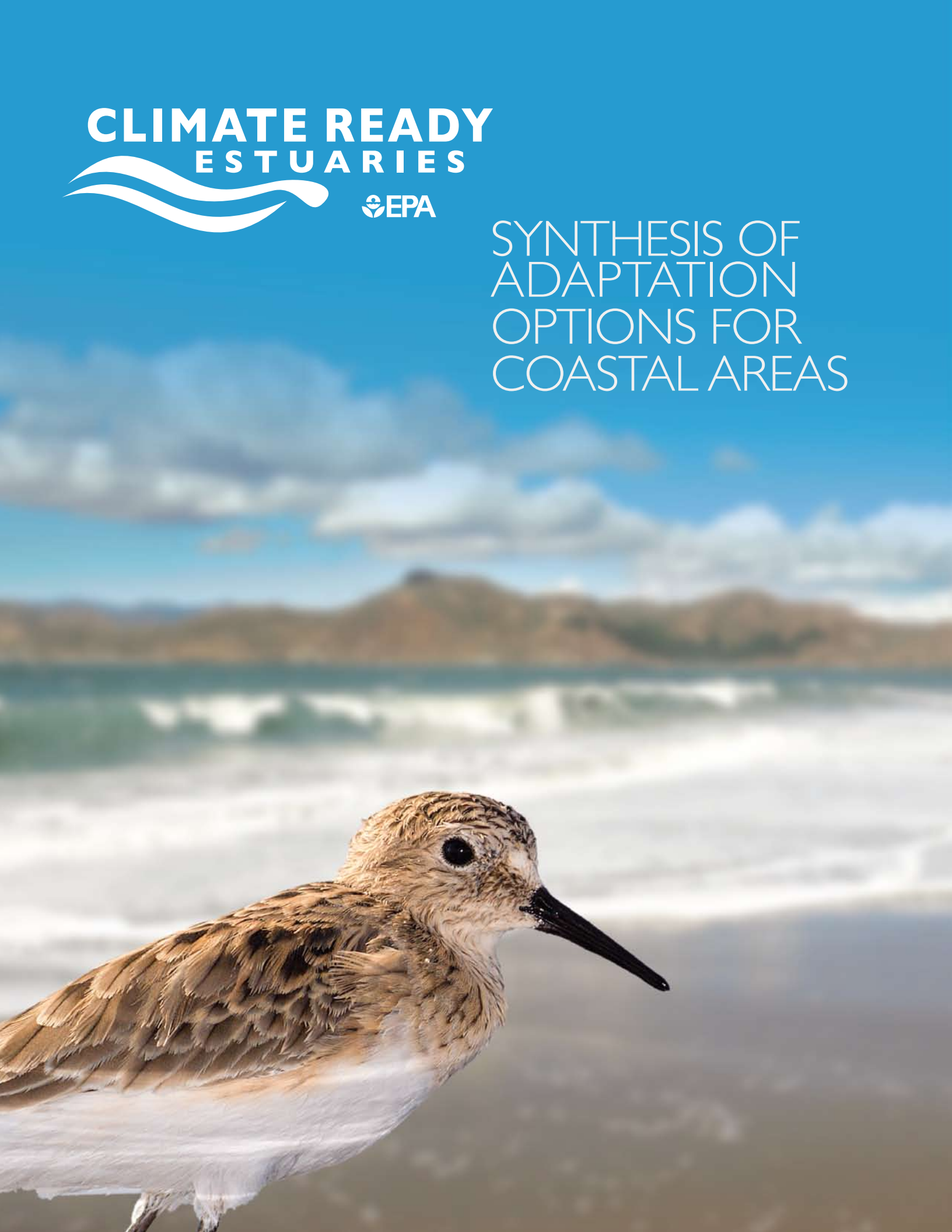
CLIMATE READY ESTUARIES

EPA

SYNTHESIS OF ADAPTATION OPTIONS FOR COASTAL AREAS



You can download this document from EPA's Climate Ready Estuaries Website at:

http://www.epa.gov/cre/adaptationoptions.html

TABLE OF CONTENTS

I. Introduction

Climate change is being observed in many of our nation's natural systems. Estuaries and other coastal systems are particularly vulnerable to many of the projected impacts of climate change. Regardless of future action to reduce emissions, the atmospheric buildup of greenhouse gases has committed the earth to some level of future climate change. Projected effects on estuaries include sea level rise, altered frequencies and intensities of precipitation, increased water temperatures, and more intense storm events. These effects will impact the health of our coastlines, including the people and species that inhabit them.

While not all of these changes will directly affect day-to-day management of estuarine systems, many of them will require some adjustment in management strategies and decision making. Managing for a changing climate is further complicated by ongoing population growth in coastal areas. As estuarine areas face an increasing risk from both the direct and indirect impacts of climate change and the consequences of human responses to climate change, managers will be faced with new and different challenges on top of existing system stressors.

Management actions can ameliorate or exacerbate a system's vulnerability to climate change. Actions taken to reduce impacts or exploit beneficial opportunities resulting from climate change are commonly referred to as climate change *adaptation*. Consideration of climate change impacts and appropriate adaptation options can help to ensure that managers' actions reduce risk, improve resiliency, and ameliorate rather than exacerbate the vulnerability of their coastal ecosystems.

This guide provides a brief introduction to key physical impacts of climate change on estuaries and a review of on-the-ground adaptation options available to coastal managers to reduce their systems' vulnerability to climate change impacts. Reducing the emissions of greenhouse gases, referred to as "mitigation," is a necessary component of the overall response to climate change, and can help avoid, reduce, or delay future impacts. However, this guide focuses on climate change adaptation for estuaries and coastal areas because: 1) estuaries are highly and uniquely vulnerable to climate change, 2) adaptation will be necessary to address impacts resulting from warming which is already unavoidable due to past and current emissions, and 3) adaptation can help reduce the long-term costs associated with climate change.[1] For more information on how communities and individuals can reduce greenhouse gas emissions, please visit EPA's Climate Change Website (http://www.epa.gov/climatechange/wycd/index.html).

The guide is organized as follows:

- Overview of key climate change impacts on coastal areas;
- Existing adaptation options; and
- Selected resources for further information.

II. Overview of Climate Change Impacts on Coastal Areas

Vulnerability of Coastal Areas to Climate Change

The Intergovernmental Panel on Climate Change (IPCC) describes climate vulnerability as a function of: (1) the character, rate, and magnitude of the climate change stressor (e.g., 1°C increase in water temperature over the next decade), (2) the sensitivity of the system to the climate stressors, and (3) the ability of the system to adjust to climate change, moderate potential damages, take advantage of opportunities, or cope with the consequences (referred to as "adaptive capacity").[2]

The character, rate, and magnitude of climate change stressors will vary regionally. For example, sea level rise will impact the bedrock coasts of New England and Oregon differently than the sandy barrier island shorelines of North Carolina.

[1] Climate change adaptation is an evolving field. As the science advances on both coastal vulnerability and adaptation options, this document will need to be revised accordingly.

[2] IPCC AR4 WGII: Impacts, Adaptation and Vulnerability, Introduction.

The nation's diverse estuarine systems will thus be vulnerable to different climate stressors and the ability of these systems to adjust to climate change will vary. The specific vulnerability of any single estuary will depend on physical features (e.g., elevation gradient, estuarine depth, size), geomorphology, and species composition. All estuaries, however, are expected to be vulnerable to climate change to some degree.[3]

Table 1 provides an overview of key climate change stressors and projected impacts on estuarine systems, which have been gleaned from several recent publications:

- The IPCC released its Fourth Assessment Report (AR4) in 2007, which is organized according to three working groups focused on: (I) *The Physical Science Basis;* (II) *Impacts, Adaptation and Vulnerability*; and (III) *Mitigation of Climate Change*. The report considers climate change impacts globally and regionally, as well as what actions can be taken to address these impacts.
- The U.S. Climate Change Science Program (CCSP) is developing 21 Synthesis and Assessment Products (SAPs) to provide information on climate change that is useful to policymakers, resource managers, stakeholders, and the public. SAP 4.1 addresses the vulnerability of coastal areas to sea level rise. SAP 4.4 focuses on adaptation options for climate sensitive ecosystems and resources. SAP 4.7 examines the impacts of climate change on transportation systems, focusing on the Gulf Coast.[4]
- The National Research Council (NRC) recently published a study entitled *Mitigating Shore Erosion Along Sheltered Coasts,* which addresses options to protect sheltered coasts against erosion.

The overview of projected impacts in Table 1 provides context for understanding how adaptation options can reduce vulnerability and address various management goals. Table 1 should not be considered as a comprehensive source of information for climate change impacts to estuaries and coastal systems. There are many other sources of information not captured here that should be consulted to obtain a more complete understanding.

Table 1. Overview of Potential Climate Change Impacts on Estuarine Systems

Climate Change Stressor	Vulnerable Area	Potential Impact on Estuarine Systems
Sea level rise[5]	Ocean shores and estuarine shores	• Coastal change (e.g., erosion, landward migration, barrier island disintegration) • Change in coastal water quality – saltwater intrusion, rising water tables
	Wetlands	• Migration of estuarine salinity gradients • Inundation and erosion of coastal marshes, beaches, mudflats, and other wetlands (leading to loss of habitat for many species) • Altered tidal range and tidal asymmetry (leading to tidal mixing and changes in sediment transport)
	Estuarine open water	• Increased salinity • Increased water depths
	Species	• Inundation and/or migration inland of marsh species (including vegetation, birds, invertebrates, and fish nurseries) • Altered structural diversity of foundation species (e.g., intertidal marsh plants) • Habitat changes (both structural and functional), which could impact a variety of species within marsh and wetland ecosystems • Less sunlight available to submerged aquatic vegetation

[3] IPCC AR4 WGII: Impacts, Adaptation and Vulnerability, Chapter 6

[4] CCSP Synthesis and Assessment Products are available online at http://www.climatescience.gov/Library/sap/sap-summary.php.

[5] Two different terms are commonly used to describe sea level rise: relative and global (or eustatic) sea level rise. As defined in IPCC AR4 WGII, "'Eustatic [global] sea-level rise' is a change in global average sea level brought about by an increase in the volume of the world ocean. 'Relative sea-level rise' refers to a local increase

Climate Change Stressor	Vulnerable Area	Potential Impact on Estuarine Systems
Increases in water temperatures	Ocean shores and estuarine shores	• Increased stratification/changed circulation • Greater vulnerability to coral bleaching events
	Wetlands	• Shift in species composition (e.g., mangroves and cypress swamps moving northward) • Reductions in water quality due to increased growth of nuisance algae and to lower oxygen levels
	Estuarine open water	• Lower oxygen levels • Increased algal blooms • Changes to microbial processes (nitrogen fixation and denitrification)
	Species	• Altered species distributions (especially seasonal distributions of birds, fish and shellfish) and increased invasive species • Increased species mortality rates (e.g., greatly increased coral reef die-off) • Extirpation of cool water species due to temperature spikes after precipitation events • Altered reproductive rates and maturation leading to declining populations
Altered timing of seasonal changes	Ocean shores and estuarine shores	• Altered winter-spring discharge rates, leading to increased erosion and runoff in some areas (West Coast in particular)
	Wetlands	• Increased/decreased precipitation (depending on region) affecting water balance/availability • Changes in timing of spring flow of pollutants
	Species	• Changes in precipitation affecting river discharge balance • Altered species migration and species distribution (especially seasonal distributions of birds, fish, and shellfish) and increased invasive species • Disruption of predator/prey availability (especially within fisheries) • Disruption in the synchronicity of food and reproductive pulses (notably in bird populations)
Increases in air temperatures	Wetlands	• Decreased water availability and drought in some regions
	Species	• Altered species distributions[6] • Altered species interactions and metabolic activity • Increased risk of disease and parasitism, especially in species engaged in symbiotic partnerships[7] • Opened niches for invasive species
Changes in precipitation	Ocean shores and estuarine shores	• Flooding of coastal areas due to higher peak stream discharge rates • Increased erosion due to high-flow discharge • Changes in volume and timing of runoff and sediment distribution
	Wetlands	• Altered winter-spring discharge rates, leading to more pronounced flooding (especially if high flow coincides with heavy precipitation events) • Reduced water quality due to changes in freshwater runoff • Changes in precipitation affecting pollutant loading levels in water bodies • Altered salinity gradient from increase/decrease of streamflow
	Species	• Local extirpations of fish, amphibians, or water-dispersed plants due to drought conditions that isolate tributaries

in the level of the ocean relative to the land, which might be due to increased volume and/or land subsidence (IPCC AR4 WGII: Glossary). The use of the term "sea level rise" throughout this document refers to relative sea level rise.

[6] For example, SAP 4.4 finds that "warm water species of zooplankton, intertidal invertebrates, and fish in marine systems have migrated into areas previously too 'cool' to support growth" (SAP 4.4, Chapter 7).

[7] SAP 4.4 reports that, "marine diseases in corals, turtles, mollusks, marine mammals, and echinoderms have increased sharply over the past three decades, especially in the Caribbean" (SAP 4.4, Chapter 7). As with most climate change stressors, temperature will interact with other stressors such as chemical pollutants and excess nutrients, which will complicate the ability to predict species responses.

Climate Change Stressor	Vulnerable Area	Potential Impact on Estuarine Systems
Elevated atmospheric CO_2	Ocean shores	• Reduced carbonate deposition in marine taxa • Increased coral reef die-off
	Wetlands	• Increased algal blooms
	Species	• Changes in plant growth and turnover • Ocean acidification, impacting upon pH-sensitive organisms
Changes in storm intensity	Oceans shores and estuarine shores	• Increased intensity of coastal storms in some areas, causing coastal erosion, altered sediment transport, inundation of tidal wetlands, and loss of established upland vegetation and structures
	Estuarine open water	• Increased magnitude of coastal storms in some areas, altering hydrological regimes
All of the above impacts statements are derived from the following reports: IPCC AR4 WGII: Chapters 3,6,19; SAP 4.1: Chapters 1-4; SAP 4.4: Chapters 6-8; SAP 4.7: Chapter 3; NRC: Chapter 2		

III. Adaptation Options for Coastal Areas

Climate change adaptation options vary based on the timing of the management response (prior to or after a climate event has occurred) and the type of action (e.g., physical, technological, institutional). Two different time frames for adaptation options are generally considered: (1) proactive measures to preserve and protect resources in anticipation of climate change impacts (a.k.a., anticipatory options); or (2) reactive measures that are implemented after climate change impacts are observed. Reactive adaptation options can be further categorized into (a) responses that are developed immediately but planned to be initiated once climate change impacts are observed; and (b) *ad hoc* reactive responses to climate change impacts after they have been observed. Managers can select among these options based on available information on risks and reversibility of the negative consequences and costs associated with action taken now versus later. Adaptation strategies undertaken in any of these time frames may involve physical changes, technological advancements, or simply management decisions that reflect awareness of climate change impacts on the region.

Different stakeholders may also be involved depending on the type of option or may all be involved in different aspects of any given adaptation strategy. Key actors could include local governments (e.g., county and city agencies, planning and zoning commissions), state governments (e.g., environmental, land, and coastal management agencies), the federal government (e.g., EPA, NOAA, Army Corps of Engineers), businesses (e.g., contractors, engineers, developers, commercial fishing operations), non-governmental organizations, research institutions, and the public.

Adaptation Options Relevant to Estuarine Management Goals

Adaptation options are organized below according to some of the major categories of management goals common to estuarine programs, including:

- Management Goal A: Maintain/restore wetlands
- Management Goal B: Maintain sediment transport
- Management Goal C: Preserve coastal land/development (including infrastructure)
- Management Goal D: Maintain shorelines utilizing "soft" measures
- Management Goal E: Maintain shorelines utilizing "hard" measures
- Management Goal F: Invasive species management
- Management Goal G: Preserve habitat for vulnerable species
- Management Goal H: Maintain water quality
- Management Goal I: Maintain water availability

Some adaptation options may apply directly or indirectly to multiple management goals. For example, allowing wetlands to migrate inland will not only maintain wetlands, but could also directly address management goals of maintaining water quality and preserving habitat for vulnerable species. Adaptation options are categorized according to the management goal they most directly affect or address.

It is also important to note that some adaptation options may contribute to the protection of human infrastructure, while causing detrimental effects to natural systems. For example, shoreline hardening could adversely affect wetlands by preventing sediment transport essential to that ecosystem. Since shoreline hardening, softening, and retreat options (i.e., promote wetland migration) all have individual benefits for shoreline and coastal protection, it may be beneficial to develop a comprehensive shoreline plan outlining which areas can benefit from the appropriate shoreline protection approach. A comprehensive shoreline plan allows managers to take into consideration priorities and tradeoffs and consider implementing different options in different areas according to which resources are most in need of protection.

The text boxes throughout this section provide specific examples of measures undertaken by states or localities.

The tables in this section provide examples of adaptation options for each management goal.
Each option is characterized according to the following categories:

- Climate Stressor Addressed – identifies one or more of the key climate stressors described in Section II (and Table 1) that the adaptation option could address.
- Additional Management Goals Addressed – indicates additional management goals that the adaptation option may help address.
- Benefits – lists some of the environmental, economic, or other benefits of the adaptation option.
- Constraints – lists some of the limitations of the adaptation option.
- Examples – includes references to specific locations and/or organizations that have implemented this adaptation option (where known/available).

Management Goal A: Maintain/Restore Wetlands

Adaptation options for maintaining/restoring wetlands primarily focus on facilitating wetland migration through changes in legislation and regulations (e.g., rolling easements) and prohibitions on shoreline hardening. Examples of these types of policies are presented in Table 2.

Programs seeking to protect existing wetlands from development, pollution, and habitat changes that may be exacerbated by sea level rise could consider developing legislation or modifying land use rules (e.g., zoning) to facilitate wetland migration inland. Programs that are not constrained by existing institutions or policies could focus on prohibiting bulkheads and allowing marshes to migrate inland.

Transportation Planning Incorporating Wetland Preservation in Houston-Galveston, Texas

Management Goal: Management Goal A: Maintain/restore wetlands

Climate Stressor Addressed: Sea level rise

The Houston-Galveston Area Council, a voluntary organization of local government officials and agencies, developed the 2035 Regional Transportation Plan, a long-range system plan that aimed to improve transportation in the region. One of the major goals of the plan was to alleviate some of the environmental impacts of transportation on habitats. The plan identified eight ecological zones within the region, paying particular attention to wetlands, which not only provide rich ecological habitats, but also protect shoreline areas from erosion and serve as buffers from flooding and coastal storms.

Source: SAP 4.7, Chapter 5

Table 2. Adaptation Options for Maintaining/Restoring Wetlands

Adaptation Option	Climate Stressor Addressed	Additional Management Goals Addressed	Benefits	Constraints	Examples
Allow coastal wetlands to migrate inland (e.g., through setbacks, density restrictions, land purchases[8])	Sea level rise	Preserve habitat for vulnerable species; Preserve coastal land/development	Maintains species habitats; maintains protection for inland ecosystems	In highly developed areas, there is often no land available for wetlands to migrate, or it can be costly to landowners	Buzzards Bay, Massachusetts[9]
Promote wetland accretion by introducing sediment	Sea level rise	Maintain sediment transport	Maintains sediment transport to wetlands, which protects coastal land from storms	Requires continual management; can be very costly	Southern Louisiana[10]
Prohibit hard shore protection	Sea level rise	Preserve habitat for vulnerable species; Maintain sediment transport	Allows for species migrations inland	Alternatives of bulkhead construction are more expensive and more difficult to obtain permits for	Numerous states and local governments have drastically reduced permits for hard protection (e.g., King County, Washington[11]).

[8] This adaptation option may not be appropriate in some locations due to biologic or geologic processes that prevent wetland migration inland, or due to lack of land available for wetlands to migrate.

[9] Buzzards Bay Action Plan: Planning for a Shifting Shoreline (1991 CCMP), http://www.buzzardsbay.org/ccmpold/ccmp-ap-shift.pdf

[10] Louisiana Comprehensive Master Plan for a Sustainable Coast, http://www.lacpra.org/index.cfm?md=pagebuilder&tmp=home&nid=24&pnid=0&pid=28&fmid=0&catid=0&elid=0

[11] King County Shoreline Erosion Control Bulletin, http://www.metrokc.gov/DDES/acrobat/cib/16.pdf

Adaptation Option	Climate Stressor Addressed	Additional Management Goals Addressed	Benefits	Constraints	Examples
Remove hard protection or other barriers to tidal and riverine flow (e.g., riverine and tidal dike removals)	Sea level rise	Maintain sediment transport; Maintain shorelines	May allow for wetland migration	Costly and destructive to shoreline property	King County, Washington[12]
Incorporate wetland protection into infrastructure planning (e.g., transportation planning, sewer utilities)	Sea level rise; Changes in precipitation	Maintain water quality; Preserve habitat for vulnerable species	Protects valuable and important infrastructure		Houston-Galveston long-range transportation plan (see text box on page 6)
Preserve and restore the structural complexity and biodiversity of vegetation in tidal marshes, seagrass meadows, and mangroves	Increases in water temperatures; Changes in precipitation	Maintain water quality; Maintain shorelines; Invasive species management	Vegetation protects against erosion, protects mainland shorelines from tidal energy, storm surge, and wave forces, filters pollutants, and absorbs atmospheric CO_2		Chesapeake Bay Living Shorelines Initiative[13]
Identify and protect ecologically significant ("critical") areas such as nursery grounds, spawning grounds, and areas of high species diversity	Altered timing of seasonal changes; Increases in air and water temperatures	Invasive species management; Preserve habitat for vulnerable species	Protecting critical areas will promote biodiversity and ecosystem services (e.g., producing and adding nutrients to coastal systems, serving as refuges and nurseries for species)	May require federal or state protection	Massachusetts Climate Protection Plan[14]
Establish rolling easements[15]	Sea level rise	Maintain water quality; Maintain sediment transport	Lower long-term costs; sediment transport remains undisturbed; property owner bears risks of sea level rise	Does not prevent migration of salinity gradient	Worcester County, Maryland; South Carolina Coastal Council; California Coastal Commission[16]

[12] King County, WA - Land Use, Planning, and Infrastructure Actions for Estuary/Nearshore, ftp://dnr.metrokc.gov/dnr/library/wria8/chapter10-comprehensive-lists/part34-lu-nearshore-estuary.pdf

[13] See Appendix B

[14] Massachusetts Climate Protection Plan, http://www.newamerica.net/files/MAClimateProtPlan0504.pdf

[15] Rolling easements are a type of easement placed along the shoreline to prevent property owners from holding back the sea but allow other types of use and activity on the land. As the sea advances, the easement automatically moves or "rolls" landward. Because shoreline stabilization structures cannot be erected, sediment transport remains undisturbed and wetlands can migrate naturally. Unlike setbacks, which prohibit development near the shore and can often result in "takings" claims if a property is deemed undevelopable due to the setback line, rolling easements place no restrictions on development. They allow the landowner to build on their property with the understanding that they will not be able to prevent shoreline erosion by armoring the shore, or the public from walking along the shore—no matter how close the shoreline gets to their structure. If erosion threatens the structure, the owner will have to relocate the building or allow it to succumb to the encroaching sea. Titus, James, 1998, Rising Seas, Coastal Erosion, and the Takings Clause: How to Save Wetlands and Beaches Without Hurting Property Owners, Maryland Law Review, 57: 1279-1399, http://yosemite.epa.gov/oar/globalwarming.nsf/UniqueKeyLookup/SHSU5BVU5C/$File/takings.pdf

[16] NOAA Office of Ocean and Coastal Resource Management, http://coastalmanagement.noaa.gov/initiatives/shoreline_ppr_easements.html

Management Goal B: Maintain Sediment Transport

Many adaptation options that maintain sediment transport are reactionary, in that they seek to reverse changes that have already occurred or changes that will continue to occur. Because sediment transport is based on a constant cycle of gains and losses, all of these options require maintenance. However, when combined with other actions, these adaptation options may work to prevent loss of coastal habitats and enable marshes to accrete at a rate consistent with sea level rise.

Adaptation options to maintain sediment transport include either trapping sediment that would otherwise migrate or reintroducing sediment into systems (see Table 3). Constructing groin structures traps sand from traveling down shore. Adding sand to beaches through beach nourishment projects that extend the shoreline or create dunes encourages sediment transport and reverses losses due to erosion. Creating a regional sediment management (RSM) plan to manage sediments from source to sink within a watershed can potentially save money, solve engineering problems, and restore natural processes.

Beach Nourishment to Protect Horseshoe Crab Habitat in Delaware Bay

Management Goal: Management Goal B: Maintain sediment transport

Climate Stressor Addressed: Sea level rise

The Delaware Department of Natural Resources and Environmental Control and the U.S. Army Corps of Engineers combined efforts to conduct a study on the impact of beach nourishment on horseshoe crab populations in the Delaware Bay. Habitats that received beach nourishment were shown to increase horseshoe crab spawning and abundance. The study also showed that the type of sediment used for nourishment is critical, with coarser estuarine beach sediments providing a more suitable habitat for horseshoe crabs.

Source: Delaware Division of Soil and Water Conservation, 2002, http://el.erdc.usace.army.mil/tessp/pdfs/New%20Horseshoe%20Crab%20Habitat.pdf

Table 3. Adaptation Options for Maintaining Sediment Transport

Adaptation Option	Climate Stressor Addressed	Additional Management Goals Addressed	Benefits	Constraints	Examples
Trap or add sand through beach nourishment – the addition of sand to a shoreline to enhance or create a beach area	Sea level rise	Preserve habitat for vulnerable species; Preserve coastal land/development; Maintain shorelines	Creates protective beach for inland areas; replenishes sand lost to erosion	Periodic maintenance cycle required; high costs to import beach material	Cape Charles, Virginia; Ocean City, Maryland; Virginia Beach, Virginia[17]; Avalon, New Jersey; Bethany Beach, Delaware[18], Delaware Bay (see text box above)
Trap sand through construction of groins – a barrier-type structure that traps sand by interrupting longshore transport	Sea level rise	Preserve coastal land/development; Maintain shorelines	Creates more natural shore face than bulkheads or revetments; quick fix	Can trigger or accelerate erosion on downdrift side and loss of beach habitat	Rappahannock River, Virginia; Ocean City, Maryland[19]; Long Beach, New York

[17] NRC 2007, Mitigating Shore Erosion Along Sheltered Coasts, Chapter 3

[18] Bethany Beach Beach Nourishment and Storm Damage Reduction Project, http://www.swc.dnrec.delaware.gov/Pages/Beach%20nourishment%202007.aspx

[19] NRC 2007, Mitigating Shore ErosionAlong Sheltered Coasts, Chapter 3

Adaptation Option	Climate Stressor Addressed	Additional Management Goals Addressed	Benefits	Constraints	Examples
Create a regional sediment management (RSM) plan	Changes in precipitation; Sea level rise	Maintain water quality	Considers entire watershed, including upstream reaches	Will require more coordination across regions, including private lands	Currently under development: New York-New Jersey Harbor Estuary Program[20]
Develop adaptive stormwater management practices (e.g., promoting natural buffers, adequate culvert sizing)	Changes in precipitation; Changes in storm intensity	Maintain water quality	Preserves natural sediment flow and protects water quality of downstream reaches	Improvements can be costly	St. John's River Water Management District[21]

[20] NY-NJ Harbor Estuary Program, http://harborestuary.org/rsm.htm

[21] St. John's River Water Management District – The Guana Marsh Renovation Project, http://agcj.tamu.edu/404/pdf/fs-guana-ex.pdf

Management Goal C: Preserve Coastal Land/ Development (Including Infrastructure)

Adaptation options that preserve coastal land and development focus on land use planning and management, land exchange and acquisition programs, and changes to infrastructure (See Table 4). These adaptation options primarily aim to preserve coastal land on which development is planned or already exists. Land use management involves using integrated approaches to coastal zone management as well as land use planning. Land exchange and acquisition programs allow for coastal land to be freed up for preservation uses. Changes to infrastructure can include limiting where hazardous and polluting structures can be built (including landfills and chemical facilities) as well as changing engineering structures that affect water bodies and will be impacted by climate change.

New Jersey Coastal Blue Acres Land Acquisition Program

Management Goal: Management Goal C: Preserve coastal land/development (including infrastructure)

Climate Stressor Addressed: Sea level rise

The Coastal Blue Acres program, organized by the New Jersey Department of Environmental Protection, is a land acquisition program that takes into account the impacts of climate change on coastal areas. The program acquires coastal lands damaged or prone to damages by storms to provide a buffer for other lands, as well as providing space for recreation and conservation. For example, program funds were used to acquire 18.5 acres in Lower Township, Cape May County as an addition to the Higbee Beach Wildlife Management Area. It provides critical undeveloped, upland and wetland habitat at the southern end of the Cape May Peninsula, and will be used for habitat and species restoration.

Source: IPCC AR4 WGII, Chapter 17; New Jersey Department of Environmental Protection, http://www.state.nj.us/dep/greenacres/index.html

Land use planning and management, as well as changes to infrastructure, would be appropriate adaptation options for programs that are looking to implement anticipatory changes. These options require working with various key stakeholders and a longer timeline for implementation. Land exchange and acquisition programs would be viable options for estuaries that have a management goal of acquiring more land in order to protect currently threatened areas.

Table 4. Adaptation Options for Preserving Coastal Land/Development (Including Infrastructure)

Adaptation Option	Climate Stressor Addressed	Additional Management Goals Addressed	Benefits	Constraints	Examples
Land exchange programs – owners exchange property in the floodplain for county-owned land outside of the floodplain	Changes in precipitation; Sea level rise; Changes in storm intensity	Preserve habitat for vulnerable species; Maintain/restore wetlands	Preserves open spaces; more land available to protect estuaries	Program is voluntary; land must be available for development elsewhere	Suffolk County, New York[22]
Integrate coastal management into land use planning	Changes in precipitation; Sea level rise; Changes in storm intensity	Preserve habitat for vulnerable species; Maintain/restore wetlands	Requires more state agency oversight; allows for conservation and management goals to be incorporated	Can be difficult to have local and state agencies agree; private property rights	Oregon; Chesapeake Bay (Virginia); Florida; North Carolina[23]
Create permitting rules that constrain locations for landfills, hazardous waste dumps, mine tailings, and toxic chemical facilities	Sea level rise; Increases in water temperatures; Changes in storm intensity	Preserve habitat for vulnerable species; Maintain/restore wetlands; Maintain water quality	Zones accordingly to protect estuaries and coastal zones	Can be difficult to enact these zoning regulations	Many states have recognized the impacts sea level rise and flooding will have on these types of facilities[24], but few have taken action

[22] The Trust for Public Land, 2008 Conservation Award Winners, http://www.tpl.org/tier3_cd.cfm?content_item_id=22135&folder_id=2867

[23] NRC 2007, Mitigating Shore Erosion Along Sheltered Coasts, Chapter 5

[24] San Francisco Bay Conservation and Development Commission, http://www.bcdc.ca.gov/planning/climate_change/climate_change.shtml

Adaptation Option	Climate Stressor Addressed	Additional Management Goals Addressed	Benefits	Constraints	Examples
Manage realignment and deliberately realign engineering structures affecting rivers, estuaries, and coastlines	Changes in precipitation; Sea level rise; Changes in storm intensity	Preserve habitat for vulnerable species; Maintain/restore wetlands; Maintain sediment transport	Reduces engineering costs; protects ecosystems and estuaries; allows for natural migration of rivers	Can be costly	United Kingdom/ European Union[25]
Land acquisition program – purchase coastal land that is damaged or prone to damage and use it for conservation	Altered timing of seasonal changes; Increases in air and water temperatures; Sea level rise; Changes in storm intensity	Preserve habitat for vulnerable species; Maintain/restore wetlands	Can provide a buffer to inland areas; prevents development on the land	Can be expensive; land may not be available	New Jersey Coastal Blue Acres (see text box on page 10)
Integrated Coastal Zone Management (ICZM) – using an integrated approach to achieve sustainability	Changes in precipitation; Sea level rise; Increases in air and water temperatures; Changes in storm intensity	Preserve habitat for vulnerable species; Maintain/restore wetlands; Maintain water availability; Maintain water quality; Maintain sediment transport; Maintain shorelines	Considers all stakeholders in planning, balancing objectives; addresses all aspects of climate change	Stakeholders must be willing to compromise; requires much more effort in planning	European Union; Australia[26]
Incorporate consideration of climate change impacts into planning for new infrastructure (e.g., homes, businesses)	Sea level rise; Changes in precipitation; Changes in storm intensity	Preserve habitat for vulnerable species; Maintain/restore wetlands	Engineering could be modified to account for changes in precipitation or seasonal timing of flows; siting decisions could take into account sea level rise	Land owners will likely resist relocating away from prime coastal locations	Rhode Island State Building Code[27]

[25] IPCC AR3 WGII: Chapter 13, http://www.ipcc.ch/ipccreports/tar/wg2/511.htm; The Effects of Biological and Physical Processes on Saltmarsh Erosion and Restoration in SE England, http://www.tyndall.ac.uk/research/theme4/workshop1/chapter_5.pdf

[26] European Commission Coastal Zone Management, http://ec.europa.eu/environment/iczm/home.htm; Australian Department of the Environment, Water, Heritage and the Arts: National Cooperative Approach to Integrated Coastal Zone Management - Framework and Implementation Plan, http://www.environment.gov.au/coasts/publications/framework/index.html; Integrated Coastal Zone Management, http://www.environment.gov.au/coasts/iczm/index.html

[27] Rhode Island Sea Grant – Coastal Resources Center, http://seagrant.gso.uri.edu/ccd/slr/SLR_policies_summary_Mar6_final.pdf

Management Goal D: Maintain Shorelines Utilizing "Soft" Measures

Approaches for maintaining shorelines in the face of sea level rise include both "soft" measures and "hard" measures. Each of these approaches or some combination of them may be appropriate depending on the characteristics of a particular location (e.g., shore protection costs, property values, the environmental importance of habitat, the feasibility of protecting shores without harming the habitat). "Soft" measures aim to develop living shorelines through beach nourishment, planting dune grasses, marsh creation, and planting submerged aquatic vegetation (SAV) (See Table 5).

Creating Marshes in the Chesapeake Bay, Maryland Shore Erosion Control Program

Management Goal: Management Goal D: Maintain shorelines utilizing "soft" measures

Climate Stressor Addressed: Sea level rise

Through the Maryland Department of Natural Resources, the Shore Erosion Control program has created over 300 marsh fringe sites along the Chesapeake Bay. The marshes have been created as "living shoreline" in order to control erosion and reduce land lost to sea level rise. These non-structural shoreline stabilization methods create a vegetative buffer for the land, improve water quality, and provide habitat to many species. The marshes were created with sand fill and stabilized through the planting of marsh grasses and the use of soils, stones, gravels, and biodegradable protective materials. Individual property owners who wish to construct these types of erosion control measures can also receive financial assistance to do so through the Shore Erosion Control program.

Source: IPCC AR4 WGII, Chapter 3; Maryland Department of Natural Resources, http://www.dnr.state.md.us/ccws/sec/index.asp

Table 5. Adaptation Options for Maintaining Shorelines through "Soft" Measures

Adaptation Option	Climate Stressor Addressed	Additional Management Goals Addressed	Benefits	Constraints	Examples
Replace shoreline armoring with living shorelines – through beach nourishment, planting vegetation, etc.	Sea level rise; Changes in storm intensity	Maintain/restore wetlands; Preserve habitat for vulnerable species; Preserve coastal land/development	Reduces negative effects of armoring (downdrift erosion); maintains beach habitat	Can be costly; requires more planning and materials than armoring	Living Shorelines Stewardship Initiative (Chesapeake Bay)[28]
Remove shoreline hardening structures such as bulkheads, dikes, and other engineered structures to allow for shoreline migration	Sea level rise	Maintain sediment transport	Allows for shoreline migration	Costly for, and destructive to, shoreline property	King County, Washington[29]; Puget Sound Action Team[30]
Plant SAV (such as sea grasses) to stabilize sediment and reduce erosion	Changes in precipitation; Sea level rise	Maintain/restore wetlands; Preserve habitat for vulnerable species; Preserve coastal land/development	Stabilizes sediment; does not require costly construction procedures	Seasonality – grasses diminish in winter months, when wave activity is often more severe because of storms; light availability is essential	Chesapeake Bay (Living Shoreline Stewardship Initiative)[31]; Tampa Bay NEP[32]

[28] See Appendix B

[29] Seahurst Bulkhead Removal and Beach Restoration Assessment, http://dnr.metrokc.gov/WRIAS/9/SRFB-seahurst-park-bulkhead-study.htm

[30] Puget Sound Alternative Shoreline Stabilization Evaluation Project, http://www.psparchives.com/our_work/restore_habitat/restore_resources.htm

[31] See Appendix B

[32] Tampa Bay Sea Grass Planting Initiative, http://www.tampabaywatch.org/index.cfm?fuseaction=content.home&pageID=24

Adaptation Option	Climate Stressor Addressed	Additional Management Goals Addressed	Benefits	Constraints	Examples
Create marsh by planting the appropriate species – typically grasses, sedges, or rushes – in the existing substrate	Sea level rise	Maintain water quality; Maintain/ restore wetlands; Preserve habitat for vulnerable species; Invasive species management	Provides protective barrier; maintains and often increases habitat	Conditions must be right for marsh to survive (e.g., sunlight for grasses, calm water); can be affected by seasonal changes	Maryland Shore Erosion Control Program[33]; Chesapeake Bay (Living Shoreline Stewardship Initiative)[34]
Create dunes along backshore of beach; includes planting dune grasses and sand fencing to induce settling of wind-blown sands	Sea level rise	Preserve coastal land/development	Protects both the beach and inland areas from sea level rise	Costs of importing sand; takes land away from public use	Chesapeake Bay (Virginia, in particular)[35]
Use natural breakwaters of oysters (or install other natural breakwaters) to dissipate wave action and protect shorelines	Increases in water temperatures; Sea level rise; Changes in precipitation; Changes in storm intensity	Preserve coastal land/development; Maintain water quality; Invasive species management	Naturally protect shorelines and marshes and inhibit erosion inshore of the reef; will induce sediment deposition	May not be sustainable in the long-term, because breakwaters are not likely to provide reliable protection against erosion in major storms	South Carolina Oyster Restoration and Enhancement (SCORE)[36]; New York/New Jersey Baykeeper Oyster Restoration Program[37];VIMS Oyster Restoration Programs (Virginia)[38]; Oyster Reef Restoration in the Mid-Atlantic[39]
Install rock sills and other artificial breakwaters in front of tidal marshes along energetic estuarine shores	Sea level rise; Changes in storm intensity	Preserve coastal land/development; Maintain water quality	Naturally protect shorelines and marshes and inhibit erosion inshore of the reef; will induce sediment deposition	May not be sustainable in the long-term, because breakwaters are not likely to provide reliable protection against erosion in major storms; requires encroachment bayward or riverward, usually beyond the property limit, complicating the process for obtaining permits for construction	St. Mary's County, Maryland[40]; Mississippi-Alabama Sea Grant Consortium (MASGC)[41]

[33] Maryland Department of Natural Resources, http://www.dnr.state.md.us/ccws/sec/index.asp

[34] See Appendix B

[35] NRC, Mitigating Shore Erosion Along Sheltered Coasts, Chapter 3; Chesapeake Bay Living Shoreline Stewardship Initiative (see Appendix B)

[36] South Carolina Oyster Restoration and Enhancement, http://score.dnr.sc.gov/index.php

[37] New York/New Jersey Baykeeper, http://www.nynjbaykeeper.org/programs/42

[38] Virginia Institute of Marine Science, Molluscan Ecology Program, http://www.vims.edu/mollusc/monrestoration/restoyreef.htm

[39] University of New Hampshire - Oyster Restoration Program, http://www.oysters.unh.edu/other_restoration.html

[40] NRC, Mitigating Shore Erosion Along Sheltered Coasts, Chapter 3

[41] Shoreline Protection Alternatives, http://www.masgc.org/pdf/masgp/07-026.pdf

Adaptation Option	Climate Stressor Addressed	Additional Management Goals Addressed	Benefits	Constraints	Examples
Restrict or prohibit development in erosion zones	Sea level rise; Changes in precipitation; Changes in storm intensity	Preserve coastal land/development; Maintain/restore wetlands	Allows for more land available to protect estuaries	Will not help areas already developed; difficult to get all parties to agree	New Jersey (limits development)[42]; San Mateo, California[43]
Redefine riverine flood hazard zones to match projected expansion of flooding frequency and extent	Sea level rise; Changes in precipitation; Changes in storm intensity	Preserve coastal land/development; Maintain/restore wetlands	Protects riverine systems and zones accordingly	Impacts on flood insurance; may require changing zoning ordinances, which can be difficult	King County, Washington[44]
Increase shoreline setbacks	Sea level rise; Changes in storm intensity	Preserve coastal land/development	Protects coastal property in the long term and prevents development directly on the shoreline	Will not help areas already developed	Buzzards Bay[45]; North Carolina Coastal Resources Commission (CRC) is developing new setback rules[46]; South Carolina[47]
Composite systems – incorporate elements of two or more methods (e.g., breakwater, sand fill, and planting vegetation)	Sea level rise; Changes in storm intensity	Preserve coastal land/development	Incorporates benefits of multiple systems; can address longer stretches of coastline	"Softer approaches" (e.g., vegetation, beach nourishment) require more maintenance over time; can become costly	Chesapeake Bay; James City County, Virginia[48]; Mississippi-Alabama Sea Grant Consortium (MASGC)[49]

[42] New Jersey Department of Environmental Protection – Coastal Zone Management Rules, http://www.state.nj.us/dep/landuse/7-7e.pdf

[43] California Environmental Resources Evaluation System – County of San Mateo Local Coastal Program Policies, http://ceres.ca.gov/planning/lcp/sanmateo/visual.html

[44] King County, WA 2007 Climate Action Plan, http://www.metrokc.gov/exec/news/2007/pdf/ClimatePlan.pdf

[45] Buzzards Bay Action Plan: Planning for a Shifting Shoreline (1991 CCMP), http://www.buzzardsbay.org/ccmpold/ccmp-ap-shift.pdf

[46] North Carolina Coastal Resources Commission, http://dcm2.enr.state.nc.us/CRC/crc.htm

[47] South Carolina Code of Regulations, http://www.scstatehouse.net/coderegs/c030.htm

[48] NRC, Mitigating Shore Erosion Along Sheltered Coasts, Chapter 3

[49] Shore Protection Alternatives, http://www.masgc.org/pdf/masgp/07-026.pdf

Management Goal E: Maintain Shorelines Utilizing "Hard" Measures

Shoreline protection can also be achieved through hardening techniques such as constructing bulkheads, seawalls, revetments, and breakwaters, or reinforcing dikes and headlands (See Table 6). Adaptation options that use hardening techniques are often preserving existing development (e.g., homes and businesses) and infrastructure (e.g., sewage systems, roads), or protecting land available for future development or infrastructure. While these options may provide immediate remediation, they may not be sustainable in protecting coastal land in the long term. Many of these adaptation options have potential negative impacts on habitats and ecosystems as well, including wetland loss where migration is blocked by hard structures.

Table 6. Adaptation Options for Maintaining Shorelines through "Hard" Measures

Adaptation Option	Climate Stressor Addressed	Additional Management Goals Addressed	Benefits	Constraints	Examples
Fortify dikes	Sea level rise; Changes in precipitation; Increases in water temperatures; Changes in storm intensity	Maintain water quality; Preserve coastal land/ development	Protect land subject to flooding and storm surges	Can be costly; salinity gradient may still migrate	Tyrell County, North Carolina (dikes primarily used to protect agricultural land)[50]
Harden shorelines with bulkheads – anchored, vertical barriers constructed at the shoreline to block erosion	Sea level rise; Changes in storm intensity	Preserve coastal land/development	Most common; simple materials used for construction; quick fix	Loss of intertidal habitats; adjacent properties must be bulkheaded to maintain consistent shorefront	Manhattan, Long Island, New York; Mobile Bay, Alabama; Delaware Bay; Pacific Northwest[51]
Harden shorelines with seawalls	Sea level rise; Changes in storm intensity	Preserve coastal land/development	Withstand greater wave energy than bulkheads; simple materials used for construction; quick fix	Loss of intertidal habitats	Puget Sound, Washington; James River in Newport News, Virginia[52]
Harden shorelines with revetments that armor the slope face of the shoreline	Sea level rise; Changes in storm intensity	Preserve coastal land/development	Simple materials used for construction; quick fix	Loss of intertidal habitats; often constructed poorly and lead to destabilization of banks, increasing erosion	Potomac River, Virginia; Northumberland County, Virginia[53]
Harden shorelines with breakwaters – structures placed offshore to reduce wave action	Sea level rise; Changes in storm intensity	Maintain water quality; Preserve coastal land/ development	Employs materials that are locally available; quick fix; create good habitat for marshes and mangroves (calm water)	Downdrift coast may be deprived of sediment, increasing erosion; loss of habitat	Chesapeake Bay[54]
Headland control – reinforce or accentuate an existing geomorphic feature or create an artificial headland (e.g., Geotextile tubes)	Sea level rise; Changes in storm intensity	Preserve coastal land/development	Can be cost-effective	May reduce sediment supply to adjacent shores, increasing erosion; loss of habitat	Hog Island, Virginia; Westmoreland County, Virginia; Texas[55]

[50] SAP 4.1, Coastal Sesitivity to Sea-Level Rise: A Focus on the Mid-Atlantic Region, Appendix G

[51] NRC, Mitigating Shore Erosion Along Sheltered Coasts, Chapter 3

[52] NRC, Mitigating Shore Erosion Along Sheltered Coasts, Chapter 3

[53] NRC, Mitigating Shore Erosion Along Sheltered Coasts, Chapter 3

[54] NRC, Mitigating Shore Erosion Along Sheltered Coasts, Chapter 3

[55] NRC, Mitigating Shore Erosion Along Sheltered Coasts, Chapter 3

Management Goal F: Invasive Species Management

Limiting invasions by non-native species as climate-driven changes modify habitat conditions may involve preventing the introduction of invasive species or removing species that are already posing a threat to native populations (see Table 7). As a reactive solution, the removal of invasive species allows for native species to be re-established and ecosystems to be restored. Preventing the introduction of invasive species requires proactive planning and strengthening of rules and regulations. [56]

In some cases, adapting to species change will be necessary. Climate change will likely shift habitats poleward, forcing some species to migrate in order to survive. Management options may have to consider climate change when making long term investments based on an assumption of species persistence.

Table 7. Adaptation Options for Invasive Species Management

Adaptation Option	Climate Stressor Addressed	Additional Management Goals Addressed	Benefits	Constraints	Examples
Strengthen rules that prevent the introductions of invasive species (e.g., enforce no discharge zones for ballast water)	Altered timing of seasonal changes; Increases in air and water temperatures	Maintain/restore wetlands; Preserve habitat for vulnerable species	Prevents difficult eradication of invasives by preventing their introductions	Difficult to regulate	Oregon[57]
Remove invasive species and restore native species	Altered timing of seasonal changes; Increases in air and water temperatures	Maintain/restore wetlands; Preserve habitat for vulnerable species	Local removals of invasives is locally viable to improve marsh characteristics that promote fish and wildlife	Difficult (if not impossible) on a larger scale	Peconic Estuary Program[58]

[56] For more information on invasive species management, see http://www.epa.gov/owow/invasive_species/invasives_management/; U.S. EPA and the Environmental Law Institute Report: Effects of Climate Change on Aquatic Invasive Species and Implications for Management and Research, http://oaspub.epa.gov/eims/eimscomm.getfile?p_download_id=472114

[57] Oregon Department of Fish & Wildlife, Oregon Invasive Species Action Plan, http://www.oregon.gov/OISC/docs/pdf/oisc_plan6_05.pdf

[58] Invasive Species Management in the Peconic Estuary, http://www.peconicestuary.org/Invasives.html

Management Goal G: Preserve Habitat for Vulnerable Species

Adaptation options to preserve habitat for vulnerable species may involve actively increasing ecosystem boundaries or removing barriers that prevent habitat expansion or migration (see Table 8). Actions to increase ecosystem boundaries could include purchasing upland development or property rights and expanding the planning horizons of land use planning to incorporate longer-term climate predictions. Actions that remove barriers to expansion might include retreating away from and abandoning coastal barriers (e.g., seawalls). The actions listed in Table 8 may be similar to those listed under Management Goal A: Maintain/Restore Wetlands, however, the primary goal of the options listed below is to help improve the resiliency of species that are vulnerable to climate change.

Removing existing ecosystem barriers could be either a reactionary or a proactive adaptation option, depending on whether it is undertaken in response to observations that habitats are shifting or in anticipation that habitats may shift. Increasing ecosystem boundaries is an anticipatory adaptation option, focusing on the potential for habitats to fluctuate in size, and allowing for flexibility in their movement.

Table 8. Adaptation Options for Preserving Habitat for Vulnerable Species

Adaptation Option	Climate Stressor Addressed	Additional Management Goals Addressed	Benefits	Constraints	Examples
Retreat from, and abandonment of, coastal barriers	Sea level rise	Maintain/restore wetlands	May help protect estuaries, allowing them to return to their natural habitat	Not politically favored due to the high value of coastal property and infrastructure	
Purchase upland development rights or property rights	Changes in precipitation; Sea level rise	Maintain/restore wetlands; Maintain water quality	Protects habitats downstream	Costly; uncertainty about sea level rise means uncertainty in the amount of property purchased	San Francisco Estuary Project (planned)[59]; Massachusetts Climate Protection Plan[60]
Expand the planning horizons of land use planning to incorporate longer climate predictions	Changes in precipitation; Sea level rise	Preserve coastal land/development	Could inhibit risky development and provide protection for estuarine habitats	Land use plans rarely incorporate hard prohibitions against development close to sensitive habitats and have limited durability over time	San Francisco Bay Conservation and Development Commission (SFBCDC) has proposed recommendations[61]

[59] San Francisco Estuary Project CCMP Section on Wetlands Management, http://sfep.abag.ca.gov/pdfs/ccmp/Wetlands_Management.pdf

[60] Massachusetts Climate Protection Plan, http://www.newamerica.net/files/MAClimateProtPlan0504.pdf

[61] Climate Change Strategy for the San Francisco Bay Region, http://www.bcdc.ca.gov/planning/climate_change/climate_change.shtml

Adaptation Option	Climate Stressor Addressed	Additional Management Goals Addressed	Benefits	Constraints	Examples
Adapt protections of important biogeochemical zones and critical habitats as the locations of these areas change with climate	Increases in air and water temperatures; Altered timing of seasonal changes; Changes in precipitation; Sea level rise	Maintain/restore wetlands	Allows for migration of critical areas	Will require consistent monitoring efforts	
Connect landscapes with corridors to enable migrations	Altered timing of seasonal changes; Sea level rise	Maintain/restore wetlands	Allows for species migration with climate change; sustains wildlife biodiversity across the landscape	May require significant effort and resources	
Design estuaries with dynamic boundaries and buffers	Altered timing of seasonal changes; Sea level rise	Maintain/restore wetlands	Protects breeding and foraging habits of highly migratory species	In highly developed areas, boundaries may already be unmovable	
Replicate habitat types in multiple areas to spread risks associated with climate change	Altered timing of seasonal changes; Increases in air and water temperatures	Maintain/restore wetlands; Invasive species management	Protects biodiversity and critical areas	Land may not be available to replicate habitats	

Management Goal H: Maintain Water Quality

Sea level rise and changes in the timing and intensity of precipitation can affect the water quality of estuaries. Protecting existing infrastructure and planning for impacts to new infrastructure can help reduce vulnerability to these impacts (e.g., sizing drainage and sewer treatment systems to accommodate changes in flow). Other options for maintaining water quality of marshes and wetlands include preventing or limiting groundwater extraction from shallow aquifers and protecting land subject to flooding by plugging canals (see Table 9).

Determining the type of adaptation option to implement is dependent on what specific management challenge a particular estuary is facing, or is expecting to face in the future. If the water quality is being threatened by development, then incorporating sea level rise into planning for new infrastructure may be appropriate. However, if saltwater intrusion is predicted to pose future risks, then options such as modifying or designing new drainage/sewer systems may be more appropriate.

The Guana Marsh Renovation Project, St. John's County, Florida

Management Goal: Management Goal H: Maintain water quality

Climate Stressor Addressed: Changes in precipitation

The water quality of the Guana Marsh has been negatively impacted by increasing development, agricultural runoff, and the elevation of water tables. The St. John's River Water Management District has developed a Guana Basin Master Plan to improve water quality and restore the marsh. This plan allowed for several different improvements to be completed, including the replacement of inadequate or failing flow structures with box culverts; the construction of a water control weir to provide water level control and storage for water quality treatment; and the removal of aquatic plants that blocked the natural channel flow. The water quality of the marsh will continue to be improved through the replacement of septic tanks with a central sewer system.

Source: St. John's River Water Management District – The Guana Marsh Renovation Project , http://agcj.tamu.edu/404/pdf/fs-guana-ex.pdf

Table 9. Adaptation Options for Maintaining Water Quality

Adaptation Option	Climate Stressor Addressed	Additional Management Goals Addressed	Benefits	Constraints	Examples
Plug drainage canals	Sea level rise; Changes in precipitation	Preserve coastal land/development	Prevent subsidence-inducing saltwater intrusion; protect land subject to flooding	Elimination of transportation routes	Louisiana[62]
Prevent or limit groundwater extraction from shallow aquifers	Sea level rise	Preserve coastal land/development; Maintain/restore wetlands; Maintain water availability	Will limit relative sea level rise by preventing subsidence and reducing saltwater intrusion into freshwater aquifers	Need to find an alternative water source	
Design new coastal drainage system	Changes in precipitation; Sea level rise; Changes in storm intensity		Many systems need to be restructured anyway	Planning and construction can be very costly and time-consuming	Vancouver, Canada (planned – CitiesPLUS 100-year plan)[63]

[62] Louisiana Department of Natural Resources, Local Coastal Programs, http://dnr.louisiana.gov/crm/coastmgt/interagencyaff/lcp/parish/cam_emu.asp

[63] IPCC AR4 WGII: Chapter 14, http://www.ipcc.ch/ipccreports/ar4-wg2.htm

Adaptation Option	Climate Stressor Addressed	Additional Management Goals Addressed	Benefits	Constraints	Examples
Incorporate sea level rise into planning for new infrastructure (e.g., sewage systems)	Sea level rise	Preserve coastal land/development	Preserves long-term functional integrity of structures; prevents contamination of water supply	Measures can be costly	Deer Island, Boston, Massachusetts[64]
Develop adaptive stormwater management practices (e.g., remove impervious surface, replace undersized culverts)	Changes in precipitation; Changes in storm intensity	Maintain/restore wetlands	Minimizes pollutant and nutrient overloading of existing wetlands	May require costly improvements	Massachusetts Bays NEP[65]; St. John's River Water Management District (see text box on page 19); New Jersey[66]

[64] IPCC AR4 WGII: Chapter 17, http://www.ipcc.ch/ipccreports/ar4-wg2.htm

[65] Action Plan for Massachusetts Bays Program Comprehensive Conservation Management Plan, http://www.mass.gov/envir/massbays/pdf/Chapter%20V%20part%201.pdf

[66] New Jersey Coastal Management Program, http://www.nj.gov/dep/cmp/309_combined_strat_7_06.pdf

Management Goal 1: Maintain Water Availability

In order to maintain water availability, adaptation options must either free up additional water sources or reallocate water distribution. Creating water markets is one option that will free up new water sources. To reallocate water distribution, "use containment areas" (where withdrawal is allocated and capped) can be established or broadened to allocate and cap water withdrawal (see Table 10).

Integrating climate change scenarios into water supply systems is an approach that may facilitate planning to both free up and reallocate water distribution.

Depending on the region, some programs may already be facing water shortages or flooding, and may benefit from reactionary adaptation options that free up new water sources. For areas that see water availability as a future problem, anticipatory measures such as establishing "use containment areas" or integrating climate change into water system planning may be better options to consider.

Water Markets in Southern California

Management Goal: Management Goal 1: Maintain water availability

Climate Change Stressor: Changes in precipitation

The Metropolitan Water District of Southern California provides water for urban water utilities in the counties of Los Angeles, San Diego, San Bernardino, Orange, Riverside, and Ventura. It has created a water market system that compensates landowners and agencies for agreeing to irrigate less land. Its 35-year contract with the Palo Verde Irrigation District specified that 29% of the valley's farm land would not be irrigated. This action freed up a large water supply for urban use and conservation.

Source: IPCC AR4 WGII, Chapter 3

Table 10. Adaptation Options for Maintaining Water Availability

Adaptation Option	Climate Stressor Addressed	Additional Management Goals Addressed	Benefits	Constraints	Examples
Create water markets – transferring land and water from agricultural to community use	Changes in precipitation; Increases in air temperatures	Preserve habitat for vulnerable species	Increases availability of water for environmental uses	Program is voluntary; landowners must be willing to give up some water	Metropolitan Water District of Southern California (see text box above)[67]
Establish or broaden "use containment areas" to allocate and cap water withdrawal	Changes in precipitation; Sea level rise		Maintains sustainable aquifer yields and prevents saltwater intrusion	Could be difficult to maintain; politically sensitive	
Integrate climate change scenarios into water supply system	Increases in air and water temperature; Changes in precipitation; Sea level rise	Preserve coastal land/development	Takes changes in temperature, precipitation, and sea level rise into account in planning	Could show that major restructuring is needed; changes could become costly	New York City[68]
Manage water demand (through water reuse, recycling, rainwater harvesting, desalination, etc.)	Increases in air and water temperatures; Changes in precipitation; Sea level rise		Increases availability of water for all uses	Requires coordination among water agencies and districts	San Francisco Estuary Project[69]

[67] IPCC AR4 WGII: Chapter 3; Metropolitan Water District of Southern California Press Release, http://www.mwdh2o.com/mwdh2o/pages/news/press_releases/2006-06/reclamation_and_met.htm

[68] IPCC AR4 WGII: Chapter 17; New York City Department of Environmental Protection Climate Change Task Force, http://ccsr.columbia.edu/cig/taskforce/index.html

[69] San Francisco Estuary Project CCMP, Water Use Chapter, http://sfep.abag.ca.gov/pdfs/ccmp/Water_Use.pdf

IV Summary: Moving Forward on Adaptation

Despite a growing awareness of the threats posed by climate change, there are relatively few examples of coastal organizations already preparing to adapt to these changes. For example, many states acknowledge sea level rise as a concern in their coastal zone management assessments, but have not yet developed a comprehensive strategy to deal with it. Part of this delayed response can be traced to institutional barriers to changes in management and individuals' behavior. Some of the primary institutional barriers to adaptation in estuarine systems include policy biases and decision paralysis due to scientific uncertainty at the local scale.

Established policies often favor one type of response over another, causing institutional biases. Policies at the federal level tend to favor shore protection over retreat in developed areas, and retreat over shore protection in undeveloped areas. Hard structures tend to be favored over living shorelines in some longstanding federal policies, but more recent state policies (e.g., Maryland) favor living shorelines that rely on soft solutions such as rebuilding an eroded marsh or bay beach.[70]

Uncertainty surrounding impacts, the relative benefits of different adaptation options, and how others will respond to climate change stressors may delay or impede decisions regarding whether and how to protect resources or abandon resources that cannot be saved. The specific effects of climate change stressors on individual systems are still highly uncertain, as are the expected responses that will result from implementing adaptation strategies. Decision makers are hesitant to act in the face of an uncertain future. Furthermore, many estuaries are managed by interdependent agencies; not knowing how other decision makers will respond to stressors makes it difficult to decide what actions to take.

Finally, the options suggested in this guide are potentially difficult and costly to implement. There may be some easy solutions; in fact, there is a strong case to be made that the sooner they are completed, the easier and perhaps cheaper they will be compared to the costs of inaction. However, in many cases, land managers and property owners will be faced with difficult and potentially costly tradeoffs and actions. More work is needed to evaluate the feasibility of options, better define the cost-effectiveness, and provide additional guidance for land managers.

Decision makers can, nevertheless, begin to take steps toward adapting to climate change. While some of the examples presented above may not provide precise models for adapting to climate change, they do provide some ideas of how others have begun to take adaptive measures to ensure existing management goals continue to be met. A list of relevant Websites is also included in Appendix A, and a list of potential contacts is included in Appendix B.

[70] NRC, Mitigating Shore Erosion Along Sheltered Coasts, Chapters 1 and 5

V. References

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Appendix A

Useful Websites

Below is a list of selected online information sources currently available to resource managers.

EPA's Climate Ready Estuaries Website **http://www.epa.gov/cre/**

This site provides information on climate change impacts and adaptation options; profiles member estuaries and their efforts to address climate change; provides details on how prospective programs can become members; and provides links to important resources, news and events, and contact information.

EPA's Climate Change Website **http://www.epa.gov/climatechange**

This site offers comprehensive and accessible information on climate change, including effects on public health and the environment as well as basic information about the science of climate change.

National Estuaries Program Website **http://www.epa.gov/owow/estuaries**

The NEP establishes partnerships with State, local, and academic interests to improve the quality of estuaries of national importance. The National Estuary Program is comprised of 28 estuaries in the U.S.

U.S. Climate Change Science Program Website **http://www.climatescience.gov**

The U.S. Climate Change Science Program integrates federal research on climate and global change as sponsored by thirteen federal agencies. This site provides a library of research reports, including all 21 Synthesis and Assessment Products.

Intergovernmental Panel on Climate Change (IPCC) Website **http://www.ipcc.ch**

The IPCC was established "to assess the scientific, technical and socio-economic information relevant for the understanding of human induced climate change, its potential impacts and options for mitigation and adaptation" (IPCC Website). The IPCC Fourth Assessment Report, including Working Group II: Impacts, Adaptation and Vulnerability, is available for download.

National Research Council Website **http://sites.nationalacademies.org/nrc/index.htm**

The National Research Council is part of a private, nonprofit institution that provides science, technology and health policy advice. This site provides access to research on various issues pertinent to NEPs. *Mitigating Shore Erosion Along Sheltered Coasts* is available for download at: http://www.nap.edu/catalog/11764.html

NOAA Coastal Services Center **http://www.csc.noaa.gov/**

This site is devoted to serving the nation's state and local coastal resource management programs. Resources available include data, software, and decision support tools. The Center also offers training to coastal managers on these resources.

NOAA Office of Ocean and Coastal Resource Management **http://coastalmanagement.noaa.gov/mystate/welcome.html**

This site provides state-specific information on activities NOAA's Office of Ocean and Coastal Resource Management is involved in, including coastal zone management, research, outreach, and funding.

Appendix B

General Contact Information for Governments, NGOs, and Program Managers

Below is a list of organizations, many of which are mentioned in this report, that have undertaken adaptation actions and may serve as resources for other communities as they move forward in adapting to climate change.

California Coastal Commission
45 Fremont, Suite 2000
San Francisco, CA 94105- 2219
(415) 904- 5200
http://www.coastal.ca.gov/

Coastal Protection and Restoration Authority of Louisiana
Capital Annex, Suite 138
1051 North 3rd Street
Baton Rouge, LA 70802
(225) 342-3968
http://www.lacpra.org/

Delaware Department of Natural Resources and Environmental Control
Division of Soil and Water Conservation
89 Kings Highway
Dover, DE 19901
http://www.swc.dnrec.delaware.gov/

Houston-Galveston Area Council
P.O. Box 22777
Houston, TX 77227-2777
http://www.h-gac.com/

King County (Washington) Shoreline Master Program
201 S. Jackson Street
Seattle, WA 98104
http://www.kingcounty.gov/environment/waterandland/shorelines.aspx

Living Shorelines Stewardship Initiative
A partnership between NOAA, National Fish and Wildlife Foundation, the Keith Campbell Foundation, and the Chesapeake Bay Trust
NOAA:
http://www.nmfs.noaa.gov/habitat/restoration
Keith Campbell Foundation:
http://www.campbellfoundation.org/html/related_projects.html
Chesapeake Bay Trust:
http://www.cbtrust.org/site/c.enJIKQNoFiG/b.2028493/k.4D43/Living_Shorelines_Grant_Program.htm
Virginia Coastal Zone Management Program:
http://www.deq.virginia.gov/coastal/livingshore.html
Maryland Department of Natural Resources:
http://shorelines.dnr.state.md.us/living.asp

Maryland Department of Natural Resources, Shore Erosion Control Program
Tawes State Office Building D-3
580 Taylor Avenue
Annapolis, Maryland 21401
http://www.dnr.state.md.us/ccws/sec/index.asp

Massachusetts Water Resources Authority
Charlestown Navy Yard
100 First Ave, Building 39
Boston, MA 02129
(617) 660-7971
http://www.mwra.state.ma.us/index.html

Metropolitan Water District of Southern California
P.O. Box 54153
Los Angeles, CA 90054-0153
(213) 217-6000
http://www.mwdh2o.com/

New Jersey Department of Environmental Protection, Green Acres Program
Bureau of Green Trust Management
PO Box 412
Trenton, NJ 08625-0412
http://www.state.nj.us/dep/greenacres/index.html

Rhode Island Coastal Resources Management Council
Stedman Government Center, Suite 3
4808 Tower Hill Road
Wakefield, RI 02879-1900
(401) 783-3370
http://www.crmc.ri.gov/

San Francisco Bay Conservation and Development Commission
50 California Street, Suite 2600
San Francisco, CA 94111
(415) 352-3600
http://www.bcdc.ca.gov/

Southwest Florida Regional Planning Council
1926 Victoria Avenue
Fort Meyers, FL 33901
(239) 338-2550
http://www.swfrpc.org/

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Office of Water
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