Currituck Sound Ecosystem Restoration Feasibility Study

U.S. Army Corps of Engineers (USACE), Wilmington District (SAW)
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Introduction

The Currituck Sound Ecosystem Restoration Feasibility Study is cooperatively conducted by the USACE Wilmington District and the non-federal sponsor, North Carolina Department of Environment and Natural Resources (NCDENR). The purpose of this study is to investigate and recommend appropriate federal actions and plans for ecosystem restoration initiatives in Currituck Sound, North Carolina. As read-ahead material for an interagency briefing, this document provides an update on status and direction of the Currituck project. In particular, this paper presents the general approach to account for environmental benefits of restoration, presents a draft conceptual model of ecosystem structure and process, proposes an objective set for the study, and outlines future model and alternative development activities. These and other topics will be covered in greater detail in the briefing. Figure 1 presents the overarching flow of activities associated with conducting an analysis of restoration benefits and status of these activities for the Currituck project.

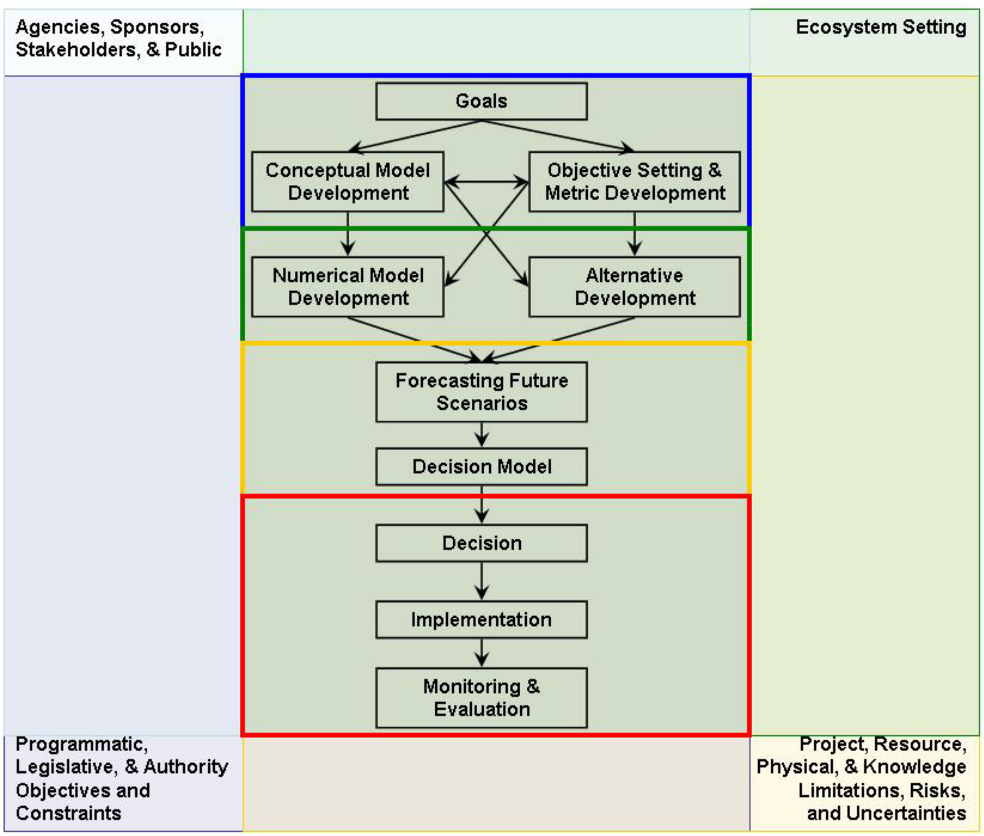

Figure 1. Environmental benefits analysis process. Outlined boxes indicate status as: completed (blue), underway (green), initiated (yellow), or future (red) efforts.

Conceptual Model[1]

Given the complex interactions among ecosystem processes in Currituck Sound, a set of conceptual models is being developed to assist the project development team (PDT) with appropriately understanding system processes, diagnosing underlying stressors, guiding numerical model development, and facilitating communication among team members. Fischenich (2008) summarizes the purpose and utility of conceptual models as:

> Conceptual models are descriptions of the general functional relationships among essential components of an ecosystem. They tell the story of "how the system works" and, in the case of ecosystem restoration, how restoration actions aim to alter those processes or attributes for the betterment of the system.

The general approach to conceptual model development was to identify significant ecological resources occurring in the basin, the primary state conditions governing these resources, and the drivers and stressors leading to these state conditions. These system components were then mapped together to better understand the underlying processes and mechanisms which restoration actions can influence. Figure 2 summarizes these three system components as well as causal ecosystem processes. It is important to note that in terms of our conceptual model, the goal is to identify the *primary* resources, states, drivers, and processes, not to comprehensively list all potential model components. Additional system components were considered, and their removal from this model is addressed in conceptual model documentation.

To develop an appropriate conceptual model, one must first identify the resources of interest to be included in the model. For instance, current velocity or substrate of a river would likely be irrelevant if one were developing a conceptual model of white-tailed deer foraging behavior. Significant ecological resources of Currituck Sound (summarized in Figure 2) were identified based on literature- and agency-reported declines in specific taxa (e.g., herring; Cahoon et al. 2009), communities (e.g., tree-nesting colonial waterbirds; Kushlan et al. 2002), and ecosystem types (e.g., seagrass; Davis and Brinson 1983, Ferguson and Wood 1989, Waycott et al. 2009).

Although state conditions within the Sound could be summarized by a nearly endless list of parameters and processes, five primary variables largely dictate the ecosystem type occurring at a given location: salinity, light, substrate, elevation, and extent of invasive macrophytes. In Currituck Sound, salinity varies widely and is in many cases the primary determinant of species composition of the vegetative community growing at a location and the associated faunal composition. Secondly, submerged aquatic vegetation (SAV) has been shown to require extremely high levels of light relative to other forms of vegetation (Orth et al. 2006), and light penetration may be compromised in many locations throughout the Sound due to turbidity from suspended sediment or increased algal productivity (Short et al. 2002). Bed substrate is highly variable and dependent upon coarse material availability from river or ocean sources (Cahoon et al. 2009).

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[1] This section summarizes conceptual model development activities. However, more detailed versions of these models are in development which will explicitly connect ecosystem components and document the literature-supported logic behind the models.

Elevation is an important factor controlling light availability to submerged habitats and hydrology to tidal wetlands. Although currently suppressed, the nuisance aquatic plant Eurasian water milfoil historically played a significant role in ecosystem structure and process within the Sound (e.g., Carter and Rybicki 1994) and non-native phragmites has invaded tidal marshes reducing biodiversity.

"Drivers are physical, chemical, or biological factors of natural or human origin" (Fischenich 2008). As such, there are many drivers of ecosystem processes within Currituck Sound operating on temporal and spatial scales ranging from seconds and centimeters (e.g., sediment transport phenomena) to millennia and thousands of kilometers (e.g., evolutionary history). In terms of this conceptual model, the primary drivers identified are wind-driven hydrodynamics, land use, recreational and commercial boating, dredging, and hydrologic connectivity. Given the relatively small size of freshwater streams and rivers feeding the Sound and the disconnected ocean inlets, hydrodynamics (i.e., velocity, depth, wave energy, sediment transport capacity, etc.) are largely determined by the wind environment, particularly fetch length and storm events (Cahoon et al. 2009). Land use on the western portion of the basin is primarily agricultural or undeveloped, while significant development persists on the eastern and northern portions of the basin (i.e., barrier island and Virginia beach development). Although quite different in nature, these land use practices both result in increase nutrient and sediment runoff which alters turbidity and light penetration. Both recreational and commercial boating operations are common in the system, which can lead to direct impact on ecosystem structure such propeller damage of seagrass (e.g., Engeman et al. 2008) as well as indirect influences such as resuspension of fine sediment and canal creation. Furthermore, maintaining commercial navigation channels through dredging may also resuspend fine sediment as well as redistribute coarse sediment to confined disposal facilities (CDFs) or for beneficial uses (e.g., mid-Sound habitat islands; Efftemeijer and Lewis 2006, Golder et al. 2008). Historical dredging practices dispersed fine material through open water disposal (Riggs et al. 1993), a currently discontinued practice. Lastly, bed substrate at a particular location is often governed by hydrologic connectivity within the basin (Cahoon et al. 2009) which includes not only seaward connectivity (e.g., historic inlets and barrier island overwash), but also watershed connectivity (e.g., floods). Hydrologic connectivity also significantly influences organism movement in both positive and negative ways (e.g., diadromous fish migration and spread of invasive macrophytes, respectively).

Multiple conceptual models are often used to describe complex systems from different viewpoints. Figure 3 presents a pictorial representation of common ecosystem types found in the Currituck Sound estuary system which was developed using the Conceptual Ecological Model Construction Assistance Tool (CEMCAT; Daylander and Fischenich 2010). Ecosystem types have been coarsely classified into three primary groupings: open water ecosystems (white boxes), back-barrier ecosystems (light blue boxes), and mainland ecosystems (green boxes). This model provides an alternative representation of how the system drivers described above interact to influence the distribution of habitat types within the Sound.

Drivers

Fetch	
Land Use	Agricultural, Urban, Shore and Bank Protection
Boating	Canals, Entrainment, Propeller Damage
Dredging	Disposal Sites, Schedule
Hydrologic Connectivity	Inlets, Island Overwash, Inland Flooding, Movement Barriers

Physio-Chemical Processes Affected

Direct Habitat Conversion	Hydrodynamics (Velocity, Depth, Wave Energy)
Suspended Sediment (Turbidity)	Nutrients (Nitrogen, Phosphorous)

Principal State Variables

Salinity Light Substrate Elevation Invasive Plants

Biological Processes

Reproduction Survival Colonization

Significant Resources

Fisheries	Migratory, Estuarine Nursery, Estuarine Resident
Waterbirds	Tree-Nesting, Sand-Nesting
Waterfowl	Migratory, Resident
Other Animals	Crustaceans, Turtles, Mammals
Vegetation	Submerged Aquatic Vegetation, Back-Barrier Marsh, Marine Forest

Figure 2. Driver-State-Resource conceptual model for Currituck Sound.

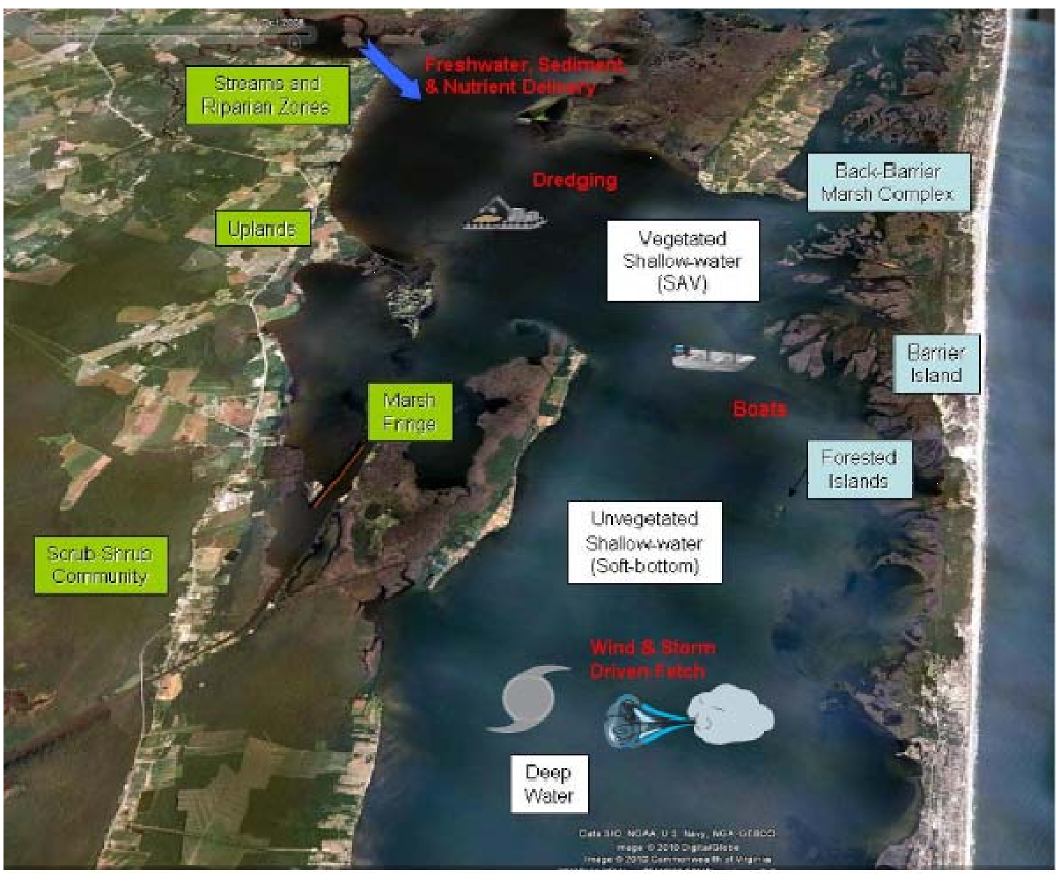

Figure 3. Conceptual model of interacting habitat types within Currituck Sound.

Objective Setting

A complete and clear statement of objectives informs almost all aspects of restoration project planning from alternative formulation and evaluation to plan comparison and recommendation (Yoe and Orth 1996, Gregory and Keeney 2002, McKay et al. 2010). Three goals have been identified for the Currituck Sound restoration project as well as supporting objectives to better define these goals. Goal 1 emphasizes the restoration of ecosystem structure, function, and dynamic processes and serves as the impetus for plan formulation. Goal 2 describes secondary benefits offered by the project which are not the focus of plan formulation but do provide ancillary benefits of particular note. Goal 3 highlights the aims of the USACE team in carrying out the restoration process. Although Goal 1 is the primary objective and source of National Ecosystem Restoration (NER) benefits, Goals 2 and 3 describe elements of the project that may help the USACE team communicate with the USACE chain-of-command, cost-share sponsor, external agencies, and other stakeholder groups. Given its influence on plan formulation, Goal 1 has been decomposed into quantifiable sub-objectives in order to clarify the direction and purpose of the project to the greatest extent possible (Refer to bulleted objective statements below as well as decomposed sub-objectives in Table 1).

Embedded in these objectives are decisions the interagency PDT has made regarding the desired endpoint of the project. As part of earlier project planning, the USACE planning team worked with the NCDENR and the interagency PDT to identify an appropriate reference condition as the target for restoration actions. Given social constraints and the uniqueness of Currituck Sound’s wind-driven estuarine community, the team agreed that the objectives should center on restoring an estuary system which is disconnected from the ocean during all but large storm events (i.e., assuming any closed inlets remain closed). Furthermore, particular ecosystem types within the Currituck basin offer disproportionate opportunities for restoration due to either their roles as critical linkages to other ecosystems or their threatened and reduced extent. Resultantly, the following goals and objectives emphasize three ecosystem types as the primary targets for restoration actions: vegetated shallow-water ecosystems, back-barrier marsh communities, and nesting islands. Actions will be pursued in other ecosystem types, but only to the extent that they effect these three primary systems. For instance, if excessive upland loading of nutrients is identified as the limiting factor for seagrass within a sub-basin, mainland riparian buffer improvement may be an appropriate action.

Goal 1: Restore significant ecosystem structure, function, and dynamic processes by providing a mosaic of interconnected ecosystem types contributing to a resilient estuarine system supporting a diverse faunal assemblage.

1.1. *HABITAT*: Provide habitat for a diverse assemblage of floral and faunal taxa.

- Increase the extent of vegetated shallow-water ecosystems
- Increase the extent of back-barrier estuarine marsh
- Increase the extent of nesting-island ecosystems
- Promote mainland and streamside ecosystems to the extent that they support vegetated shallow-bottom, back-barrier marsh, and island systems
- Provide an appropriately balanced distribution of habitat types

1.2. *CONNECTIVITY*: Promote connectivity of diverse ecosystem types.

- Promote connectivity of habitat types for living resources
- Provide sufficient connectivity of ecosystem types to maintain a desirable nutrient, sediment, and salinity regime
- Promote an appropriate landscape arrangement of ecosystem types

1.3. *SUSTAINABILITY*: Promote sustainability of restored ecosystems.

- Promote a self-sustaining hydro-geomorphic regime
- Promote ecosystem processes that are capable of adapting to sea level rise
- Increase system resilience to coastal storm disturbance

<u>Goal 2</u>: Protect existing economic, social, and cultural resources.

2.1. Economically-beneficial resources

- Support commercial fisheries and shellfisheries
- Provide for commercial and non-commercial recreational opportunities including, but not limited to: hunting, fishing, wildlife observation, guide services for fishing and waterfowl, and boating
- Maintain opportunities for existing navigation volumes and rates
- Maintain or decrease flood risk

2.2. Social resources

- Establish avenues for public education pertaining to the unique nature of the Currituck Sound ecosystem
- Incorporate recreational opportunities into project designs to the extent appropriate for USACE restoration projects (USACE 2000)

2.3. Cultural resources

- Highlight unique tribal history of Monkey Island
- Embrace waterfowl hunting heritage in the basin
- Provide for fair treatment and equal involvement of historically disenfranchised communities
- Maintain existing subsistence fishing opportunities

<u>Goal 3</u>: Implement a collaborative, comprehensive, system-wide study.

3.1. Plan and implement project collaboratively

- Provide opportunities for interaction with non-federal cost share sponsors, federal- and non-federal resource agencies, and the academic community
- Provide opportunities for public and industry interaction on more than one occasion in more than one location
- Consider ongoing external activities and documented future plans in the planning of this interagency study

3.2. Apply a systems approach to project planning

- Examine potential restoration actions throughout the watershed
- Consider the potential for project interaction with existing and future infrastructure and land use

Table 1. Decomposed objectives and sub-objectives for Goal 1[2].

Objective	Sub-Objective
Objective 1.1. Provide habitat for a diverse assemblage of faunal taxa	
Increase the extent of vegetated shallow-water ecosystems	Increase the availability of food and/or habitat (spawning, rearing, predator avoidance) resources for fisheries, colonial nesting waterbirds, and waterfowl through planting/seeding SAV beds. Potential target areas include Region 1- Strategic Habitat Areas (NCDMF 2009), Monkey Island, and Back Bay.
	Increase the capacity for natural SAV seed recruitment and germination in currently unvegetated bottom by creating marsh barriers to reduce wave energy and associated turbidity. Sites may include Region 1- Strategic Habitat Areas, Monkey Island, and Back Bay.
	Reduce turbidity within Currituck Sound associated with resuspension of sediment from small-boat and vessel activities.
	Provide confined disposal facilities capable of managing authorized dredged material volumes from the AIWW navigation channel.
Increase the extent of back-barrier estuarine marsh	Nourish back barrier estuarine marsh through provision of coarse sediment. Potential sites include relict flood deltas features associated with "Old Currituck," "New Currituck," "Musketo," and "Caffeys" inlets.
	Create and/or restore marsh island ecosystems lost to erosion, subduction, and/or invaded by exotic species since the 1950's. Potential sites include Knott's Island, porpoise point, Mary Islands, and the Narrows.
	Increase and/or protect back barrier fringe marsh lost to erosion or invaded by exotic species. Specific sites and quantities for this objective have not yet been identified.
Increase the extent of nesting-island ecosystems	Increase colonial tree-nesting waterbird habitat.
	Increase colonial sand-nesting waterbird habitat.
	Restore and protect Monkey Island to 1950's acreage and manage vegetation suitable for nesting.

[2] Additional site-specific information will be added to these objectives and sub-objectives as it becomes available through examination of existing and historical extents of habitat in the Sound as well as through information provided by the interagency PDT.

Table 1. Decomposed objectives and sub-objectives for Goal 1 (cont.).

Objective	Sub-Objective
Objective 1.1. Provide habitat for a diverse assemblage of faunal taxa	
Promote mainland and streamside ecosystems to the extent that they support vegetated shallow-water, marsh, and nesting-island systems	Restore and/or protect critical mainland marsh and wetland ecosystems.
	Create and/or preserve riparian buffer to promote streamside ecosystems at urban and agricultural watersheds previously identified by the NCCLT as "high water quality enhancement areas."
Provide an appropriately balanced distribution of habitat types	Promote a distribution of all habitat types which maximizes ecosystem output within the Sound.
	Eradicate and/or manage non-native plant and animal species at restored/created sites.
Objective 1.2. Promote connectivity of diverse ecosystem types	
Promote connectivity of habitat types for living resources	Promote connectivity of colonial nesting waterbird habitat that provides for multiple components of the life history of species of interest (e.g., nesting, foraging).
	Promote access to potential river herring spawning habitat.
Provide sufficient connectivity of ecosystem types to maintain a desirable nutrient, sediment, and salinity regime.	Strategically arrange project components to promote connectivity of freshwater and tidal resources at appropriate magnitude, frequency, duration, timing, and rate of change.
	Strategically arrange project components to promote appropriate levels of nutrient and sediment uptake (e.g., encourage ecosystem processing of nutrients and sediment).
Promote an appropriate landscape arrangement of ecosystem types	Strategically arrange project components to provide synergistic benefits for other components.
	Provide suitable shape and edge of project components that encourages biotic utilization.
Objective 1.3. Promote sustainability of restored ecosystems	
Promote a self-sustaining hydro-geomorphic regime	Design considerations for constructed habitats will consider sloped elevations to allow for expansion of habitat.
Promote ecosystem processes that are capable of adapting to sea level rise	Design considerations for constructed habitats will consider planting arrangements, based on reference ecosystems, using highly productive plant species that are capable of adapting to sea level rise.
Increase system resilience to coastal storm disturbance	Design considerations for constructed habitats will include physical protection where appropriate to support system resilience.

Forecasting Ecological Outcomes

In order to appropriately select sites and justify project worth, benefits associated with a restoration project must be forecasted over the expected life of the project (i.e., 50 years; USACE 2000). Forecasting ecological outcomes over such long temporal scales is confounded by many factors including, but not limited to, inherent ecological complexity within a single ecosystem type, complex interactions among ecosystem types, changes in physical conditions throughout the project life (e.g., sea level rise), and changes in social attitudes, just to name a few (Cahoon et al. 2009, Day et al. 2008). Given the diverse nature of the ecosystems of interest and influential processes acting on them, it is not expected that a single tool or model will address all forecasting needs. Thus, a modeling PDT is being assembled to develop an appropriate suite of tools to forecast restoration outcomes under these complicating factors. It is expected that any models applied will draw heavily from existing tools and models (Table 2). Multiple forecasting models will be proposed to assess site selection and benefit computation. For instance, a spatially-explicit decision support tool may be required to combine the multiple factors contributing to site selection (e.g., velocity, depth, suspended sediment, nutrient concentrations, connectivity, etc.; Lin et al. 2006), while benefit reporting for cost-effectiveness analysis may rely on a different, albeit related, set of criteria (e.g., acreage, connectivity, sustainability, proportion of habitat types).

Table 2. Abbreviated summary of tools and models used as the basis for Currituck Sound site selection and benefit reporting models.

Model Type	Model Description
Hydrodynamic, geomorphic, and water quality	• Coupled CH3D-ICM estuary hydrodynamic and water quality model (ERDC unpublished) • Wave Exposure Model (WEMo; Fonseca and Malhotra 2010)) • Tidally corrected optical water quality model (Biber et al. 2008) • SWAT watershed runoff model (Garcia 2009) • Dare County analysis of geomorphic change (Sea Level Affecting Marshes Model; Mickler and Welch 2009)
Ecological Community	• Wetland Value Assessment (USFWS 2007) • Relevant hydrogeomorphic method (HGM) handbooks (Rheinhardt et al. 2002, Shafer and Yozzo 1998, Shafer et al. 2002, 2007, USACE 2008a)
Individual taxa	• Relevant Habitat Evaluation Procedure (HEP) models applicable (USACE 2008b): waterbirds (great blue heron, white ibis, least tern, great egret), waterfowl (American black duck, blue winged teal, mallard, northern pintail, wood duck), fish and shellfish (blueback herring, American shad, striped bass, largemouth bass, red drum, croaker), others (diamondback terrapin, muskrat) • SAV models: Kemp et al. (2004), Lawson et al. (2007), Short and Neckles (1999), Short et al. (2002) • Other habitats or population models (Galbraith et al. 2002, 2005)

Because of the inherent uncertainties associated with ecological forecasting, any tools or models applied will be subjected to both scenario and sensitivity testing to examine the robustness of the decision. In particular, USACE coastal projects are required to examine three alternative future scenarios associated with sea level rise (USACE 2009): (1) a historic (or "low") scenario, (2) an "intermediate" scenario based on NRC and IPCC projections, and (3) a "high" scenario based on NRC and IPCC projections. Barrier island morphology and coastal storm intensity have the potential to be significant factors in future conditions (Riggs and Ames 2003, Cahoon et al. 2009). However, at this point, changes in island morphology and storm intensity are uncertain and challenging to predict. Thus, these factors will be addressed qualitatively for each of the three sea level rise scenarios. In addition to scenario uncertainty, models adapted or developed for site selection and benefits reporting will be subjected to sensitivity analyses addressing model structure and parameterization.

Preliminary Restoration Alternatives

Alternative development will be guided by the objectives, conceptual models, and forecasting tools described above as well as known opportunities identified throughout the basin (i.e., those identified in existing habitat conservation plans). Preference will be given to alternatives capable of adapting to sea level rise throughout the project life and those exhibiting greater capacity to resist and recover from coastal storm disturbances (i.e., greater resilience). Potential restoration alternatives and opportunities identified at this juncture include, but are not limited to:

- Beneficial use of dredge material
- Operational changes to boating or dredging conditions (e.g., channel dredging, material disposal, or no wake zones)
- Restoration of historic nesting islands that have eroded (e.g., Monkey Island)
- SAV, marsh, or island planting or seeding
- Installation of breakwaters to induce and/or increase sediment settling, island development, or marsh accretion or protect restored habitats
- Alteration of existing canals
- Watershed restoration actions (e.g., riparian buffers and BMPs) targeting excessive sediment or nutrient loading

Symbols and Acronyms

ADCIRC	Coastal circulation and storm surge model (www.unc.edu/ims/adcirc/)
CH3D	Curvilinear-grid Hydrodynamics 3D
ERDC	U.S. Army Engineer Research and Development Center, Vicksburg, MS
HEP	Habitat Evaluation Procedure
HGM	Hydrogeomorphic Method of wetland assessment
ICM	Finite volume eutrophication model (Cerco and Cole 1995)
SLAMM	Sea Level Affecting Marshes Model
NCDENR	North Carolina Department of Environment and Natural Resources
NOAA	National Oceanic and Atmospheric Administration
PDT	Project Development Team
SAV	Submerged aquatic vegetation
SAW	USACE Wilmington District

SWAT	Soil and Water Assessment Tool (www.swatmodel.tamu.edu)
USACE	U.S. Army Corps of Engineers
USFWS	U.S. Fish and Wildlife Service
WEMo	Wave Exposure Model
WVA	Wetland Value Assessment

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Additional Literature Resources[3]

Topic	Sub-Topic	References
Submerged Aquatic Vegetation (SAV)	General physiology and faunal utilization	Beck et al. (2001), Bell et al. (2008), Duffy (2006), Fonseca et al. (1998), Heck et al. (2003, 2008), Hughes et al. (2009), Kemp et al. (2004), Koch and Beer (1996), Orth et al. (2006, 2010), Short and Neckles (1999), van Katwijk et al. (2010), Waycott et al. (2009), Wicks et al. (2009), Wyda et al. (2002)
	Modeling extent	Bekkby et al. (2008), Biber et al. (2008), Fonseca and Molhotra (2010), Kemp et al. (2004), Lawson et al. (2007), Short and Neckles (1999), Short et al. (2002), Uhrin and Kirsch (2008)
	Restoration and Planting	Ailstock et al. (2010), Busch et al. (2010), Lewis (1987), Golden et al. (2010), Fonseca et al. (2002), Hengst et al. (2010), Irving et al. (2010), Koch et al. (2010), Lewis et al. (1998), Marion and Orth (2010ab), Moore et al. (2010), Shafer and Bergstrom (2010), Shafer et al. (2003), Tanner et al. (2010), Treat and Lewis (2006), Uhrin and Kirsch (2008)
	Boating damage	Engeman et al. (2008), Hallac et al. (2008)
	Dredge material	Erftemeijer and Lewis (2006), Golder et al. (2008), Riggs et al. (1993)
	Nutrients	Fourqurean et al. (2003), McGlathery et al. (2007), Paerl et al. (2006), Valiela et al. (1997)
Marshes		Craft et al. (2009), Day et al. (2008), Lin et al. (2006), Lynn and Reed (2002), Reed et al. (2008), Rheinhardt et al. (2002), Shafer and Yozzo (1998), Shafer et al. (2002, 2007), USFWS (2007), Valiela et al. (1997)
Back-Barrier Islands		Cleary et al. (1979), Cowgill et al. (1989), Erwin (1980), Erwin et al. (2004), Golder et al. (2008), Rounds and Erwin (2002), Rounds et al. (2004), USFWS (2002b)
Barrier Islands		Birkemeier et al. (1984), Mallinson et al. (2008), Pilkey et al. (2009), Riggs and Ames (2003, 2006), Riggs et al. (2009)
General Assessments	Birds and Fish Inventories	Hunter et al. (2006), Ma et al. (2010), Musick et al. (2000), NAWMP (2004), Parnell and Soots (1979), State of the Birds (2010), USFWS (2002ab), USSCP (2001)
	Mid-Atlantic	Cahoon et al. (2009), Daniels et al. (1995), DCERP (2008), Rogers and McCarty (2000), Titus et al. (2009)
	North Carolina	Fear et al. (2008), NC (2005, 2009ab), Paerl et al. (2006), Parnell and Soots (1979), Riggs and Ames (2003), Riggs et al. (2008), Riggs et al. (2009), Waite et al. (1994), Watson and Malloy (2006)
	Currituck	Davis and Brinson (1983), Fine (2008), Forte and Martz (2007), Lawson et al. (2007), Morton and Kane (1994), Sinncock (1965)

[3] This table was assembled in an attempt to synthesize some of the relevant literature which the team will draw upon as the project progresses.