13th Ave with riffles to restore aquatic habitat. ○ Acquire commercial properties on east bank and widen river on east bank. ○ Add wetland benches to narrow the low flow channel.											•	•	•

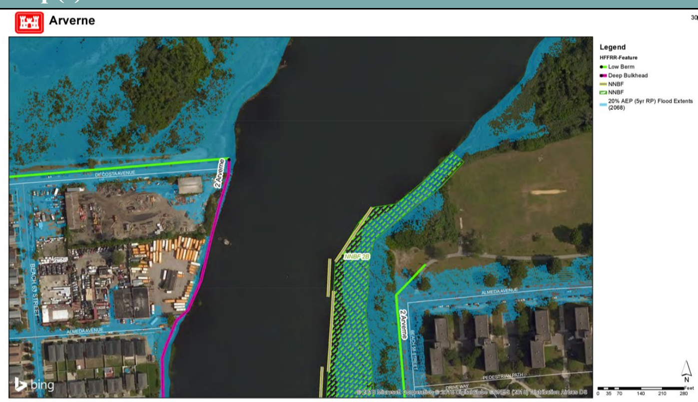
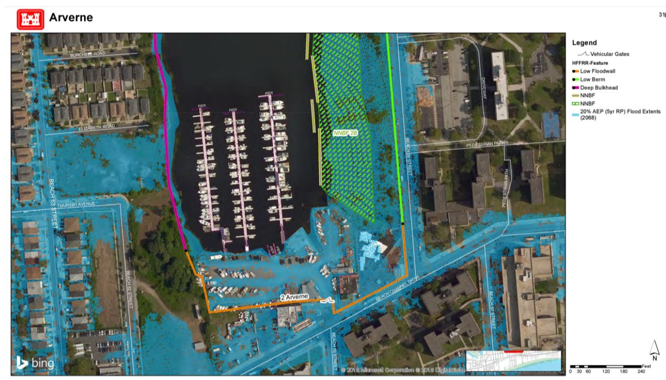
A.4 JAMAICA BAY

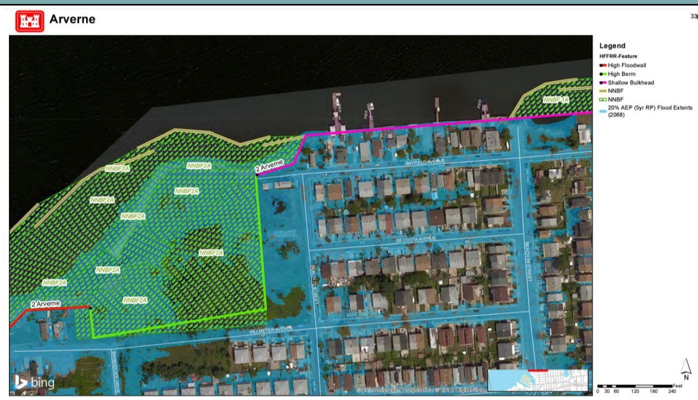
A.4.1 Determining Population With Walking Access to Jamaica Bay Project Sites

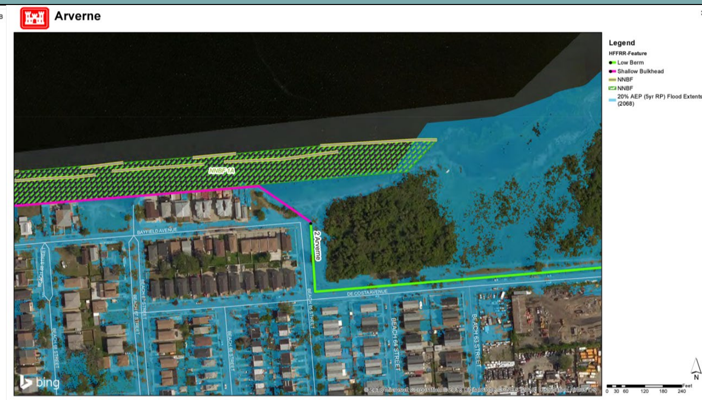
In order to determine the number of people within a 10-minute walking distance of each project site in Jamaica bay with recreation opportunities, the study team used 2020 census data at the block level and ran a network analysis in ArcGIS to calculate walking distances from all locations where roads provided access to recreational sites. Sites were identified through kayak launch documentation from NPS and NYC Parks, and GIS data on piers and landings. The team calculated the walking time around each, and merged each of the access point buffers together in order to develop one buffer per site and analyze population in GIS.

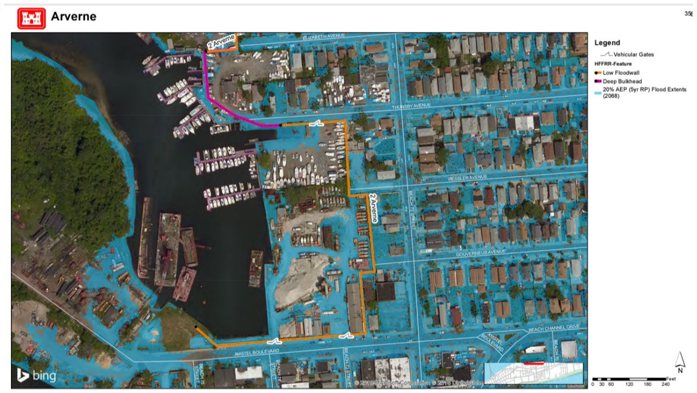
A.4.2 Additional Supporting Tables and Figures

Table A-6. Maps of High Frequency Flood Risk Reduction Features and Hudson-Raritan Estuary Ecosystem project sites.

Project Site	Map(s)
Arverne	 

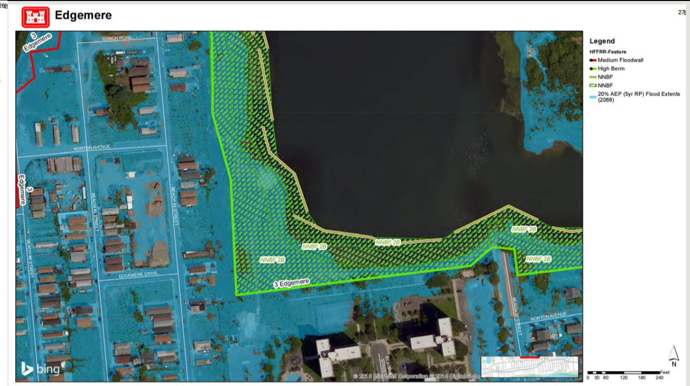
<table>
<tr><th>Project Site</th><th>Map(s)</th></tr>
<tr><td></td><td>


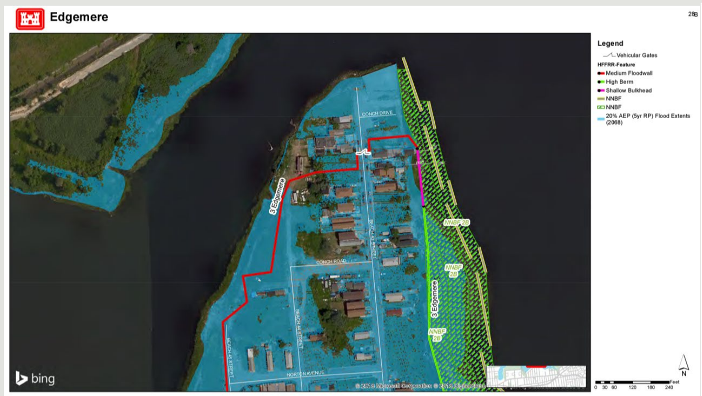


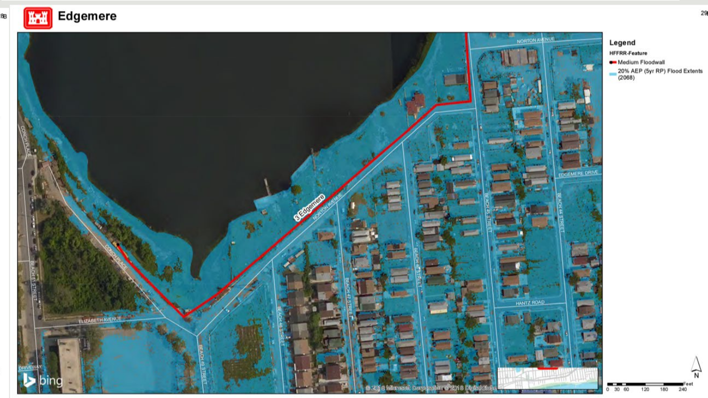


</td></tr>
</table>

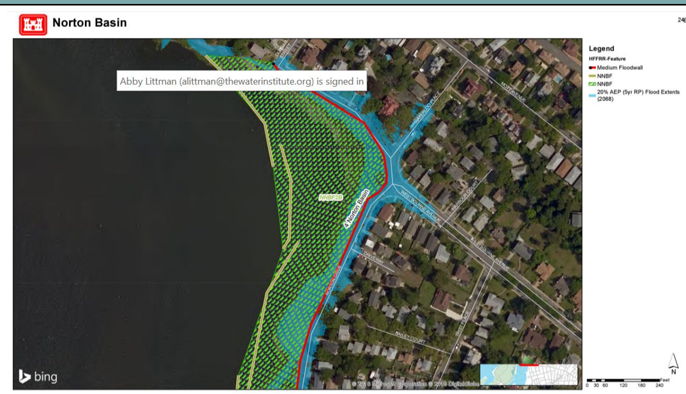
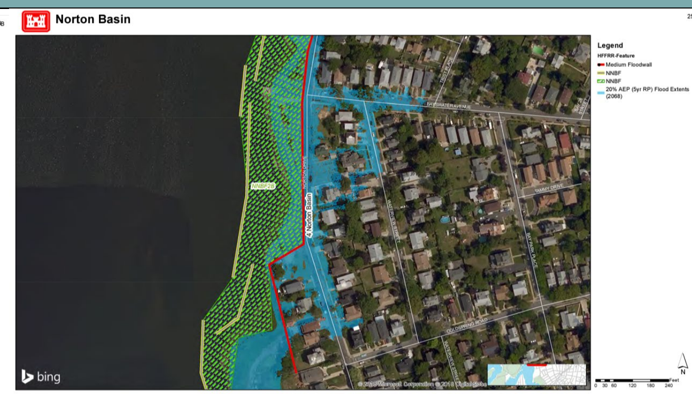
<table>
<tr><th>Project Site</th><th>Map(s)</th></tr>
<tr><td>Edgemere</td><td>





</td></tr>
</table>

Project Site	Map(s)
Norton Basin	 
Bayswater	

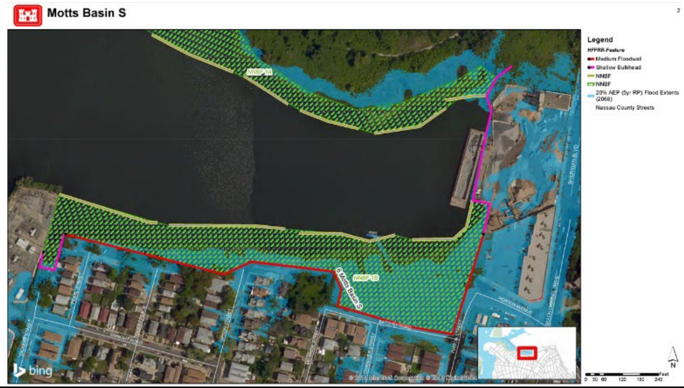
Project Site	Map(s)
Motts Basin South	 

Table A-7. Unit Day Value guidelines for assigning points for general recreation (USACE, 2021e).

Criteria	Judgment Factors				
Recreation Experience[33] Total Points: 30	Two general activities[34] (0-4)	Several general activities (5-10)	Several general activities; one high quality value activity[35] (11-16)	Several general activities; more than one high quality activity (17-23)	Numerous high quality value activities; some general activities (24-30)
Availability of Opportunity[36] Total Points: 18	Several within 1 hr. travel time; a few within 30 min. travel time (0-3)	Several within 1 hr. travel time; none within 30 min. travel time (4-6)	One or two within 1 hr. travel time; none within 45 min. travel time (7-10)	None within 1 hr. travel time (11-14)	None within 2 hr. travel time (15-18)
Carrying Capacity[37] Total Points: 14	Minimum facility for development for public health and safety (0-2)	Basic facility to conduct activity(ies) (3-5)	Adequate facilities to conduct without deterioration of the resource or activity experience (6-8)	Optimum facilities to conduct activity at site potential (9-11)	Ultimate facilities to achieve intent of selected alternative (12-14)
Accessibility Total Points: 18	Limited access by any means to site or within site (0-3)	Fair access, poor quality roads to site; limited access within site (4-6)	Fair access, fair road to site; fair access, good roads within site (7-10)	Good access, good roads to site; fair access, good roads within site (11-14)	Good access, high standard road to site; good access within site (15-18)
Environmental Quality Total Points: 20	Low aesthetic factors[38] that significantly lower quality[39] (0-2)	Average aesthetic quality; factors exist that lower quality to minor degree (3-6)	Above average aesthetic quality; no factors exist that lower quality (11-15)	High aesthetic quality; no factors exist that lower quality (11-15)	Outstanding aesthetic quality; no factors exist that lower quality (16-20)

[33] Value for water-oriented activities should be adjusted if significant seasonal water level changes occur.

[34] General activities include those that are common to the region and that are usually of normal quality. This includes picnicking, camping, hiking, riding, cycling, and fishing and hunting of normal quality.

[35] High quality value activities include those that are not common to the region and/or Nation, and that are usually of high quality.

[36] Likelihood of success at fishing and hunting.

[37] Value should be adjusted for overuse.

[38] Major esthetic qualities to be considered include geology and topography, water, and vegetation.

[39] Factors to be considered to lowering quality include air and water pollution, pests, poor climate, and unsightly adjacent areas.

Table A-8. Assigning Unit Day Value points for general recreation for Jamaica Bay

Criteria	Possible Points	Score Range	Median Score	Justification	Common or site specific
Recreation experience	30	(17-23)	20	General Activities: Picnicking, cycling, fishing (3) High Quality Value activities: Bird Watching, Kayaking (2)	Site specific – range from 0-4 up to 17-23
Availability of opportunity	18	(4-6)	5	If all recreation opportunities related to projects were gone	Site specific range from (0-3) up to (15-18)
Carrying Capacity	14	(6-8)	7	This varied between all project locations, also changing from before to after the project	Site specific range from
Accessibility	18	(7-10)	8.5	Varied between project locations, based upon road and path access availability and condition	Site specific range
Environmental quality	20	(11-15)	13	Overall. Note that this improves substantively after project and between sites	Site variation
			Total: 53.5 ($9.57)		

Table A-9. Observational data used to inform Unit Day Value scoring (all project sites).

Site	Recreational Experience		Availability of Opportunity		Carrying Capacity		Accessibility		Environmental Quality	
	Before	After	Before	After	Before	After	Before	After	Before	After
Arverne	Fishing	Fishing, walking, cycling, picnicking	One or two within 1 hr walking time	One or two within 1 hr walking time	Dangerous site, trash, and old cars / derelict buildings	Basic but safe that would not detract from activity	Limited access	Fair access via roads and paths to and within site	Trash and old buildings significantly lower quality	Above average aesthetic for neighborhood, viewsheds may need to be selected
Edgemere	Fishing	Fishing, walking, cycling, picnicking	One or two within 1 hr walking time	One or two within 1 hr walking time	Dangerous site, trash, and old cars / derelict buildings	Basic but safe that would not detract from activity	Limited access	Fair access via roads and paths to and within site	Trash and old buildings significantly lower quality	Above average aesthetic for neighborhood, viewsheds may need to be selected
Norton Basin	Fishing	Fishing, walking, cycling, picnicking	One or two within 1 hr walking time	One or two within 1 hr walking time	Dangerous site, trash, and old cars / derelict buildings	Basic but safe that would not detract from activity	Limited access	Fair access via roads and paths to and within site	Trash and old buildings significantly lower quality	Above average aesthetic for neighborhood, viewsheds may need to be selected
Bayswater	Fishing, walking, cycling, picnicking	Fishing, walking - high quality, cycling, picnicking	One or two within 1 hr walking time	One or two within 1 hr walking time	Basic facilities to conduct activities	Adequate facilities without detracting from experience	Fair access with fair roads to site	Good access with good roads site	Average aesthetic quality, proximity to storage areas	Above average aesthetic quality for area, marsh edge improved
Motts Basin North	Fishing, walking, cycling, picnicking	Fishing, walking - high quality, cycling, picnicking	One or two within 1 hr walking time	One or two within 1 hr walking time	Basic facilities to conduct activities	Adequate facilities without detracting from experience	Fair access with fair roads to site	Good access with good roads site	Average aesthetic quality, proximity to storage areas	Above average aesthetic quality for area, marsh edge improved

Site	Recreational Experience		Availability of Opportunity		Carrying Capacity		Accessibility		Environmental Quality	
	Before	After	Before	After	Before	After	Before	After	Before	After
Motts Basin South	Fishing	Fishing, walking, cycling, picnicking	One or two within 1 hr walking time	One or two within 1 hr walking time	Dangerous site, trash, and old cars / derelict buildings	Basic but safe that would not detract from activity	Limited access	Fair access via roads and paths to and within site	Trash and old buildings significantly lower quality	Above average aesthetic for neighborhood, viewsheds may need to be selected
Dead Horse Bay	Hiking, Walking, Fishing, Boating – high quality	Hiking, Walking, Fishing, Boating – high quality	One or two within 1 hr walking time	One or two within 1 hr walking time	Very basic, unsafe	Basic that would not deteriorate site or the resource	Fair access	Fair but improved access by boat	Average aesthetic due to site degradation	Above average aesthetic due to project
Fresh Creek	Walking – high quality, Fishing, Picnicking	Walking – high quality, Fishing, Picnicking	One or two within 1 hr walking time	One or two within 1 hr walking time	Very basic	Basic that would not deteriorate site or the resource	Fair access	Fair but improved access	Average aesthetic due to site degradation	Above average aesthetic due to project
Duck Point Stony Creek Pumpkin Patch West Pumpkin Patch East Elders Point	Kayaking - high quality, fishing, picnicking, bird watching	High quality kayaking, bird watching, fishing, also picnicking, hiking	In degraded state there are several equivalent sites within 1 hr	In restored state there are none within a 2-hour travel time	Basic (degraded) facilities to carry out activity	Ultimate facilities for carrying out activities	Good access, good roads to site (launch points)	Good access, good roads to site (launch points)	Average aesthetic quality - degraded marsh, mostly open water	Outstanding aesthetic quality - restored marsh with creeks and edge features
Head of Bay	-	-	-	-	-	-	-	-	-	-

Table A-10. Unit Day Value scoring breakdown: without project implementation.

		Without Project Scoring Breakdown						
	Site	Recreation Experience (0-30)	Availability of Opportunity (0-18)	Carrying Capacity (0-14)	Accessibility (0-18)	Environmental Quality (0-20)	Total Points	Conversion of Points to $
Perimeter Sites	Arverne	2	9	1	2	1	15	$5.35
	Edgemere	2	9	1	2	1	15	$5.35
	Norton Basin	2	9	1	2	1	15	$5.35
	Bayswater	11	9	3	7	6	36	$6.75
	Motts Basin North	11	9	3	7	6	36	$6.75
	Motts Basin South	2	9	1	2	1	15	$5.35
	Dead Horse Bay	11	9	3	7	6	36	$6.75
	Fresh Creek	11	9	3	7	6	36	$6.75
Marsh Island Sites	Duck Point, Stony Creek, Pumpkin Patch West, Pumpkin Patch East, Elders Point, Head of Bay[40]	11	5	4	8	6	34	$6.75

[40] Marsh island sites were assumed to serve the same population and without being able to differentiate between visits to each island, all marsh island sites were combined; resulting in one single UDV score.

Table A-11. Unit Day Value scoring breakdown: with project implementation.

		With Project Scoring Breakdown							
	Site	Recreation Experience (0-30)	Availability of Opportunity (0-18)	Carrying Capacity (0-14)	Accessibility (0-18)	Environmental Quality (0-20)	**Total Points**	**Conversion of Points to $**	***Difference** (with/without project)*
Perimeter Sites	Arverne	14	9	7	10	10	50	$9.57	*$4.22*
	Edgemere	14	9	7	10	10	50	$9.57	*$4.22*
	Norton Basin	14	9	7	10	10	50	$9.57	*$4.22*
	Bayswater	14	9	7	10	10	50	$9.57	*$2.82*
	Motts Basin North	14	9	7	10	10	50	$9.57	*$2.82*
	Motts Basin South	14	9	7	10	10	50	$9.57	*$4.22*
	Dead Horse Bay	14	9	7	10	10	50	$9.57	*$2.82*
	Fresh Creek	14	9	7	10	10	50	$9.57	*$2.82*
Marsh Island Sites	Duck Point, Stony Creek, Pumpkin Patch West, Pumpkin Patch East, Elders Point, Head of Bay[41]	24	16	14	8	16	78	$10.97	*$4.22*

[41] Marsh island sites were assumed to serve the same population and without being able to differentiate between visits to each island, all marsh island sites were combined; resulting in one single UDV score.

Table A-12. Data considerations for Unit Day Value calculations (perimeter sites).

Site	Action	Project Cover	Population with Access	Change in Population Accessing with Project Implementation	Justification	UDV Score Without Project	UDV Without Project ($)	UDV Score with Project	UDV with Project ($)	Change in Total Annual UDVs
Arverne	Marsh creation	12,300 ft	20,490	5000 up to 20,490	Substantive increase due to current poor condition	15	$5.35	50	$9.57	$169,339
Edgemere	Marsh creation	6,300 ft	11,950	3000 up to 11950	Substantive increase due to current poor condition	15	$5.35	50	$9.57	$98,311
Norton Basin	Marsh creation	2,400 ft	5,770	1500 up to 5770	Substantive increase due to current poor condition	15	$5.35	50	$9.57	$47,193
Bayswater	Marsh creation	1,500 ft	3,568	2500 up to 3568	Minimal change (local only)	36	$6.75	50	$9.57	$17,270
Motts Basin North	Marsh Creation	28 acres	1,017	500 up to 1017	Minimal change (local only)	36	$6.75	50	$9.57	$6,357
Motts Basin South	Marsh creation	N/A	11,486	2500 up to 11486	Substantive increase due to current poor condition	15	$5.35	50	$9.57	$96,546
Dead Horse Bay	Marsh creation	30.6 acres	0[42]	1000 up to 30,000	Increase due to improved ecosystem condition; there is a boat marina next door and fishing should improve	36	$6.75	50	$9.57	$0
	Tidal channel/ creek restoration	2.31 acres	-	-	-	-	-	-	-	-
Fresh Creek	Tidal channel/ creek restoration	45.08 acres	34,069		5000 up to 34069 due to improved condition	36	$6.75	50	$9.57	$292,290
	Maritime Forest	10.7 acres	-	-	-	-	-	-	-	-

[42] Radioactive contamination was found at Dead Horse Bay (adjacent to Floyd Bennett Field) in 2020 and has since been closed to visitors. Since the Feasibility Study was also completed in 2020, the study team determined that it would not be possible to estimate UDV benefits for this site.

Table A-13. Data considerations for Unit Day Value calculations (Marsh Island sites)

Site	Action	Project Cover	Average Annual Fishing Visits to Jamaica Bay Wildlife Refuge (2017-2021)	Change with project Implementation	Justification	UDV Score Without Project	UDV Without Project ($)	UDV Score with Project	UDV with Project ($)	Change in Total Annual UDVs
Duck Point	Marsh Creation	38.6 acres	636,022[43]	500 to 636,022	500 without project as island rapidly turns to open water, 636,022 with project. (Assessed only one island presuming the same visitors would go to any island)	34	$8.44	78	$12.94	$8,225,904
	Sand fill	213,776 cy								
	Tidal channel/creek restoration	1.03 acres								
	Shallows	7.57 acres								
Stony Creek	Marsh creation	51.5 acres								
	Sand fill	151,360 cy								
Pumpkin Patch West	Marsh creation	23.2 acres								
Pumpkin Patch East	Marsh creation	28.8 acres								
	Sand fill	351,952 cy								
Elders Point	Marsh creation	27.5 acres								
	Sand fill	284,891 cy								
Head of Bay	Oyster Reef Expansion	10.1 acres	No access points identified	No recreation benefit identified	-	-	-	-	-	N/A

[43] The study team applied this number once to account for annual visitation among all marsh island sites.

APPENDIX B. USACE PERSONNEL AND STAKEHOLDERS CONTRIBUTING TO STUDY

Table B-1. USACE Advisory Committee members

Name	Office/Title
Wesley Coleman	SWD/Acting Director of Programs
Brian Harper	Regional Planning & Environmental Center/Director of Civil Works Planning
Juliette Hayes	SPD/Business Management Division Chief
Susan Layton	SAD/Acting Chief of Planning and Policy
Gregory Miller	MVD//Operating Director of the National Ecosystem Restoration Planning Center of Expertise
Scott Nicholson	USACE
Joseph Redican	Headquarters/Deputy Chief of Planning and Policy Division
Mindy Simmons	Environmental Planning and Policy Division/Senior Policy Advisor
Peter Sturdivant	Omaha District/Chief of Engineering
Robert Thomas	Galveston District/Chief of Engineering and Construction
Forrest Vanderbilt	Navigation and Civil Works Decision Support Center/Interagency Program Manager
William Veatch	MVD/Regional Technical Specialist for Climate Adaptation
Maria Wegner	SWD/Acting Chief of Planning and Policy
Rena Weichenberg	NAD/Environmental Team Lead

Table B-2. Additional stakeholder contributors

Name	Organization
Olivia Dorothy	American Rivers
Eileen Shader	American Rivers
David Conrad	Association of State Floodplain Managers, Inc.
Rowan Schmidt	Earth Economics
David McLaughlin	Environmental Defense Fund
Natalie Peyronnin Snider	Environmental Defense Fund
Jessica Grannis	National Audubon Society
Gina Mason	National Oceanic & Atmospheric Administration
David Muth	National Wildlife Federation
Jessie Ritter	National Wildlife Federation
Ilana Rubin	National Wildlife Federation
Melissa Samet	National Wildlife Federation
Lydia Olander	Council on Environmental Quality; Duke University
Lori Cary-Kothera	Council on Environmental Quality
Eli Fenichel	Office of Science and Technology Policy
Heather Tallis	Office of Science and Technology Policy
Sonia Wang	Office of Science and Technology Policy
Jimmy Hague	The Nature Conservancy
Sarah Murdock	The Nature Conservancy
Christy Plumer	Theodore Roosevelt Conservation Partnership
Andrew Wilkins	Theodore Roosevelt Conservation Partnership
Jennifer Orr-Greene	Trout Unlimited

EWN®

Engineering With Nature

US Army Corps of Engineers®

THE WATER INSTITUTE