Appendix 1. State and Local Information on Vulnerable Species and Coastal Policies in the Mid-Atlantic

OVERVIEW

Appendix 1 discusses many of the species that depend on potentially vulnerable habitat in specific estuaries, providing local elaboration of the general issues examined in Chapter 5. It also describes key statutes, regulations, and other policies that currently define how state and local governments are responding to sea level rise, providing support for some of the observations made in Part III. This set of information was not developed as a quantitative nor analytical assessment and therefore is not intended as a complete or authoritative basis for decision-making; rather, it is a starting point for those seeking to discuss local impacts and to examine the types of decisions and potential policy responses related to sea-level rise.

The sections concerning species and habitat are largely derived from a U.S. EPA report developed in support of this Synthesis and Assessment Product (U.S. EPA, 2008), with additional input from stakeholders as well as expert and public reviewers. That report synthesized what peer-reviewed literature was available, and augmented that information with reports by organizations that manage the habitats under discussion, databases, and direct observations by experts in the field. The sections that concern state and local policies are based on statutes, regulations, and other official documents published by state and local governments.

Characterizations of likelihood in this Product are largely based on the judgment of the authors and on published peer-reviewed literature and existing policies, rather than a formal quantification of uncertainty. Data on how coastal ecosystems and specific species may respond to climate change is limited to a small number of site-specific studies, often carried out for purposes unrelated to efforts to evaluate the potential impact of sea level rise. Although being able to characterize current understanding—and the uncertainty associated with that information—is important, quantitative and qualitative assessments of likelihood are not unavailable for the site-specific issues discussed in this Appendix. Unlike the main body of the Product, any likelihood statements in this Appendix regarding specific habitat or species reflect likelihood as expressed in particular reports being cited. Statements about the implications of coastal policies in this Appendix are based on the authors qualitative assessment of available published literature and of the governmental policies. Published information, data, and tools are evolving to further examine sea-level rise at this scale.

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A1.A. Long Island

The North Shore of Long Island is generally characterized by high bluffs of glacial origin, making this area less susceptible to problems associated with increased sea level. The South Shore, by contrast, is generally low lying and fronted by barrier islands, except for the easternmost portion. As a result, there are already major planning efforts underway in the region to preserve the dry lands under threat of inundation. A brief discussion of these efforts, especially on the South Shore, is provided in Section A1.A.2 of this Appendix. Maps and estimates of the area of land close to sea level are provided in Titus and Richman (2001). Further information on portions of the South Shore can be found in Gornitz *et al.* (2002).

A1.A.1 Environmental Implications

North Shore and Peconic Bay.

Of the 8,426 hectares (ha) (20,820 acres [ac]) of tidal wetlands in Long Island Sound, about 15 percent are in New York, primarily along the shores of Westchester and Bronx counties (Holst *et al.*, 2003). Notable areas of marsh are in and around Stony Brook Harbor and West Meadow, bordering the Nissequogue River and along the Peconic Estuary (NYS DOS, 2004). In general, tidal wetlands along the North Shore are limited; the glacial terminal moraine[70] resulted in steep uplands and bluffs and more kettle-hole[71] wetlands along the eastern portion (LISHRI, 2003). In the eastern portion, there has already been a significant loss of the historical area of vegetated tidal wetlands (Holst *et al.*, 2003; Hartig and Gornitz, 2004), which some scientists partially attribute to sea-level rise (Mushacke, 2003).

The loss of vegetated low marsh reduces habitat for several rare bird species (*e.g.*, seaside sparrow) that nest only or primarily in low marsh (see Section 5.2). Low marsh also provides safe foraging areas for small resident and transient fishes (*e.g.*, weakfish, winter flounder). Diamondback terrapin live in the creeks of the low marsh, where they feed on

[70] A glacial terminal moraine is a glacial deposit landform that marks the limit of glacial advance.
[71] A kettle hole is a depression landform formed in glacial deposit sediments from a time when a large block of glacial ice remained and melted after a glacial retreat.

plants, mollusks, and crustaceans (LISF, 2008). Some wetlands along Long Island Sound may be allowed to respond naturally to sea-level rise, including some in the Peconic Estuary. Where migration is possible, preservation of local biodiversity as well as some regionally rare species is possible (Strange *et al.*, 2008).

Beaches are far more common than tidal wetlands in the Long Island Sound study area. Several notable barrier beaches exist. For example, the sandy barrier-beach system fronting Hempstead Harbor supports a typical community progression from the foreshore to the bay side, or backshore (LISHRI, 2003). The abundant invertebrate fauna provide forage for sanderling, semipalmated plovers, and other migrating shorebirds (LISHRI, 2003). The maritime beach community between the mean high tide and the primary dune provides nesting sites for several rare bird species, including piping plover, American oystercatcher, black skimmer, least tern, common tern, roseate tern, the Northeastern beach tiger beetle, and horseshoe crab (LISHRI, 2003) (see Box A1.1). Diamondback terrapin use dunes and the upper limit of the backshore beach for nesting (LISHRI, 2003).

Since nearly all of the Long Island Sound shoreline is densely populated and highly developed, the land may be armored in response to sea-level rise, raising the potential for beach loss. The Long Island Sound Habitat Restoration Initiative cautions: "Attempts to alter the natural cycle of deposition and erosion of sand by construction of bulkheads, seawalls, groins, and jetties interrupt the formation of new beaches" (LISHRI, 2003).

Shallow water habitats are a major ecological feature in and around the Peconic Estuary. Eelgrass beds provide food, shelter, and nursery habitats to diverse species, including worms, shrimp, scallops and other bivalves, crabs, and fish (PEP, 2001). Horseshoe crabs forage in the eelgrass beds of Cedar Point/Hedges Bank, where they are prey for loggerhead turtles (federally listed as threatened), crabs, whelks, and sharks (NYS DOS, 2004). Atlantic silverside spawn here; silverside eggs provide an important food source for seabirds, waterfowl, and blue crab, while adults are prey for bluefish, summer flounder, rainbow smelt, white perch, Atlantic bonito, and striped bass (NYS DOS, 2004). The Cedar Point/Hedges Bank Shallows eelgrass beds are known for supporting a bay scallop fishery of statewide importance (NYS DOS, 2004).

Other noteworthy habitats that could be affected by sea-level rise include the sea-level fen vegetation community that grows along Flanders Bay (NYS DOS, 2004), and the Long Island's north shore tidal flats, where longshore drift carries material that erodes from bluffs and later deposits it to form flats and barrier spits or shoals (LISHRI, 2003). One of the largest areas of tidal mudflats on the North Shore is near Conscience Bay, Little Bay, and Setauket Harbor west of Port Jefferson (NYS DOS, 2004). Large beds of hard clams, soft clams, American oysters, and ribbed mussels are found in this area (NYS DOS, 2004).

South Shore.

Extensive back-barrier salt marshes exist to the west of Great South Bay in southern Nassau County (USFWS, 1997). These marshes are particularly notable given widespread marsh loss on the mainland shoreline of southern Nassau County (NYS DOS and USFWS, 1998; USFWS, 1997). To the east of Jones Inlet, the extensive back-barrier and fringing salt marshes are keeping pace with current rates of sea-level rise, but experts predict that the marshes' ability to keep pace is likely to be marginal if the rate of sea-level rise increases moderately, and that the marshes are likely to be lost under higher sea-level rise scenarios (Strange *et al.*, 2008, interpreting the findings of Reed *et al.*, 2008). Opportunities for marsh migration along Long Island's South Shore would be limited if the mainland shores continue to be bulkheaded. Outside of New York City, the state requires a minimum 22.9-meter (m) (75-foot [ft]) buffer around tidal wetlands to allow marsh migration, but outside of this buffer, additional development and shoreline protection are permitted[72] (NYS DEC, 2006). Numerous wildlife species could be affected by salt marsh loss. For example, the Dune Road Marsh west of Shinnecock Inlet provides nesting sites for several species that are already showing significant declines, including clapper rail, sharp-tailed sparrow, seaside sparrow, willet, and marsh wren (USFWS, 1997). The salt marshes of Gilgo State Park provide nesting sites for northern harrier, a species listed by the state as threatened (NYS DOS, 2004).

Of the extensive tidal flats along Long Island's southern shoreline, most are found west of Great South Bay and east of Fire Island Inlet, along the bay side of the barrier islands, (USFWS, 1997) in the Hempstead Bay–South Oyster Bay complex, (USFWS, 1997) and around Moriches and Shinnecock Inlets (NYS DOS and USFWS, 1998). These flats provide habitat for several edible shellfish species, including soft clam, hard clam, bay

[72] The state has jurisdiction up to 300 feet beyond the tidal wetland boundary in most areas (but only 150 feet in New York City).

scallop, and blue mussel. The tidal flats around Moriches and Shinnecock Inlets are particularly important foraging areas for migrating shorebirds. The South Shore Estuary Reserve Council asserts that "because shorebirds concentrate in just a few areas during migration, loss or degradation of key sites could devastate these populations" (NYS DOS and USFWS, 1998).

The back-barrier beaches of the South Shore also provide nesting sites for the endangered roseate tern and horseshoe crabs (USFWS, 1997). Shorebirds, such as the red knot, feed preferentially on horseshoe crab eggs during their spring migrations.

Increased flooding and erosion of marsh and dredge spoil islands will reduce habitat for many bird species that forage and nest there, including breeding colonial waterbirds, migratory shorebirds, and wintering waterfowl. For example, erosion on Warner Island is reducing nesting habitat for the federally endangered roseate tern and increasing flooding risk during nesting (NYS DOS and USFWS, 1998). The Hempstead Bay–South Oyster Bay complex includes a network of salt marsh and dredge spoil islands that are important for nesting by herons, egrets, and ibises. Likewise, Lanes Island and Warner Island in Shinnecock Bay support colonies of the state-listed common tern and the roseate tern (USFWS, 1997).

BOX A1.1: Effects on the Piping Plover

Piping Plover *Charadrius melodus*
Habitat: The piping plover, federally listed as threatened, is a small migratory shorebird that primarily inhabits open sandy barrier island beaches on Atlantic coasts (USFWS, 1996). Major contributing factors to the plover's status as threatened are beach recreation by pedestrians and vehicles that disturb or destroy plover nests and habitat, predation by mammals and other birds, and shoreline development that inhibit the natural renewal of barrier beach and overwash habitats (USFWS, 1996). In some locations, dune maintenance for protection of access roads associated with development appears to be correlated with absence of piping plover nests from former nesting sites (USFWS, 1996).

Locations: The Atlantic population of piping plovers winters on beaches from the Yucatan Peninsula to North Carolina. In the summer, they migrate north and breed on beaches from North Carolina to Newfoundland (CLO, 2004). In the mid-Atlantic region, breeding pairs of plovers can be observed on coastal beaches and barrier islands, although suitable habitat is limited in some areas. In New York, piping plovers breed more frequently on Long Island's sandy beaches, from Queens to the Hamptons, in the eastern bays and in the harbors of northern Suffolk County. New York's Breezy Point barrier beach, at the mouth of Jamaica Bay, consistently supports one of the largest piping plover nesting sites in the entire New York Bight coastal region (USFWS, 1997). New York has seen an increase in piping plover breeding pairs in the last decade from less than 200 in 1989 to near 375 in recent years (2003 to 2005), representing nearly a quarter of the Atlantic coast's total breeding population (USFWS, 2004a). Despite this improvement, piping plovers remain state listed as endangered in New York (NYS DEC, 2007).

Impact of Sea-Level Rise: Where beaches are prevented from migrating inland by shoreline armoring, sea-level rise will negatively impact Atlantic coast piping plover populations. To the degree that developed shorelines result in erosion of ocean beaches, and to the degree that stabilization is undertaken as a response to sea-level rise, piping plover habitat will be lost. In contrast, where beaches are able to migrate landward, plovers may find newly available habitat. For example, on Assateague Island, piping plover populations increased after a storm event that created an overwash area on the north of the island (Kumer, 2004). This suggests that if barrier beaches are allowed to migrate in response to sea-level rise, piping plovers might adapt to occupy new inlets and beaches created by overwash events.

Beach nourishment, the anticipated protection response for much of New York's barrier beaches such as Breezy Point, can benefit piping plovers and other shorebirds by increasing available nesting habitat in the short term, offsetting losses at eroded beaches, but may also be detrimental, depending on timing and implementation (USFWS, 1996). For instance, a study in Massachusetts found that plovers foraged on sandflats created by beach nourishment (Cohen *et al*,, 2005). However, once a beach is built and people spread out to enjoy it, many areas become restricted during nesting season. Overall, throughout the Mid-Atlantic, coastal development and shoreline stabilization projects constitute the most serious threats to the continuing viability of storm-maintained beach habitats and their dependent species, including the piping plover (USFWS, 1996).

Photograph credit: USFWS, New Jersey Field Office /Gene Nieminen, 2006.

A1.A.2 Development, Shore Protection, and Coastal Policies

New York State does not have written policies or regulations pertaining specifically to sea-level rise in relation to coastal zone management, although sea-level rise is becoming recognized as a factor in coastal erosion and flooding by New York State Department of State (DOS) in the development of regional management plans.

Policies regarding management and development in shoreline areas are primarily based on three laws. Under the Tidal Wetlands Act program, the Department of Environmental Conservation (DEC) classifies various wetland zones and adjacent areas where human activities may have the potential to impair wetland values or adversely affect their function; permits are required for most activities that take place in these areas. New construction greater than 9.3 square meters (sq m) (100 square feet [sq ft]), excluding docks, piers, and bulkheads) as well as roads and other infrastructure must be set back 22.9 m (75 ft) from any tidal wetland, except within New York City where the setback is 9.1 m (30 ft)[73].

The Waterfront Revitalization and Coastal Resources Act (WRCRA) allows the DOS to address sea-level rise indirectly through policies regarding flooding and erosion hazards (NOAA, 1982). Seven out of 44 written policies related to management, protection, and use of the coastal zone address flooding and erosion control. These polices endeavor to move development away from areas threatened by coastal erosion and flooding hazards, to ensure that development activities do not exacerbate erosion or flooding problems and to preserve natural protective features such as dunes. They also provide guidance for public funding of coastal hazard mitigation projects and encourage the use of nonstructural erosion and flood control measures where possible (NYS DOS, 2002).

Under the Coastal Erosion Hazard Areas Act program, the DEC identified areas subject to erosion and established two types of erosion hazard areas (structural hazard and natural protective feature areas) where development and construction activities are regulated[74]. Permits are required for most activities in designated natural protective feature areas. New development (*e.g.*, building, permanent shed, deck, pool, garage) is prohibited in

[73] Article 25, Environmental Conservation Law Implementing Regulations-6NYCRR PART 661.
[74] Environmental Conservation Law, Article 34

nearshore areas, beaches, bluffs, and primary dunes. These regulations, however, do not extend far inland and therefore do not encompass the broader area vulnerable to sea-level rise.

New York State regulates shore protection structures along estuaries and the ocean coast differently. The state's Coastal Erosion Hazard Law defines coastal erosion hazard areas as those lands with an average erosion rate of at least 30 cm (1 ft) per year.[75] Within those erosion hazard areas, the local governments administer the programs to grant or deny permits, generally following state guidelines.[76] Those guidelines requires that individual property owners first evaluate non-structural approaches; but if they are unlikely to be effective, hard structures are allowed (New York State, 2002).

Shoreline structures, which by definition include beach nourishment in New York State, are permitted only when it can be shown that the structure can prevent erosion for at least thirty years and will not cause an increase in erosion or flooding at the local site or nearby locations (New York State, 2002). Setbacks, relocation, and elevated walkways are also encouraged before hardening.

Currently, all of the erosion hazard areas are along the open coast. Therefore, the state does not directly regulate shore protection structures along estuarine shores. However, under the federal Coastal Zone Management Act, New York's coastal management program reviews federal agency permit applications, to ensure consistency with policies

[75] § New York Environmental Conservation Law 34-0103 (3)(a)
[76] § New York Environmental Conservation Law 34-0105

of the State's coastal management program (NOAA, 2008a; USACE, 2007). The state has objected to nationwide permit 13 issued by the Corps of Engineer's wetlands regulatory program (see Section 12.2.2 in Chapter 12), which provides a general authorization for erosion control structures (NYS DOS, 2006). The effect of that objection is that nationwide permit 13 does not automatically provide a property owner with a permit for shore protection unless the state concurs with such an application (NYS DOS, 2006). The state has also objected to the application of nationwide permits 3 (which includes maintenance of existing shore protection structures) and 31 (maintenance of existing flood control activities) within special management areas (NYS DOS, 2006).

Similar to the New York metropolitan area, the policies for Long Island reflect the fact that the region is intensely developed in the west and developing fast in the east. Much of the South Shore, particularly within Nassau County, is already developed and has already been protected, primarily by bulkheads. The Long Island Sound Management Program estimates that approximately 50 percent of the Sound's shoreline is armored (NYS DOS, 1999).

Some of the South Shore's densely developed communities facing flooding problems, such as Freeport and Hempstead, have already implemented programs that call for elevating buildings and infrastructure in place and installing bulkheads for flood protection. The Town of Hempstead has adopted the provisions of the state's Coastal Erosion Hazards Area Act, described in Section A1.B of this Appendix, because erosion and flooding along Nassau County's ocean coast have been a major concern. The Town of Hempstead has also been actively working with the U.S. Army Corps of Engineers

(USACE) to develop a long-term storm damage reduction plan for the heavily developed Long Beach barrier island (USACE, 2003).

Beach nourishment and the construction of flood and erosion protection structures are also common on the island. For example, in the early 1990s USACE constructed a substantial revetment around the Montauk Lighthouse at the eastern tip of Long Island and after a new feasibility study has proposed construction of a larger revetment (Bleyer, 2007). USACE is also reformulating a plan for the development of long-term storm damage prevention projects along the 134 kilo (km) 83 mile [mi]) portion of the South Shore of Suffolk County. As part of this effort, USACE is assessing at-risk properties within the 184 square kilometer (sq km) (71 square miles [sq mi]) floodplain, present and future sea-level rise, restoration and preservation of important coastal landforms and processes, and important public uses of the area (USACE, 2008b).

To obtain state funding for nourishment, communities must provide public access every 800 m (0.5 mi) (New York State, 2002). In 1994, as terms of a legal settlement between federal, state, and local agencies cooperating on the rebuilding of the beach through nourishment, the community of West Hampton provided six walkways from the shorefront road to allow public access to the beach (Dean, 1999). In communities that have not had such state-funded projects, however, particularly along portions of the bay shore communities in East Hampton, South Hampton, Brookhaven, and Islip, public access to tidal waters can be less common (NYS DOS, 1999).

The Comprehensive Coastal Management Plan (CCMP) of the Peconic Bay National Estuary Program Management Plan calls for "no net increase of hardened shoreline in the Peconic Estuary". The intent of this recommendation is to discourage individuals from armoring their coastline; yet this document is only a management plan and does not have any legal authority. However, towns such as East Hampton are trying to incorporate the plan into their own programs. In 2006, the town of East Hampton adopted and is now enforcing a defined zoning district overlay map that prevents shore armoring along much of the town's coastline (Town of East Hampton, 2006). Despite such regulations, authorities in East Hampton and elsewhere recognize that there are some areas where structures will have to be allowed to protect existing development.

The New York Department of State (DOS) is also examining options for managing erosion and flood risks through land use measures, such as further land exchanges. For example, there is currently an attempt to revise the proposed Fire Island to Montauk Point Storm Damage Reduction Project to consider a combination of nourishment and land use measures. One option would be to use beach nourishment to protect structures for the next few decades, during which time development could gradually be transferred out of the most hazardous locations. Non-conforming development could eventually be brought into conformance as it is reconstructed, moved, damaged by storms or flooding, or other land use management plans are brought into effect.

A1.B. New York Metropolitan Area

The New York metropolitan area has a mixture of elevated and low-lying coastlines. Low-lying land within 3 m of mean sea level (Gornitz *et al*., 2002) include the borough of Queens' northern and southeastern shore, respectively (where New York's two major airports, LaGuardia and John F. Kennedy International Airport, are located); much of the recreational lands along Jamaica Bay's Gateway National Recreation Area (*e.g.*, Floyd Bennett Field, Jamaica Bay Wildlife Refuge, Fort Tilden, Riis Park); and the Staten Island communities of South Beach and Oakwood Beach. In New Jersey, the heavily developed coast of Hudson County (including Hoboken, Jersey City, and Bayonne) is also within 3 m, as is much of the area known as the Meadowlands (area around Giants Stadium). Other areas with sections of low-lying lands are found in Elizabeth and Newark, New Jersey (near Newark Airport). The area also includes the ecologically-significant Raritan Bay-Sandy Hook habitat complex at the apex of the New York region (also known as the New York Bight), where the east-west oriented coastline of New England and Long Island intersects the north-south oriented coastline of the mid-Atlantic at Sandy Hook.

Given its large population, the effects of hurricanes and other major storms combined with higher sea levels could be particularly severe in the New York metropolitan area. With much of the area's transportation infrastructure at low elevation (most at 3 m or less), even slight increases in the height of flooding could cause extensive damage and bring the thriving city to a relative standstill until the flood waters recede (Gornitz *et al.*, 2002).

Comprehensive assessments of the vulnerability of the New York City metropolitan area are found in Jacob *et al.* (2007) and Gornitz *et al.* (2002). Jacob *et al.* summarize vulnerability, coastal management and adaptation issues. Gornitz *et al*. details the methodology and results of a study that summarizes vulnerability to impacts of climate change, including higher storm surges, shoreline movement, wetland loss, beach nourishment and some socioeconomic implications. These assessments use sea-level rise estimates from global climate models available in 2002. Generalized maps depicting lands close to sea level are found in Titus and Richman (2001) and Titus and Wang (2008).

If sea-level rise impairs coastal habitat, many estuarine species would be at risk. This Section provides additional details on the possible environmental implications of sea-level rise for the greater New York metropolitan area, including New York City, the lower Hudson River, the East River, Jamaica Bay, the New Jersey Meadowlands, Raritan Bay and Sandy Hook Bay. The following subsections discuss tidal wetlands, beaches, tidal flats, marsh and bay islands, and shallow waters. (Sections A1.A.2 and A1.D.2 discuss the statewide coastal policies of New York and New Jersey.)

Tidal Wetlands. Examples of this habitat include:

- *Staten Island*: The Northwest Staten Island/Harbor Herons Special Natural Waterfront Area is an important nesting and foraging area for herons, ibises, egrets, gulls, and waterfowl (USFWS, 1997). Several marshes on Staten Island, such as Arlington Marsh and Saw Mill Creek Marsh, provide foraging areas for the birds of the island heronries. Hoffman Island and Swinburne Island, east of Staten Island, provide important nesting habitat for herons and cormorants, respectively (Bernick, 2006).

- *Manhattan*: In the marsh and mudflat at the mouth of the Harlem River at Inwood Hill Park (USFWS, 1997) great blue herons are found along the flat in winter, and snowy and great egrets are common from spring through fall (NYC DPR, 2001).
- *Lower Hudson River*: The Piermont Marsh, a 412 hectare (ha) (1,017 acre [ac]) brackish wetland on the western shore of the lower Hudson River has been designated for conservation management by New York State and the National Oceanic and Atmospheric Administration (NOAA) (USFWS, 1997). The marsh supports breeding birds, including relatively rare species such as Virginia rail, swamp sparrow, black duck, least bittern, and sora rail. Anadromous and freshwater fish use the marsh's tidal creeks as a spawning and nursery area. Diamondback terrapin reportedly nest in upland areas along the marsh (USFWS, 1997).
- *Jamaica Bay*: Located in Brooklyn and Queens, this bay is the largest area of protected wetlands in a major metropolitan area along the U.S. Atlantic Coast. The bay includes the Jamaica Bay Wildlife Refuge, which has been protected since 1972 as part of the Jamaica Bay Unit of the Gateway National Recreation Area. Despite extensive disturbance from dredging, filling, and development, Jamaica Bay remains one of the most important migratory shorebird stopover sites in the New York Bight (USFWS, 1997). The bay provides overwintering habitat for many duck species, and mudflats support foraging migrant species (Hartig *et al.*, 2002). The refuge and Breezy Point, at the tip of the Rockaway Peninsula, support populations of 214

species that are state or federally listed or of special emphasis, including 48 species of fish and 120 species of birds (USFWS, 1997). Salt marshes such as Four Sparrow Marsh provide nesting habitat for declining sparrow species and serve 326 species of migrating birds (NYC DPR, undated). Wetlands in some parts of the bay currently show substantial losses (Hartig *et al.*, 2002).

- *Meadowlands***:** The Meadowlands contain the largest single tract of estuarine tidal wetland remaining in the New York/New Jersey Harbor Estuary and provide critical habitat for a diversity of species, including a number of special status species. Kearney Marsh is a feeding area for the state-listed endangered least tern, black skimmer, and pied-billed grebe. Diamondback terrapin, the only turtle known to occur in brackish water, is found in the Sawmill Wildlife Management Area (USFWS, 1997).
- *Raritan Bay-Sandy Hook***:** The shorelines of southern Raritan Bay include large tracts of fringing salt marsh at Conaskonk Point and from Flat Creek to Thorn's Creek. These marshes are critical for large numbers of nesting and migrating bird species. The salt marsh at Conaskonk Point provides breeding areas for bird species such as green heron, American oystercatcher, seaside sparrow, and saltmarsh sharp-tailed sparrow, as well as feeding areas for herons, egrets, common tern, least tern, and black skimmer. In late May and early June, sanderlings, ruddy turnstones, semipalmated sandpipers, and red knots feed on horseshoe crab eggs near the mouth of Chingarora Creek. Low marsh along the backside of Sandy Hook spit provides forage and protection for the young of marine fishes, including winter flounder, Atlantic menhaden, bluefish, and striped bass, and critical habitat for characteristic

bird species of the low marsh such as clapper rail, willet, and marsh wren (USFWS, 1997).

Estuarine Beaches. Relatively few areas of estuarine beach remain in the New York City metropolitan area, and most have been modified or degraded (USFWS, 1997; Strange, 2008a). In Jamaica Bay, remaining estuarine beaches occur off Belt Parkway (*e.g.*, on Plumb Beach) and on the bay islands (USFWS, 1997). Sandy beaches are still relatively common along the shores of Staten Island from Tottenville to Ft. Wadsworth. The southern shoreline of Raritan Bay includes a number of beaches along Sandy Hook Peninsula and from the Highlands to South Amboy, some of which have been nourished. There are also beaches on small islands within the Shrewsbury-Navesink River system (USFWS, 1997).

Although limited in area, the remaining beaches support an extensive food web. Mud snails and wrack-based species (*e.g.*, insects, isopods, and amphipods) provide food for shorebirds including the piping plover, federally listed as threatened (USFWS, 1997). The beaches around Sandy Hook Bay have becoming important nestling places in winter for several species of seals (USFWS, 1997). The New Jersey Audubon Society reports that its members have observed gulls and terns at the Raritan Bay beach at Morgan on the southern shore, including some rare species such as black-headed gull, little gull, Franklin's gull, glaucous gulls, black tern, sandwich tern, and Hudsonian godwit. Horseshoe crabs lay their eggs on area beaches, supplying critical forage for shorebirds (Botton *et al*., 2006). The upper beach is used by nesting diamondback terrapins; human-made sandy trails in Jamaica Bay are also an important nest site for terrapins in the region, although the sites are prone to depredations by raccoons (Feinberg and Burke, 2003).

Tidal flats. Like beaches, tidal flats are limited in the New York City metropolitan region, but the flats that remain provide important habitat, particularly for foraging birds. Tidal flats are also habitat for hard and soft shell clams, which are important for recreational and commercial fishermen where not impaired by poor water quality. Large concentrations of shorebirds, herons, and waterfowl use the shallows and tidal flats of Piermont Marsh along the lower Hudson River as staging areas for both spring and fall migrations (USFWS, 1997). Tidal flats in Jamaica Bay are frequented by shorebirds and waterfowl, and an intensive survey of shorebirds in the mid-1980s estimated more than 230,000 birds of 31 species in a single year, mostly during the fall migration (Burger, 1984). Some 1,460 ha (3,600 ac) of intertidal flats extend offshore an average of 0.4 km (0.25 mi) from the south shore of the Raritan and Sandy Hook Bays, from the confluence of the Shrewsbury and Navesink Rivers, west to the mouth of the Raritan River. These flats are important foraging and staging areas for migrating shorebirds, averaging over 20,000 birds, mostly semipalmated plover, sanderling, and ruddy turnstone. The flats at the mouth of Whale Creek near Pirate's Cove attract gulls, terns, and shorebirds year round. Midwinter waterfowl surveys indicate that an average of 60,000 birds migrate through the Raritan Bay-Sandy Hook area in winter (USFWS, 1997). Inundation with rising seas will eventually make flats unavailable to short-legged shorebirds, unless they can shift feeding to marsh ponds and pannes (Erwin *et al.*, 2004). At the same time, disappearing saltmarsh islands in the area are transforming into intertidal mudflats. This may increase habitat for shorebirds at low tide, but it leaves less habitat for refuge at high tide (Strange, 2008a).

Shallow water habitat. This habitat is extensive in the Hudson River, from Stony Point south to Piermont Marsh, just below the Tappan Zee Bridge (USFWS, 1997). This area features the greatest mixing of ocean and freshwater, and concentrates nutrients and plankton, resulting in a high level of both primary and secondary productivity. Thus, this part of the Hudson provides key habitat for numerous fish and bird species. It is a major nursery area for striped bass, white perch, tomcod, and Atlantic sturgeon, and a wintering area for the federally endangered shortnose sturgeon. Waterfowl also feed and rest here during spring and fall migrations. Some submerged aquatic vegetation (SAV) is also found here, dominated by water celery, sago pondweed, and horned pondweed (USFWS, 1997).

Marsh and bay islands. Throughout the region, these islands are vulnerable to sea-level rise (Strange, 2008a). Between 1974 and 1994, the smaller islands of Jamaica Bay lost nearly 80 percent of their vegetative cover (Strange, 2008a, citing Hartig *et al.*, 2002). Island marsh deterioration in Jamaica Bay has led to a 50 percent decline in area between 1900 and 1994 (Gornitz *et al.*, 2002). Marsh loss has accelerated, reaching an average annual rate of 18 ha (45 ac) per year between 1994 and 1999 (Hartig *et al.*, 2002). The islands provide specialized habitat for an array of species:

- Regionally important populations of egrets, herons, and ibises are or have been located on North and South Brother islands in the East River and on Shooter's Island, Prall's Island, and Isle of Meadows in Arthur Kill and Kill van Kull (USFWS, 1997).
- North and South Brother Islands have the largest black crowned night heron colony in New York State, along with large numbers of snowy egret, great egret, cattle egret, and glossy ibis (USFWS, 1997).
- Since 1984, an average of 1,000 state threatened common tern have nested annually in colonies on seven islands of the Jamaica Bay Wildlife Refuge (USWFS, 1997).
- The heronry on Carnarsie Pol also supports nesting by great black-backed gull, herring gull, and American oystercatcher (USFWS, 1997).
- The only colonies of laughing gull in New York State, and the northernmost breeding extent of this species, occur on the islands of East High Meadow, Silver Hole Marsh, Jo Co Marsh, and West Hempstead Bay (USFWS, 1997).
- Diamondback terrapin nest in large numbers along the sandy shoreline areas of the islands of Jamaica Bay, primarily Ruler's Bar Hassock (USFWS, 1997).

A1.C. New Jersey Shore

The New Jersey shore has three types of ocean coasts (see Chapter 3 of this Product). At the south end, Cape May and Atlantic Counties have short and fairly wide "tide-dominated" barrier islands. Behind the islands, 253 sq km (97 sq mi) of marshes dominate the relatively small open water bays. To the north, Ocean County has "wave dominated" coastal barrier islands and spits. Long Beach Island is 29 km (18 mi) long and only two to three blocks wide in most places; Island Beach to the north is also long and narrow. Behind Long Beach Island and Island Beach lie Barnegat and Little Egg Harbor Bays. These shallow estuaries range from 2 to 7 km (about 1 to 4 mi) wide, and have 167 sq km (64 sq mi) of open water (USFWS, 1997) with extensive eelgrass, but only 125 sq km (48 sq mi) of tidal marsh (Jones and Wang, 2008). Monmouth County's ocean coast is entirely headlands, with the exception of Sandy Hook at the northern tip of the Jersey Shore. Non-tidal wetlands are immediately inland of the tidal wetlands along most of the mainland shore[77].

A1.C.1 Environmental Implications

There have been many efforts to conserve and restore species and habitats in the barrier island and back-barrier lagoon systems in New Jersey. Some of the larger parks and wildlife areas in the region include Island Beach State Park, Great Bay Boulevard State Wildlife Management Area, and the E.B. Forsythe National Wildlife Refuge (Forsythe Refuge) in Ocean and Atlantic counties. Parts of the Cape May Peninsula are protected by the Cape May National Wildlife Refuge (USFWS, undated[a]), the Cape May Point State Park (NJDEP, undated) and The Nature Conservancy's (TNC's) Cape May Migratory Bird Refuge (TNC, undated).

Tidal and Nearshore Nontidal Marshes. There are 18,440 ha (71 sq mi), 29,344 ha (113 sq mi), and 26,987 ha (104 sq mi) of tidal salt marsh in Ocean, Atlantic, and Cape May counties, respectively (Jones and Wang, 2008). The marshes in the study area are keeping

[77] For comprehensive discussions of the New Jersey shore and the implications of sea level rise, see Cooper *et al.* (2005), Lathrop and Love (2007), Najjar *et al.* (2000) and Psuty and Ofiara (2002)

pace with current local rates of sea-level rise of 4 millimeters (mm) per year, but are likely to become marginal with a 2 mm per year acceleration and be lost with a 7 mm per year acceleration, except where they are near local sources of sediments (*e.g.*, rivers such as the Mullica and Great Harbor rivers in Atlantic County) (Strange 2008b, interpreting the findings of Reed *et al*., 2008).

There is potential for wetland migration in Forsythe Refuge, and other lands that preserve the coastal environment such as parks and wildlife management areas. Conservation lands are also found along parts of the Mullica and Great Egg Harbor Rivers in Atlantic County. However, many estuarine shorelines in developed areas are hardened, limiting the potential for wetland migration (Strange, 2008b).

As marshes along protected shorelines experience increased tidal flooding, there may be an initial benefit to some species. If tidal creeks become wider and deeper fish may have increased access to forage on the marsh surface (Weinstein, 1979). Sampling of larval fishes in high salt marsh on Cattus Island, Beach Haven West, and Cedar Run in Ocean County showed that high marsh is important for mummichog, rainwater killifish, spotfin killifish, and sheepshead minnow (Talbot and Able, 1984). The flooded marsh surface and tidal and nontidal ponds and ditches appear to be especially important for the larvae of these species (Talbot and Able, 1984). However, as sea level rises, and marshes along hardened shorelines convert to open water, marsh fishes will lose access to these marsh features and the protection from predators, nursery habitat, and foraging areas provided by the marsh (Strange 2008b).

Loss of marsh area would also have negative implications for the dozens of bird species that forage and nest in the region's marshes. Initially, deeper tidal creeks and marsh pools will become inaccessible to short-legged shorebirds such as plovers (Erwin *et al.*, 2004). Long-legged waterbirds such as the yellow-crowned night heron, which forages almost exclusively on marsh crabs (fiddler crab and others), will lose important food resources (Riegner, 1982). Eventually, complete conversion of marsh to open water will affect the hundreds of thousands of shorebirds that stop in these areas to feed during their migrations. The New Jersey Coastal Management Program estimates that some 1.5 million migratory shorebirds stopover on New Jersey's shores during their annual migrations (Cooper *et al.*, 2005). Waterfowl also forage and overwinter in area marshes. Mid-winter aerial waterfowl counts in Barnegat Bay alone average 50,000 birds (USFWS, 1997). The tidal marshes of the Cape May Peninsula provide stopover areas for hundreds of thousands of shorebirds, songbirds, raptors, and waterfowl during their seasonal migrations (USFWS, 1997). The peninsula is also an important staging area and overwintering area for seabird populations. Surveys conducted by the U.S. Fish and Wildlife Service from July through December 1995 in Cape May County recorded more than 900,000 seabirds migrating along the coast (USFWS, 1997).

As feeding habitats are lost, local bird populations may no longer be sustainable (Strange, 2008b). For example, avian biologists suggest that if marsh pannes and pools continue to be lost in Atlantic County as a result of sea-level rise, the tens of thousands of shorebirds that feed in these areas may shift to feeding in impoundments in the nearby Forsythe Refuge. Such a shift would increase shorebird densities in the refuge ten-fold and reduce population sustainability due to lower per capita food resources and disease from crowding (Erwin *et al.*, 2006).

Local populations of marsh nesting bird species will also be at risk where marshes drown. This will have a particularly negative impact on rare species such as seaside and sharp-tailed sparrows, which may have difficulty finding other suitable nesting sites. According to a synthesis of published studies in Greenlaw and Rising (1994) and Post and Greenlaw (1994), densities in the region ranged from 0.3 to 20 singing males per hectare and 0.3 to 4.1 females per hectare for the seaside and sharp-tailed sparrows, respectively (Greenlaw and Rising, 1994). Loss and alteration of suitable marsh habitats are the primary conservation concerns for these and other marsh-nesting passerine birds (BBNEP, 2001).

Shore protection activities (nourishment and vegetation control) are underway to protect the vulnerable freshwater ecosystems of the Cape May Meadows (The Meadows), which are located behind the eroding dunes near Cape May Point (USACE, 2008a). Freshwater coastal ponds in The Meadows are found within about one hundred meters (a few hundred feet) of the shoreline and therefore could easily be inundated as seas rise. The ponds provide critical foraging and resting habitat for a variety of bird species, primarily migrating shorebirds (NJDEP, undated). Among the rare birds seen in The Meadows by local birders are buff-breasted sandpipers, arctic tern, roseate tern, whiskered tern, Wilson’s phalarope, black rail, king rail, Hudsonian godwit, and black-necked stilt (Kerlinger, undated). The Nature Conservancy, the United States Army Corps of Engineers (USACE), and the New Jersey Department of Environmental Protection

(NJDEP) have undertaken an extensive restoration project in the Cape May Migratory Bird Refuge, including beach replenishment to protect a mile-long stretch of sandy beach that provides nesting habitat for the piping plover (federally listed as threatened), creation of plover foraging ponds, and creation of island nesting sites for terns and herons (TNC, 2007).

Estuarine Beaches. Estuarine beaches are largely disappearing in developed areas where shoreline armoring is the preferred method of shore protection. The erosion or inundation of bay islands would also reduce the amount of beach habitat. Many species of invertebrates are found within or on the sandy substrate or beach wrack (seaweed and other decaying marine plant material left on the shore by the tides) along the tide line of estuarine beaches (Bertness, 1999). These species provide a rich and abundant food source for bird species. Small beach invertebrates include isopods and amphipods, blood worms, and beach hoppers, and beach macroinvertebrates include soft shell clams, hard clams, horseshoe crabs, fiddler crabs, and sand shrimp (Shellenbarger Jones, 2008a).

Northern diamondback terrapin nest on estuarine beaches in the Barnegat Bay area (BBNEP, 2001). Local scientists consider coastal development, which destroys terrapin nesting beaches and access to nesting habitat, to be one of the primary threats to diamondback terrapins, along with predation, road kills, and crab trap bycatch (Strange, 2008b, citing Wetland Institute [undated]).

Loss of estuarine beach could also have negative impacts on various beach invertebrates, including rare tiger beetles (Strange, 2008b). Two sub-species likely exist in coastal New Jersey: *Cicindela dorsalis dorsalis*, the northeastern beach tiger beetle, which is a federally listed threatened species and a state species of special concern and regional priority, and *Cicindela dorsalis media*, the southeastern beach tiger beetle, which is state-listed as rare (NJDEP, 2001). In the mid-1990s, the tiger beetle was observed on the undeveloped ocean beaches of Holgate and Island Beach. Current surveys do not indicate whether this species is also found on the area's estuarine beaches, but it feeds and nests in a variety of habitats (USFWS, 1997). The current abundance and distribution of the northeastern beach tiger beetle in the coastal bays is a target of research (State of New Jersey, 2005). At present, there are plans to reintroduce the species in the study region at locations where natural ocean beaches remain (State of New Jersey, 2005).

Tidal Flats. The tidal flats of New Jersey's back-barrier bays are critical foraging areas for hundreds of species of shorebirds, passerines, raptors, and waterfowl (BBNEP, 2001). Important shorebird areas in the study region include the flats of Great Bay Boulevard Wildlife Management Area, North Brigantine Natural Area, and the Brigantine Unit of the Forsythe Refuge (USFWS, 1997). The USFWS estimates that the extensive tidal flats of the Great Bay alone total 1,358 ha (3,355 ac). Inundation of tidal flats with rising seas would eliminate critical foraging opportunities for the area's abundant avifauna. As tidal flat area declines, increased crowding in remaining areas could lead to exclusion and mortality of many foraging birds (Galbraith *et al.*, 2002; Erwin *et al.*, 2004). Some areas may become potential sea grass restoration sites, but whether or not "enhancing" these sites as eelgrass areas is feasible will depend on their location, acreage, and sediment type (Strange, 2008b).

Shallow Nearshore Waters and Submerged Aquatic Vegetation (SAV). The Barnegat Estuary is distinguished from the lagoons to the south by more open water and SAV and less emergent marsh. Within the Barnegat Estuary, dense beds of eelgrass are found at depths under 1 m, particularly on sandy shoals along the backside of Long Beach Island and Island Beach, and around Barnegat Inlet, Manahawkin Bay, and Little Egg Inlet. Eelgrass is relatively uncommon from the middle of Little Egg Harbor south to Cape May, particularly locations where water depths are more than 1 m, such as portions of Great South Bay (USFWS, 1997).

Seagrass surveys from the 1960s through the 1990s indicate that there has been an overall decline in seagrass beds in Barnegat Estuary, from 6,823 ha (16,847 ac) in 1968 to an average of 5,677 ha (14,029 ac) during the period 1996 to 1998 (BBNEP, 2001). Numerous studies indicate that eelgrass has high ecological value as a source of both primary (Thayer *et al.*, 1984) and secondary production (Jackson *et al.*, 2001) in estuarine food webs. In Barnegat Estuary eelgrass beds provide habitat for invertebrates, birds, and fish that use the submerged vegetation for spawning, nursery, and feeding (BBNEP, 2001). Shallow water habitat quality may also be affected by adjacent shoreline protections. A Barnegat Bay study found that where shorelines are bulkheaded, SAV, woody debris, and other features of natural shallow water habitat are rare or absent, with a resulting reduction in fish abundance (Byrne, 1995).

Marsh and Bay Islands. Large bird populations are found on marsh and dredge spoil islands of the New Jersey back-barrier bays. These islands include nesting sites protected from predators for a number species of conservation concern, including gull-billed tern, common tern, Forster's tern, least tern, black skimmer, American oystercatcher, and piping plover (USFWS, 1997). Diamondback terrapins are also known to feed on marsh islands in the bays (USFWS, 1997).

Some of the small islands in Barnegat Bay and Little Egg Harbor extend up to about 1 m above spring high water (Jones and Wang, 2008), but portions of other islands are very low, and some low islands are currently disappearing. Mordecai (MLT, undated) and other islands (Strange, 2008b) used by nesting common terns, Forster's terns, black skimmers, and American oystercatchers are vulnerable to sea-level rise and erosion (MLT, undated). With the assistance of local governments, the Mordecai Land Trust is actively seeking grants to halt the gradual erosion of Mordecai Island, an 18-ha (45-ac) island just west of Beach Haven on Long Beach Island (MLT, undated). Members of the land trust have documented a 37 percent loss of island area since 1930. The island's native salt marsh and surrounding waters and SAV beds provide habitat for a variety of aquatic and avian species. NOAA National Marine Fisheries Service considers the island and its waters Essential Fish Habitat for spawning and all life stages of winter flounder as well as juvenile and adult stages of Atlantic sea herring, bluefish, summer flounder, scup, and black sea bass (MLT, undated). The island is also a strategically-located nesting island for many of New Jersey's threatened and endangered species, including black skimmers, least terns, American bitterns, and both yellow-crowned and black-crowned night herons (MLT, 2003).

Sea-level fens. New Jersey has identified 12 sea-level fens, encompassing 126 acres. This rare ecological community is restricted in distribution to Ocean County, New Jersey, between Forked River and Tuckerton, in an area of artesian groundwater discharge from the Kirkwood-Cohansey aquifer. Additional recent field surveys have shown possible occurrences in the vicinity of Tuckahoe in Cape May and Atlantic counties (Walz *et al.*, 2004). These communities provide significant wetland functions in the landscape as well as supporting 18 rare plant species, of which one is state-listed as endangered. (Walz *et al.*, 2004).

A1.C.2 Development, Shore Protection, and Coastal Policies

At least five state policies affect the response to sea-level rise along New Jersey's Atlantic Coast: the Coastal Facility Review Act, the Wetlands Act, the State Plan, an unusually strong public trust doctrine, and the state's strong support for beach nourishment—and opposition to both erosion-control structures and shoreline retreat—along ocean shores. This section discusses the latter policy; the first four are discussed in Section A1.D.2 of this Appendix.

In 1997, then-Governor Whitman promised coastal communities that "there will be no forced retreat," and that the government would not force people to leave the shoreline. That policy does not necessarily mean that there will always be government help for shore protection. Nevertheless, although subsequent administrations have not expressed this view so succinctly, they have not withdrawn the policy either. In fact, the primary debate in New Jersey tends to be about the level of public access required before a community is eligible to receive beach nourishment, not the need for shore protection itself (see Chapter 8 of this Product).

With extensive development and tourism along its shore, New Jersey has a well-established policy in favor of shore protection along the ocean[78]. The state generally prohibits new hard structures along the ocean front; but that was not always the case. A large portion of the Monmouth County shoreline was once protected with seawalls, with a partial or total loss of beach (Pilkey *et al.*, 1981). Today, beach nourishment is the preferred method for reversing beach erosion and providing ocean front land with protection from coastal storms (Mauriello, 1991). The entire Monmouth County shoreline now has a beach in front of the old seawalls. Beach nourishment has been undertaken or planned for at least one community in every coastal county from Middlesex along Raritan Bay, to Salem along the Delaware River. Island Beach State Park, a barrier spit along the central portion of Barnegat Bay just north of Long Beach Island, is heavily used by New Jersey residents and includes the official beach house of the Governor. Although it is a state park, it is currently included in the authorized USACE Project for beach nourishment from Manasquan to Barnegat Inlet. In the case of Cape May Meadows[79],

[78] For example, the primary coastal policy document during the Whitman administration suggested that even mentioning the term "retreat" would divide people and impede meaningful discussion of appropriate policies, in part because retreat can mean government restrictions on development or simply a decision by government not to fund shore protection (see NJDEP, 1997). Governor Whitman promised coastal mayors and residents that "there will be no forced retreat."

[79] The Meadows are within Cape May Point State Park and the Nature Conservancy's Cape May Migratory Bird Refuge.

environmental considerations have prompted shore protection efforts (USACE, 2008a). The area's critical freshwater ecosystem is immediately behind dunes that have eroded severely as a result of the jetties protecting the entrance to the Cape May Canal.

Some coastal scientists have suggested the possibility of disintegrating barrier islands along the New Jersey shore (see Chapter 3). Although the bay sides of these islands are bulkheaded, communities are unlikely to seriously consider the option of being encircled by a dike as sea level rises (see Box A1.2). Nevertheless, Avalon uses a combination of floodwalls and checkvalves to prevent tidal flooding; and Atlantic City's stormwater management system includes underground tanks with checkvalves. These systems have been implemented to address current flooding problems; but they would also be a logical first step in a strategy to protect low-lying areas with structural solutions as sea level rises[80]. Other authors have suggested that a gradual elevation of barrier islands is more likely (see Box A1.2).

Wetlands along the back-barrier bays of New Jersey's Atlantic coast are likely to have some room to migrate inland, because they are adjacent to large areas of non-tidal wetlands. One effort at the state level to preserve such coastal resources is the state's Stormwater Management Plan, which establishes a special water resource protection area that limits development within 91.4 m (300 ft) along most of its coastal shore (NJDEP DWM, 2004). Although the primary objective of the regulation is to improve coastal water quality and reduce potential flood damage, it serves to preserve areas suitable for the landward migration of wetlands.

[80] See Chapter 5 of this Product for explanation of structural mechanisms to combat flooding.

BOX A1.2: Shore Protection on Long Beach Island

The effects of sea-level rise can be observed on both the ocean and bay sides of this 29-km (18-mi) long barrier island. Along the ocean side, shore erosion has threatened homes in Harvey Cedars and portions of Long Beach township. During the 1990s, a steady procession of dump trucks brought sand onto the beach from inland sources. In 2007, the USACE began to restore the beach at Surf City and areas immediately north. The beach had to be closed for a few weeks, however, after officials discovered that munitions (which had been dumped offshore after World War II) had been inadvertently pumped onto the beach.

High tides regularly flood the main boulevard in the commercial district of Beach Haven, as well as the southern two blocks of Central Avenue in Ship Bottom. Referring to the flooded parking lot during spring tides, the billboard of a pizza parlor in Beach Haven Crest boasts "Occasional Waterfront Dining."

U.S. EPA's 1989 Report to Congress used Long Beach Island as a model for analyzing alternative responses to rising sea level, considering four options: a dike around the island, beach nourishment and elevating land and structures, an engineered retreat which would include the creation of new bayside lands as the ocean eroded, and making no effort to maintain the island's land area (U.S. EPA, 1989; Titus *et al*., 1991). Giving up the island was the most expensive option (Weggel *et al*., 1989; Titus, 1990). The study concluded that a dike would be the least expensive in the short run, but unacceptable to most residents due to the lost view of the bay and risk of being on a barrier island below sea level (Titus, 1990). In the long run, fostering a landward migration would be the least expensive, but it would unsettle the expectations of bay front property owners and hence require a lead time of a few generations between being enacted and new bayside land actually being created. Thus, the combination of beach nourishment and elevating land and structures appeared to be the most realistic, and U.S. EPA used that assumption in its nationwide cost estimate (U.S. EPA, 1989; Titus *et al*., 1991).

Long Beach Township, Ship Bottom, Harvey Cedars, and Beach Haven went through a similar thinking process in considering their preferred response to sea-level rise. In resolutions enacted by their respective councils, they concluded that a gradual elevation of their communities would be preferable to either dikes or the retreat option. In the last ten years, several structural moving companies have had ongoing operations, continually elevating homes (see Figure 12.5).

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Box Figure A1.2 Street flooding in Long Beach Island, New Jersey at one of the higher tides.

A1.D. Delaware Estuary

A1.D.1 Environmenal Implications

On both sides of Delaware Bay, most shores are either tidal wetlands or sandy beaches with tidal wetlands immediately behind them. In effect, the sandy beach ridges are similar to the barrier islands along the Atlantic, only on a smaller scale. Several substantial communities with wide sandy beaches on one side and marsh on the other side are along Delaware Bay—especially on the Delaware side of the bay. Although these communities are potentially vulnerable to inundation, shoreline erosion has been a more immediate threat to these communities. Detailed discussions of the dynamics of Delaware shorelines are found in Kraft and John (1976).

Delaware Bay is home to hundreds of species of ecological, commercial, and recreational value (Dove and Nyman, 1995). Unlike other estuaries in the Mid-Atlantic, the tidal range is greater than the ocean tidal range, generally about 2 m. In much of Delaware Bay, tidal marshes appear to be at the low end of their potential elevation range, increasing their vulnerability to sea-level rise (Kearney *et al.*, 2002). Recent research indicates that 50 to 60 percent of Delaware Bay's tidal marsh has been degraded, primarily because the surface of the marshes is not rising as fast as the sea (Kearney *et al.*, 2002). One possible reason is that channel deepening projects and consumptive withdrawals of fresh water have changed the sediment supply to the marshes (Sommerfield and Walsh, 2005). Many marsh restoration projects are underway in the Delaware Bay (*cf*. Teal and Peterson, 2005): dikes have been removed to restore tidal flow and natural marsh habitat and biota; however, in some restoration areas invasion by common reed (*Phragmites australis)* has been a problem (Abel and Hagan, 2000; Weinstein *et al.*, 2000).

The loss of tidal marsh as sea level rises would harm species that depend on these habitats for food and shelter, including invertebrates, finfish, and a variety of bird species (Kreeger and Titus, 2008). Great blue herons, black duck, blue and green-winged teal, Northern harrier, osprey, rails, red winged blackbirds, widgeon, and shovelers all use the salt marshes in Delaware Bay. Blue crab, killifish, mummichog, perch, weakfish, flounder, bay anchovy, silverside, herring, and rockfish rely on tidal marshes for feeding on the mussels, fiddler crabs, and other invertebrates and for protection from predators (Dove and Nyman, 1995).

Delaware Bay is a major stopover area for six species of migratory shorebirds, including most of the Western Hemisphere's population of red knot (USFWS, 2003). On their annual migrations from South America to the Arctic, nearly a million shorebirds move through Delaware Bay, where they feed heavily on invertebrates in tidal mudflats, and particularly on horseshoe crab eggs on the bay's sandy beaches and foreshores (Walls *et al.*, 2002). Horseshoe crabs have been historically abundant on the Delaware Bay shores. A sea-level rise modeling study estimated that a 6-centimeter (cm) (2-ft) rise in relative sea level over the next century could reduce shorebird foraging areas in Delaware Bay by 57 percent or more by 2100 (Galbraith *et al.*, 2002).

Invertebrates associated with cordgrass stands in the low intertidal zone include grass shrimp, ribbed mussel, coffee-bean snail, and fiddler crabs (Kreamer, 1995). Blue crab, sea turtles, and shorebirds are among the many species that prey on ribbed mussels; fiddler crabs are an important food source for bay anchovy and various species of shorebirds (Kreamer, 1995). Wading birds such as the glossy ibis feed on marsh invertebrates (Dove and Nyman, 1995). Waterfowl, particularly dabbling ducks, use low marsh areas as a wintering ground.

Sandy beaches and foreshores account for the majority of the Delaware and New Jersey shores of Delaware Bay. As sea level rises, beaches can be lost if either shores are armored or if the land behind the existing beach has too little sand to sustain a beach as the shore retreats (Nordstrom, 2005). As shown in Table A1.1, so far only 4 percent (Delaware) and 6 percent (New Jersey) of the natural shores have been replaced with shoreline armoring. Another 15 percent (Delaware) and 4 percent (New Jersey) of the shore is developed. Although conservation areas encompass 58 percent of Delaware Bay's shores, they include only 32 percent of beaches that are optimal or suitable habitat for horseshoe crabs (Kreeger and Titus, 2008).

Beach nourishment has been relatively common along the developed beach communities on the Delaware side of the bay. Although beach nourishment can diminish the quality of habitat for horseshoe crabs, nourished beaches are more beneficial than an armored shore; most beach nourishment along the New Jersey shore of Delaware Bay has been justified by environmental benefits (Kreeger and Titus, 2008; USACE 1998b,,c).

Table A1.1 The shores of Delaware Bay: Habitat type and conservation status of shores suitable for horseshoe crabs.

Shoreline length	Delaware		New Jersey		New Jersey and Delaware
By Habitat Type (percent of bay shoreline	km	%	km	%	%
Beach	68	74	62	42	54
Armored Shore	3.7	4	8.3	6	5
Organic	20	22	78	53	41
Total Shoreline	91	100	148	100	100
By Indicator of Future Shore Protection (km)					
Shore Protection Structures	2.7	2.9	5.1	3.4	3
Development	13	15	5.7	3.8	8
By Suitability for Horseshoe Crab (percent of Bay shoreline					
Optimal Habitat	31.3	34	26.0	18	24
Suitable Habitat	10.5	12	5.1	3.5	6.6
Less Suitable Habitat	29.0	32	49.0	33	33
Unsuitable Habitat	20.0	22	67.0	46	37
Within Conservations Lands by Suitability for Horseshoe Crab (percent of equally suitable lands)					
Optimal Habitat	12.9	41	9.6	37	39
Optimal and Suitable Habitat	13.6	33	9.8	32	32
Optimal, Suitable, and Less Suitable Habitat	32.2	46	43.3	54	50
All Shores	44.7	49	92.7	63	58
Source: Kreeger and Titus (2008), compiling data developed by Lathrop et al. (2006).					

Many Delaware Bay beaches have a relatively thin layer of sand. Although these small beaches currently have enough sand to protect the marshes immediately inland from wave action, some beaches may not be able to survive accelerated sea-level rise even in areas without shoreline armoring, unless artificial measures are taken to preserve them (Kreeger and Titus (2008). For example, Delaware has already nourished beaches with the primary purpose of restoring horseshoe crab habitat (Smith *et al.*, 2002) (see Box A1.3.).

BOX A1.3: Horseshoe Crabs and Estuarine Beaches

The Atlantic horseshoe crab (*Limulus polyphemus)*, an ancient species that has survived virtually unchanged for more than 350 million years, enters estuaries each spring to spawn along sandy beaches. The species has experienced recent population declines, apparently due to overharvesting as well as habitat loss and degradation (Berkson and Shuster, 1999).

Population Status and Sea-Level Rise

In Delaware Bay, as elsewhere along its range, horseshoe crabs depend on narrow sandy beaches and the alluvial and sand bar deposits at the mouths of tidal creeks for essential spawning habitat. A product of wave energy, tides, shoreline configuration, and over longer periods, sea-level rise, the narrow sandy beaches utilized by horseshoe crabs are diminishing at sometimes alarming rates due to beach erosion as a product of land subsidence and sea-level increases (Nordstrom, 1989; Titus *et al.*, 1991). At Maurice Cove in Delaware Bay, for example, portions of the shoreline have eroded at a rate of 4.3 m per year between 1842 and 1992 (Weinstein and Weishar, 2002); an estimate by Chase (1979) suggests that the shoreline retreated 150 m landward in a 32-year period, exposing ancient peat deposits that are believed to be suboptimal spawning habitat (Botton *et al.*, 1988). If human infrastructure along the coast leaves estuarine beaches little or no room to transgress inland as sea level rises, concomitant loss of horseshoe crab spawning habitat is likely (Galbraith *et al.*, 2002). Kraft *et al.* (1992) estimated this loss, along with wetland "drowning", as greater than 90 percent in Delaware Bay (about 33,000 ha).

Horseshoe Crab Spawning and Shorebird Migrations

Each spring, horseshoe crab spawning coincides with the arrival of hundreds of thousands of shorebirds migrating from South America to their sub-Arctic nesting areas. While in Delaware Bay, shorebirds feed extensively on horseshoe crab eggs to increase their depleted body mass before continuing their migration (Castro and Myers, 1993; Clark, 1996). Individual birds may increase their body weight by nearly one-third before leaving the area. There is a known delicate relationship between the horseshoe crab and red knots (Baker *et al*., 2004). How other shorebirds might be affected by horseshoe crab population decline is uncertain (Smith *et al.*, 2002).

Numerous other animals, including diamondback terrapins, and Kemp's ridley sea turtles, rely on the sandy beaches of Delaware Bay to lay eggs or forage on invertebrates such as amphipods and clams. When tides are high, numerous fish also forage along the submerged sandy beaches, such as killifish, mummichog, rockfish, perch, herring, silverside, and bay anchovy (Dove and Nyman, 1995).

A1.D.2 Development, Shore Protection, and Coastal Policies

A1.D.2.1 New Jersey

Policies that may be relevant for adapting to sea-level rise in New Jersey include policies related to the Coastal Facility Review Act (CAFRA), the (coastal) Wetlands Act of 1970, the State Plan, an unusually strong public trust doctrine, and strong preference for beach nourishment along the Atlantic Ocean over hard structures or shoreline retreat. This Section discusses the first four of these policies (nourishment of ocean beaches is discussed in Section A1.C of this Appendix).

CAFRA applies to all shores along Delaware Bay and the portion of the Delaware River south of Killcohook National Wildlife Area, as well as most tidal shores along the tributaries to Delaware Bay. The act sometimes limits development in the coastal zone, primarily to reduce runoff of pollution into the state's waters (State of New Jersey, 2001). Regulations promulgated under the Wetlands Act of 1970 prohibit development in tidal wetlands unless the development is water-dependent and there is no prudent alternative (NJAC 7:7E-2.27 [c]). Regulations prohibit development of freshwater wetlands under most circumstances (NJAC 7:7E-2.27 [c]). The regulations also prohibit development within 91.4 m (300 ft of tidal wetland, unless the development has no significant adverse impact on the wetlands (NJAC 7:7-3.28 [c]). These regulations, like Maryland's Critical Areas Act (see Section A1.E.2), may indirectly reduce the need for shore protection by ensuring that homes are set back farther from the shore than would otherwise be the case (NOAA 2007, see Section 6.2 in Chapter 6). For the same reason, existing restrictions of development in nontidal wetlands (see Section 10.3) may also enable tidal wetlands to migrate inland.

The New Jersey state plan provides a statewide vision of where growth should be encouraged, tolerated, and discouraged—but local government has the final say. In most areas, lands are divided into five planning areas. The state encourages development in (1) metropolitan and (2) suburban planning areas, and in those (3) fringe planning areas that are either already developed or part of a well-designed new development. The state discourages development in most portions of (4) rural planning areas and (5) land with valuable ecosystems, geologic features, or wildlife habitat, including coastal wetlands and barrier spits/islands (State of New Jersey, 2001). However, even these areas include developed enclaves, known as "centers" where development is recognized as a reality (State of New Jersey, 2001). The preservation of rural and natural landscapes in portions of planning areas (4) and (5) is likely to afford opportunities for wetlands to migrate inland as sea level rises. Nevertheless, New Jersey has a long history of building dikes along Delaware Bay and the Delaware River to convert tidal wetlands to agricultural lands (see Box 5.1) and dikes still protect some undeveloped lands.

BOX A1.4: The Gibbstown Levee, New Jersey

The Gibbstown Levee along the Delaware River in New Jersey once served a function similar to the dikes in Cumberland County, preventing tidal inundation and lowering the water table to a level below mean sea level. When the dike was built 300 years ago (USACE, undated[a]), the tides were 1 m lower and the combination dike and tide gate kept the water levels low enough to permit cultivation. But rising sea level and land subsidence have left this land barely above low tide, and many lands drain too slowly to completely drain during low tide. Hence, farmland has converted to non-tidal wetland.

By keeping the creek a meter or so lower than it would be if it rose and fell with the tides, the levee improves drainage during rainstorms for Greenwich Township. Nevertheless, it is less effective today than when the sea was 50 to 100 cm lower. During extreme rainfall, the area can flood fairly easily because the tide gates have to be closed most of the day. Heavy rain during a storm surge is even more problematic because for practical purposes there is no low tide to afford the opportunity to get normal drainage by opening the tide gate. Evacuations were necessary during hurricane Floyd when part of this dike collapsed as a storm tide brought water levels of more than ten feet above mean low water (NCDC, 1999).

Officials in Greenwich Township are concerned that the dikes in Gloucester County are in danger of failing. "The Gibbstown Levee was repaired in many places in 1962 by the U.S. Army Corps of Engineers under Public Law 84-99" (USACE, 2004). Part of the problem appears to be that most of these dikes are the responsibility of meadow companies originally chartered in colonial times. These companies were authorized to create productive agricultural lands from tidal marshes. Although harvests of salt hay once yielded more than enough revenue to maintain the dikes, this type of farming became less profitable during the first half of the twentieth century. Moreover, as sea level has continued to rise, the land protected by the dikes has mostly reverted to marsh (Weinstein *et al.*, 2000; Abel *et al*., 2000). Revenues from these lands, if any, are insufficient to cover the cost of maintaining the dikes (DiMuzio, 2006). As a result, the dikes are deteriorating, leading officials to fear a possible catastrophic dike failure during storm, or an increase in flood insurance rates (DELO, 2006). The officials hope to obtain federal funding (DELO, 2006).

Even if these dikes and their associated tide gates are fortified, the dry land will gradually be submerged unless pumping facilities are installed (see Section 6.2 in Chapter 6), because much of the area is barely above low tide even today (Titus and Wang 2008). Although freshwater marshes in general seem likely to be able to keep pace with rising sea level (Reed *et al.*, 2008), wetlands behind dikes do not always fare as well as those exposed to normal tidal currents (Reed *et al*., 2008). Over longer periods of time, increases in salinity of the Delaware River resulting from rising sea level and reduced river flows during droughts could enable saltwater to invade these fresh marshes (Hull and Titus, 1986), which would convert them to open water ponds.

If pumping facilities are not sufficient for a daily pumping of all the very low lands protected by the dikes, the primary impact of the dikes could be to prevent flooding from storm surges and ordinary tides. For the isolated settlements along Marsh Dike Road and elsewhere, elevating homes and land surfaces may be possible; although property values are less than along the barrier islands, sources for fill material are closer. One could envision that Gibbstown, Bridgetown, and other more populated communities could be encircled with a ring dike with a pumping system that drains only the densely developed area; or they too may elevate land as the sea rises.

In Cumberland County, salt marsh has been reclaimed for agricultural purposes for more than 200 years (Sebold, 1992 and references therein). Over the last few decades, many of the dikes that were constructed have been dismantled. Some have failed during storms. Others have been purchased by conservation programs seeking to restore wetlands, most notably Public Service Enterprise Group (PSEG) in its efforts to offset possible environmental effects of a nuclear power plant. Although the trend is for dike removal, the fact that diked farms have been part of the landscape for centuries leads one to the logical inference that dikes may be used to hold back a rising sea once again. Cumberland County has relatively little coastal development, yet the trend in coastal communities that have not become part of a conservation program has been for a gradual retreat from the shore. Several small settlements along Delaware Bay are gradually being abandoned.

The state plan contemplates a substantial degree of agricultural and environmental preservation along the Delaware River and its tidal tributaries in Salem and lower Gloucester County. An agricultural easement program in Gloucester County reinforces that expectation. Farther up the river, in the industrial and commercial areas, most of the shoreline is already bulkheaded, to provide the vertical shore that facilitates docking—but the effect is also to stop coastal erosion. The eventual fate of existing dikes, which protect lightly developed areas, is unclear (Box A1.4).

The public trust doctrine in New Jersey has two unique aspects. First, the public has an easement along the dry beach between mean high water and the vegetation line. Although other states have gradually acquired these easements in most recreational communities, few states have general access along the dry beach. As a result, people are entitled to walk along river and bay beaches. The laws of Delaware and Pennsylvania, by contrast, grant less public access along the shore. In most states, the public owns the land below mean high water. In these two states, the public owns the land below mean low water. The public has an easement along the wet beach between mean low and mean high water, but only for navigation, fishing, and hunting—not for recreation (see Chapter 8 of this Product for additional details)

Second, the New Jersey Supreme Court has held that the public is entitled to perpendicular access to the beach[81]. The holding does not mean that someone can indiscriminately walk across any landowner's property to get to the water, but it does require governments to take prudent measures to ensure that public access to the water accompanies new subdivisions[82].

As trustee, the New Jersey Department of Environmental Protection has promulgated rules preserving the public trust rights to parallel and perpendicular access. The regulations divide new construction (including shore protection structures) into three classes: single family homes (or duplexes); development with two or three homes; and all other residential and nonresidential development. Along most of the tidal Delaware River, any development other than a single family home requires a public walkway at least 3 m (10 ft) wide along the shore. By contrast, along Delaware Bay, areas where one

[81] Matthews v Bay Head Improvement Association, 471 A.2d 355. Supreme Court of NJ (1984).
[82] Federal law requires similar access before an area is eligible for beach nourishment.

might walk along the beach rather than require a walkway, the regulations have a more general requirement for public access. (See Table A1.2).

Table A1.2 New Jersey Regulatory Requirements for (Parallel) Access along, and (Perpendicular) to the Shore for New Development or Shore Protection Structures Along Delaware Estuary.

	Single Family[4]	Two or Three Residential Structures[5]	All other Development[6]
Designated Urban Rivers[1]	No requirement	*Along the shore*: 20-ft preservation buffer, including 10-ft wide walkway *To the shore*: 10-ft wide walkway every half mile.	*Along the Shore*: 30-ft preservation buffer, including 16-ft wide walkway *To the Shore*: 20-ft wide preservation buffer, including 10-ft wide walkway, every half mile
Beaches along Major Bodies of Water[2]	Access along and to the beach is required.	Access along and to the beach is required.	Access along and to the beach is required.
All other coastal areas (except Hudson River)	No requirement	Alternative access on site or nearby.	Access along the beach and shore is required.

[1] Within this region, Cohansey River within Bridgeton, Maurice River within Millville, and Delaware River from the CAFRA boundary upstream to the Trenton Makes Bridge (Trenton). Also applies to Arthur Kill, Kill Van Kull west of Bayonne Bride, Newark Bay, Elizabeth Riber, Hackwnsask River, Rahway River, and Raritan River.
[2] Delaware Bay within this region. Also Atlantic Ocean, Sandy Hook Bay, and Raritan Bay.
[3] See Section B of this Appendix for Hudson River requirements.
[4] NJAC 7:7E-8.11 (f)(6-7)
[5] NJAC 7:7E-8.11 (f)(4-5)
[6] NJAC 7:7E-8.11 (d-e)

A1.D.2.2 Delaware

Kent County does not permit subdivisions—and generally discourages most development—in the 100-year coastal floodplain, as does New Castle County south of the Chesapeake and Delaware Canal[83]. Because the 100-year floodplain for storm surge extends about 2 m above spring high water, which is often more than one kilometer inland, the floodplain regulations often require a greater setback than the erosion-hazard (see *e.g.*, A1.G.2) and environmental (*e.g.*, A1.E.2 and A1.F.2) setbacks elsewhere in the mid-Atlantic. Thus, a greater amount of land may be available for potential wetland

[83] See Kent County Ordinances § 7.3 and New Castle Ordinance 40.10.313

migration (see Section 6.2 in Chapter 6). Nevertheless, if sea level continues to rise, it is logical to assume that this buffer would not last forever.

Preservation easements and land purchases have also contributed to a major conservation buffer (DDA, 2008), which would leave room for wetlands to migrate inland as sea level rises (see Chapter 6.2). The state is purchasing agricultural preservation easements in the coastal zone, and a significant portion of the shore is in Prime Hook or Bombay Hook National Wildlife Refuge. The majority of the shore south of the canal is part of some form of preservation or conservation land.

A1.D.2.3 Pennsylvania

Pennsylvania[84] is the only state in the nation along tidal water without an ocean coast[85]. As a result, the state's sensitivity to sea-level rise is different than other states. Floods in the tidal Delaware River are as likely to be caused by extreme rainfall over the watershed as storm surges. The Delaware River is usually fresh along almost all of the Pennsylvania shore. Because Philadelphia relies on freshwater intakes in the tidal river, the most important impact may be the impact of salinity increases from rising sea level on the city's water supply (Hull and Titus, 1986).

The state of Pennsylvania has no policies that directly address the issue of sea-level rise[86]. Nevertheless, the state has several coastal policies that might form the initial basis

[84] This section only addresses the Pennsylvania side of the river because Section C in this Appendix addressed the policy context for shore protection in New Jersey.
[85] This statement also applies to the District of Columbia.
[86] Philadelphia's flood regulations do consider sea level rise.

for a response to sea-level rise, including state policies on tidal wetlands and floodplains, public access, and redeveloping the shore in response to the decline of water-dependent industries.

Tidal Wetlands and Floodplains

Pennsylvania's Dam Safety and Waterway Management Rules and Regulations[87] require permits for construction in the 100-year floodplain or wetlands. The regulations do not explicitly indicate whether landowners have a right to protect property from erosion or rising water level. A permit for a bulkhead or revetment seaward of the high-water mark can be awarded only if the project will not have a "significant adverse impact" on the "aerial extent of a wetland" or on a "wetland's values and functions". A bulkhead seaward of the high-water mark, however, eliminates the tidal wetlands on the landward side. If such long-term impacts were viewed as "significant," permits for bulkheads could not be awarded except where the shore was already armored. But the state has not viewed the elimination of mudflats or beaches as "significant" for purposes of these regulations; hence it is possible to obtain a permit for a bulkhead.

The rules do not restrict construction of bulkheads or revetments landward of the high water mark. However, they do prohibit permits for any "encroachment located in, along, across or projecting into a wetland, unless the applicant affirmatively demonstrates that…the … encroachment will not have an adverse impact on the wetland…"[88].

[87] These regulations were issued pursuant to the Dam Safety and Encroachment Act of 1978. Laws of Pennsylvania, The Dam Safety and Encroachments Act of November 26, 1978, P.L. 1375, No. 325.
[88] Pennsylvania Code, Chapter 105. Dam Safety and Waterway Management, Pennsylvania Department of Environmental Protection, 1997. Subchapter 105.18b.

Therefore, shoreline armoring can eliminate coastal wetlands (or at least prevent their inland expansion[89]) as sea level rises by preventing their landward migration. Like the shore protection regulations, Pennsylvania's Chapter 105 floodplains regulations consider only existing floodplains, not the floodplains that would result as the sea rises.

Public Access

Public access for recreation is an objective of the Pennsylvania Coastal Zone Management program. This policy, coupled with ongoing redevelopment trends in Pennsylvania, may tend to ensure that future development includes access along the shore. If the public access is created by setting development back from the shore, it may tend to also make a gradual retreat possible. If keeping public access is a policy goal of the governmental authority awarding the permit for shore protection, then public access need not be eliminated, even if shores are armored (see Titus, 1998 and Table A1.2).

Development and Redevelopment

Industrial, commercial, residential, recreational, wooded, vacant, transportation, and environmental land uses all occupy portions of Pennsylvania's 100-km coast. Generally speaking, however, the Pennsylvania coastal zone is consistently and heavily developed. Only about 18 percent of the coastal area is classified as undeveloped (DVRPC, 2003a).

[89] Chapter 3 of this Product concludes that most tidal wetlands in Pennsylvania are likely to keep pace with projected rates of sea level rise. However, that finding does not address erosion of wetlands at their seaward boundary. Even though wetlands can keep vertical pace with the rising water level, narrow fringing wetlands along rivers can be eliminated by shoreline armoring as their seaward boundaries erode and their landward migration is prevented. Moreover, even where the seaward boundary keeps pace, preventing an expansion of wetlands might be viewed as significant.

Much of the shoreline has been filled or modified with bulkheads, docks, wharfs, piers, bulkheads, revetments and other hard structures over the past two centuries.

The Pennsylvania coast is moving from an industrial to a post-industrial landscape. The coastal zone is still dominated by manufacturing and industrial land uses, but a steady decline in the industrial economy over the past 60 years has led to the abandonment of many industrial and manufacturing facilities. Some of these facilities sit empty and idle; others have been adapted for uses that are not water dependent.

A majority of Pennsylvania's Delaware River shore is classified as developed, but sizable expanses (especially near the water) are blighted and stressed (DVRPC, 2003b; U.S. Census Bureau, 2000). Because of the decaying industrial base, many residential areas along the Delaware River have depressed property values, declining population, high vacancy rates, physical deterioration, and high levels of poverty and crime (DVRPC, 2003b; U.S. Census Bureau, 2000). Many—perhaps most—of the refineries, chemical processing plants, and other manufacturing facilities that operate profitably today may close in the next 50 to 100 years. (Pennsylvania, 2006)

New paradigms of waterfront development have emerged that offer fresh visions for southeastern Pennsylvania's waterfront. In late 2001, Philadelphia released the Comprehensive Redevelopment Plan for the North Delaware Riverfront—a 25-year redevelopment vision for a distressed ten-mile stretch of waterfront led by the design firm Field Operations. Delaware County, meanwhile, developed its Delaware County Coastal

Zone Compendium of Waterfront Provisions (1998) to guide revitalization efforts along its coast. Likewise, Bucks County just finished a national search for a design firm to create a comprehensive plan outlining the revitalization of its waterfront. Meanwhile, the Schuylkill River Development Corporation produced the Tidal Schuylkill River Master Plan.

All of these plans and visions share common elements. They view the region's waterfronts as valuable public amenities that can be capitalized on, and they view the estuary as something for the region to embrace, not to turn its back on. They emphasize public access along the water's edge, the creation of greenways and trails, open spaces, and the restoration of natural shorelines and wetlands where appropriate (DRCC, 2006).

A1.E. The Atlantic Coast of Virginia, Maryland, and Delaware (including coastal bays)

Between Delaware and Chesapeake Bays is the land commonly known as the Delmarva Peninsula. The Atlantic coast of the Delmarva consists mostly of barrier islands separated by tidal inlets of various sizes (Theiler and Hammar-Klose, 1999; Titus *et al.*, 1985). Behind these barrier islands, shallow estuaries and tidal wetlands are found. The large area of tidal wetlands behind Virginia's barrier islands to the south are mostly mudflats; marshes and shallow open water are more common in Maryland and adjacent portions of Virginia and Delaware. The barrier islands themselves are a small portion of the low land in this region (Titus and Richman, 2001). The northern portion of the Delaware shore consists of headlands, rather than barrier islands (see Chapter 3 of this Product).

A1.E.1 Environmental Implications

*Tidal Marshes and Marsh Islands***.** The region's tidal marshes and marsh-fringed bay islands provide roosting, nesting, and foraging areas for a variety of bird species, both common and rare, including shorebirds (piping plover, American oystercatcher, spotted sandpiper), waterbirds (gull-billed, royal, sandwich, and least terns and black ducks) and wading birds such as herons and egrets (Conley, 2004). Particularly at low tide, the marshes provide forage for shorebirds such as sandpipers, plovers, dunlins, and sanderlings (Burger *et al*., 1997). Ducks and geese, including Atlantic brants, buffleheads, mergansers, and goldeneyes, overwinter in the bays' marshes (DNREC, undated). The marshes also provide nesting habitat for many species of concern to federal and state agencies, including American black duck, Nelson's sparrow, salt marsh sharp-tailed sparrow, seaside sparrow, coastal plain swamp sparrow, black rail, Forster's tern, gull-billed tern, black skimmers, and American oystercatchers (Erwin *et al*., 2006).

The marshes of the bay islands in particular are key resources for birds, due to their relative isolation and protection from predators and to the proximity to both upland and intertidal habitat. For example, hundreds of horned grebes prepare for migration at the north end of Rehoboth Bay near Thompson's Island (Ednie, undated). Several bird species of concern in this region nest on shell piles (shellrake) on marsh islands, including gull-billed terns, common terns, black skimmers, royal tern, and American oystercatchers (Erwin, 1996; Rounds *et al*., 2004). Dredge spoil islands in particular are a favorite nesting spot for the spotted sandpiper, which has a state conservation status of vulnerable to critically imperiled in Maryland, Delaware, and Virginia (Natureserve, 2008). However, marsh islands are also subject to tidal flooding, which reduces the reproductive success of island-nesting birds (Eyler *et al.*, 1999).

Sea-level rise is considered a major threat to bird species in the Virginia Barrier Island/Lagoon Important Bird Area (IBA) (Watts, 2006). Biologists at the Patuxent Wildlife Research Center suggest that submergence of lagoonal marshes in Virginia would have a major negative effect on marsh-nesting birds such as black rails, seaside sparrows, saltmarsh sharp-tailed sparrows, clapper rails, and Forster's terns (Erwin *et al.*, 2004). The U.S. Fish and Wildlife Service considers black rail and both sparrow species "birds of conservation concern" because populations are already declining in much of their range (USFWS, 2002). The number of bird species in Virginia marshes was found to be directly related to marsh size; the minimum marsh size found to support significant marsh bird communities was 4.1 to 6.7 ha (10 to 15 ac) (Watts, 1993).

The region's tidal marshes also support a diversity of resident and transient estuarine and marine fish and shellfish species that move in and out of marshes with the tides to take advantage of the abundance of decomposing plants in the marsh, the availability of invertebrate prey, and refuge from predators (Boesch and Turner, 1984; Kneib, 1997). Marine transients include recreationally and commercially important species that depend on the marshes for spawning and nursery habitat, including black drum, striped bass, bluefish, Atlantic croaker, sea trout, and summer flounder. Important forage fish that spawn in local marsh areas include spot, menhaden, silver perch, and bay anchovy.

Shellfish species found in the marshes include clams, oysters, shrimps, ribbed mussels, and blue crabs (Casey and Doctor, 2004).

Salt Marsh Adaptation to Sea-level Rise. Salt marshes occupy thousands of acres in eastern Accomack and Northampton counties (Fleming *et al.*, 2006). Marsh accretion experts believe that most of these marshes are keeping pace with current rates of sea-level rise, but are unlikely to continue to do so if the rate of sea-level rise increases by another 2 mm per year (Strange 2008c, interpreting the findings of Reed *et al*., 2008). However, some very localized field measurements indicate that accretion rates may be insufficient to keep pace even with current rates of sea-level rise (Strange, 2008d). For instance, accretion rates as low as 0.9 mm per year (Phillips Creek Marsh) and as high as 2.1 mm per year (Chimney Pole Marsh) have been reported (Kastler and Wiberg, 1996), and the average relative sea-level rise along the Eastern Shore is estimated as 2.8 to 4.2 mm per year (May, 2002).

In some areas, marshes may be able to migrate onto adjoining dry lands. For instance, lands in Worcester County that are held for the preservation of the coastal environment might allow for wetland migration. Portions of eastern Accomack County that are opposite the barrier islands and lagoonal marshes owned by The Nature Conservancy are lightly developed today, and in some cases already converting to marsh. In unprotected areas, marshes may be able to migrate inland in low-lying areas. From 1938 to 1990 mainland salt marshes on the Eastern Shore increased in area by 8.2 percent, largely as a result of encroachment of salt marsh into upland areas (Kastler and Wiberg, 1996).

The marsh islands of the coastal bays are undergoing rapid erosion; for example, Big Piney Island in Rehoboth Bay experienced erosion rates of 10 m (30 ft) per year between 1968 and 1981, and is now gone (Swisher, 1982; Strange *et al*., 2008). Seal Island in Little Assawoman Bay is eroding rapidly after being nearly totally devegetated by greater snow geese (Strange, 2008c). Island shrinking is also apparent along the Accomack County, Virginia shore; from 1949 to 1990, Chimney Pole marsh showed a 10 percent loss to open water (Kastler and Wiberg, 1996). The United States Army Corps of Engineers (USACE) has created many small dredge spoil islands in the region, many of which are also disappearing as a result of erosion (Federal Register, 2006).

Sea-Level Fens. The rare sea-level fen vegetation community is found in a few locations along the coastal bays, including the Angola Neck Natural Area along Rehoboth Bay in Delaware and the Mutton Hunk Fen Natural Area Preserve fronting Gargathy Bay in eastern Accomack County (VA DCR, undated [a][b]). The Division of Natural Heritage within the Virginia Department of Conservation and Recreation believes that chronic sea-level rise with intrusions of tidal flooding and salinity poses "a serious threat to the long-term viability" of sea-level fens (VA DCR, 2001).

Shallow Waters and Submerged Aquatic Vegetation (SAV). Eelgrass beds are essential habitat for summer flounder, bay scallop, and blue crab, all of which support substantial recreational and commercial fisheries in the coastal bays (MCBP, 1999). Various waterbirds feed on eelgrass beds, including brant, canvasback duck, and American black duck (Perry and Deller, 1996). Shallow water areas of the coastal bays that can maintain higher salinities also feature beds of hard and surf clams (DNREC, 2001).

Tidal Flats. Abundant tidal flats in this region provide a rich invertebrate food source for a number of bird species, including whimbrels, dowitchers, dunlins, black-bellied plovers, and semi-palmated sandpipers (Watts and Truitt, 2002). Loss of these flats could have significant impacts. For example, 80 percent of the Northern Hemisphere's whimbrel population feeds on area flats, in large part on fiddler crabs (TNC, 2006). The whimbrel is considered a species "of conservation concern" by the United States Fish and Wildlife Service, Division of Migratory Bird Management (USFWS, 2002).

Beaches. Loss of beach habitat due to sea-level rise and erosion below protective structures could have a number of negative consequences for species that use these beaches:

- Horseshoe crabs rarely spawn unless sand is at least deep enough to nearly cover their bodies, about 10 cm (4 inches [in]) (Weber, 2001). Shoreline protection structures designed to slow beach loss can also block horseshoe crab access to beaches and can entrap or strand spawning crabs when wave energy is high (Doctor and Wazniak, 2005).
- The rare northeastern tiger beetle depends on beach habitat (USFWS, 2004b).
- *Photuris bethaniensis* is a globally rare firefly located only in interdunal swales on Delaware barrier beaches (DNREC, 2001).

- Erosion and inundation may reduce or eliminate beach wrack communities of the upper beach, especially in developed areas where shores are protected (Strange, 2008c). Beach wrack contains insects and crustaceans that provide food for many species, including migrating shorebirds (Dugan *et al.*, 2003).
- Many rare beach-nesting birds, such as piping plover, least tern, common tern, black skimmer, and American oystercatcher, nest on the beaches of the coastal bays (DNREC, 2001)

Coastal Habitat for Migrating Neotropical Songbirds. Southern Northampton County is one of the most important bird areas along the Atlantic Coast of North America for migrating neotropical songbirds such as indigo buntings and ruby-throated hummingbirds (Watts, 2006). Not only are these birds valued for their beauty but they also serve important functions in dispersing seeds and controlling insect pests. It is estimated that a pair of warblers can consume thousands of insects as they raise a brood (Mabey *et al.*, undated). Migrating birds concentrate within the tree canopy and thick understory vegetation found within the lower 10 km (6 mi) of the peninsula within 200 m (650 ft) of the shoreline. Loss of this understory vegetation as a result of rising seas would eliminate this critical stopover area for neotropical migrants, many of which have shown consistent population declines since the early 1970s (Mabey *et al.*, undated)

A1.E.2 Development, Shore Protection, and Coastal Policies

A1.E.2.1 Atlantic Coast

Less than one-fifth of the Delmarva's ocean coast is developed, and the remaining lands are owned by private conservation organizations or government agencies. Almost all of the Virginia Eastern Shore's 124-km (77-mi) ocean coast is owned by the U.S. Fish and Wildlife Service, NASA, the State, or The Nature Conservancy[90]. Of Maryland's 51 km (32 mi) of ocean coast, 36 km (22 mi) are along Assateague Island National Seashore. The densely populated Ocean City occupies approximately 15 km (9 mi). More than three-quarters of the barrier islands and spits in Delaware are part of Delaware Seashore State Park, while the mainland coast is about evenly divided between Cape Henlopen State Park and resort towns such as Rehoboth, Dewey Beach, and Bethany Beach. With approximately 15 km of developed ocean coast each, Maryland and Delaware have pursued beach nourishment to protect valuable coastal property and preserve the beaches that make the property so valuable (Hedrick *et al.*, 2000).

With development accounting for only 15 to 20 percent of the ocean coast, the natural shoreline processes are likely to dominate along most of these shores. Within developed areas, counteracting shoreline erosion in developed areas with beach nourishment may continue as the primary activity in the near term. A successful alternative to beach nourishment, as demonstrated by a USACE (2001a) and National Park Service project to mitigate jetty impacts along Assateague Island, is to restore sediment transport rates by mechanically bypassing sand from the inlet and tidal deltas into the shallow nearshore areas that have been starved of their natural sand supply. Beginning in 1990, the USACE and the Assateague Island National Seashore partnered to develop a comprehensive

[90] A few residential structures are on Cedar Island, and Cobbs and Hog Islands have some small private inholdings (Ayers, 2005).

restoration plan for the northern end of Assateague Island. The “North End Restoration Project” included two phases. The first phase, completed in 2002, provided a one-time placement of sand to replace a portion of sand lost over the past 60 years due to the formation of the inlet and subsequent jetty stabilization efforts. The second phase is focused on re-establishing a natural sediment supply by mechanically bypassing sand from the inlet and tidal deltas into the shallow nearshore areas[91].

A1.E 2.2 Coastal Bay Shores

The mainland along the back-barrier bays has been developed to a greater extent than the respective ocean coast in all three states (MRLCC, 2002; MDP, 1999; DOSP, 1997). Along the coastal bays, market forces have led to extensive development at the northern end of the Delmarva due to the relatively close proximity to Washington, Baltimore, and Philadelphia. Although connected to the densely populated Hampton Roads area by the Chesapeake Bay Bridge-Tunnel, southern portions of the Delmarva are not as developed as the shoreline to the north. Worcester County, Maryland, reflects a balance between development and environmental protection resulting from both recognition of existing market forces and a conscious decision to preserve Chincoteague Bay. Development is extensive along most shores opposite Ocean City and along the bay shores near Ocean City Inlet. In the southern portion of the county, conservation easements or the Critical Areas Act preclude development along most of the shore. Although the Critical Areas Act encourages shore protection, and conservation easements in Maryland preserve the right to armor the shore (MET, 2006), these low-lying lands are more vulnerable to

[91] See <http://www.nps.gov/asis/naturescience/resource-management-documents.htm>

inundation than erosion (*e.g.*, Titus *et al*., 1991) and are therefore possible candidates for wetland migration.

Of the three states, Maryland has the most stringent policies governing development along coastal bays Under the Chesapeake and Atlantic Coastal Bays Critical Areas Protection Program, new development must be set back at least 100 ft from tidal wetlands or open water[92]. In most undeveloped areas, the statute also limits future development density to one home per 20 ac within 305 m (1000 ft) of the shore[93] and requires a 61-m (200-ft) setback.[94] In Virginia, new development must be set back at least 30 m (100 ft). (see Section A1.F.2 in this Appendix for additional discussion of the Maryland and Virginia policies.) The Delaware Department of Natural Resources has proposed a 30-m (100-ft) setback along the coastal bays (DNREC, 2007); Sussex County currently requires a 15-m (50-ft) setback[95].

While shore protection is currently more of a priority along the Atlantic Coast, preventing the inundation of low-lying lands may eventually be necessary as well. Elevating these low areas appears to be more practical than erecting a dike around a narrow barrier island (Titus, 1990). Most land surfaces on the bayside of Ocean City were elevated during the initial construction of residences (McGean, 2003). In an appendix for U.S. EPA's 1989 Report to Congress, Leatherman (1989) concluded that the only portion of Fenwick

[92] Maryland Natural Resources Code §8-1807(a). Code of Maryland Regulations §27.01.09.01 (C);
[93] Code of Maryland Regulations §27.01.02.05(C)(4).
[94] Maryland Natural Resources Code §8-1808.10
[95] Sussex County, DE. 2007. Buffer zones for wetlands and tidal and perennial non-tidal waters. §115-193, Sussex County Code. Enacted July 19, 1988 by Ord. No. 521.

Island where bayside property would have to be elevated with a 50 cm rise in sea level would be the portion in Delaware (*i.e.*, outside of Ocean City). He also concluded that Wallops Island, South Bethany, Bethany, and Rehoboth Beach are high enough to avoid tidal inundation for the first 50 to 100 cm of sea-level rise. The Town of Ocean City has begun to consider how to respond to address some of the logistical problems of elevating a densely developed barrier island (see Box A1.5).

The Maryland Coastal Bays Program considers erosion (due to sea-level rise) and shoreline hardening major factors contributing to a decline in natural shoreline habitat available for estuarine species in the northern bays (MCBP, 1999). Much of the shoreline of Maryland's northern coastal bays is protected using bulkheads or stone riprap, resulting in unstable sediments and loss of wetlands and shallow water habitat (MCBP, 1999). Armoring these shorelines will prevent inland migration of marshes, and any remaining fringing marshes will ultimately be lost (Strange 2008c). The Coastal Bays Program estimated that more than 600 ha (1,500 ac) of salt marshes have already been lost in the coastal bays as a result of shoreline development and stabilization techniques (MCBP, 1999). If shores in the southern part of Maryland's coastal bays remain unprotected, marshes in low-lying areas would be allowed to potentially (see Chapter 4) expand inland as sea level rises (Strange 2008c).

BOX A1.5: Elevating Ocean City as Sea Level Rises

Logistically, the easiest time to elevate low land is when it is still vacant, or during a coordinated rebuilding. Low parts of Ocean City's bay side were elevated during the initial construction. As sea level rises, the town of Ocean City has started thinking about how it might ultimately elevate.

Ocean City's relatively high bay sides make it much less vulnerable to inundation by spring tides than other barrier islands. Still, some streets are below the 10-year flood plain, and as sea level rises, flooding will become increasingly frequent.

However, the town cannot elevate the lowest streets without considering the implications for adjacent properties. A town ordinance requires property owners to maintain a 2 percent grade so that yards drain into the street. The town construes this rule as imposing a reciprocal responsibility on the town itself to not elevate roadways above the level where yards can drain, even if the road is low enough to flood during minor tidal surges. Thus, the lowest lot in a given area dictates how high the street can be.

As sea level rises, failure by a single property owner to elevate could prevent the town from elevating its streets, unless it changes this rule. Yet public health reasons require drainage, to prevent standing water in which mosquitoes breed. Therefore, the town has an interest in ensuring that all property owners gradually elevate their yards so that the streets can be elevated as the sea rises without causing public health problems.

The Town of Ocean City (2003) has developed draft rules that would require that, during any significant construction, yards be elevated enough to drain during a 10-year storm surge for the life of the project, considering projections of future sea-level rise. The draft rules also state that Ocean City's policy is for all lands to gradually be elevated as the sea rises.

A1.F Chesapeake Bay

The Chesapeake Bay region accounts for more than one-third of the lowland in the Mid-Atlantic (see Titus and Richman 2001). Accordingly, the first subsection (A1.F.1) on vulnerable habitat, development, and shore protection) divides the region into seven subregions. Starting with Hampton Roads, the subsections proceed clockwise around the Bay to Virginia's Middle Peninsula and Northern Neck, then up the Potomac River to Washington, D.C., then up Maryland's Western Shore, around to the Upper Eastern Shore, and finally down to the Lower Eastern Shore. The discussions for Virginia are largely organized by planning district; the Maryland discussions are organized by major section of shore. The second subsection compares the coastal policies of Maryland and Virginia that are most relevant to how these states respond to rising sea level[96].

[96] As this report was being finalized, a comprehensive study of the impacts of sea level rise on the Chesapeake Bay region was completed by the National Wildlife Federation (Glick *et al.,* 2008).

A1.F.1 Inundation, Development and Shore Protection, and Vulnerable Habitat

A1.F.1.1 Hampton Roads

Most of the vulnerable dry land in the Hampton Roads region is located within Virginia Beach and Chesapeake. These low areas are not, however, in the urban portions of those jurisdictions. Most of Virginia Beach's very low land is either along the back-barrier bays near the North Carolina border, or along the North Landing River. Most of Chesapeake's low land is around the Northwest River near the North Carolina border, or the along the Intracoastal Waterway. The localities located farther up the James and York Rivers have less low land. An important exception is historic Jamestown Island, which has been gradually submerged by the rising tides since the colony was established 400 years ago (see Box 10.1 in Chapter 10).

Development and Shore Protection

Norfolk is home to the central business district of the Hampton Roads region. Newport News has similar development to Norfolk along its southern shores, with bluffs giving rise to less dense residential areas further north along the coast. The city of Hampton is also highly developed, but overall has a much smaller percentage of commercial and industrial development than Norfolk or Newport News.

Outside of the urban core, localities are more rural in nature. These localities find themselves facing mounting development pressures and their comprehensive plans outline how they plan to respond to these pressures (*e.g.*, Suffolk, 1998; York County, 1999; James City County, 2003; Isle of Wight County, 2001). Overall, however, the makeup of these outlying localities is a mix of urban and rural development, with historic towns and residential development dotting the landscape.

Virginia Beach has sandy shores along both the Atlantic Ocean and the mouth of Chesapeake Bay. Dunes dominate the bay shore, but much of the developed ocean shore is protected by a seawall, and periodic beach nourishment has occurred since the mid-1950s (Hardaway *et al.*, 2005). Along Chesapeake Bay, by contrast, the Virginia Beach shore has substantial dunes, with homes set well back from the shore in some areas. Although the ground is relatively high, beach nourishment has been required on the bay beaches at Ocean Park (Hardaway *et al.*, 2005). Norfolk has maintained its beaches along Chesapeake Bay mostly with breakwaters and groins. Shores along other bodies of water are being armored. Of Norfolk's 269 km (167 mi) of shoreline, 113 km (70 mi) have been hardened (Berman *et al.*, 2000).

Overall trends in the last century show the dunes east of the Lynn Haven inlet advancing into the Bay (Shellenbarger Jones and Bosch, 2008c). West from the inlet, erosion, beach nourishment, and fill operations as well as condominium development and shoreline armoring have affected the accretion and erosion patterns (Hardaway *et al.*, 2005). Along the shores of Norfolk, the rate of erosion is generally low, and beach accretion occurs along much of the shore (Berman *et al.*, 2000). Most of the shore along Chesapeake Bay is protected by groins and breakwaters, and hence relatively stable (Hardaway *et al.*, 2005). On the other side of the James River, the bay shoreline is dominated by marshes, many of which are eroding (Shellenbarger Jones and Bosch, 2008c). .

Since 1979, Virginia Beach has had a “Green Line”, south of which the city tries to maintain the rural agricultural way of life. Because development has continued, Virginia Beach has also established a “Rural Area Line,” which coincides with the Green Line in the eastern part of the city and runs 5 km (3 mi) south of it in the western portion. Below the Rural Area Line, the city strongly discourages development and encourages rural legacy and conservation easements (VBCP, 2003). In effect, the city’s plan to preserve rural areas will also serve to preserve the coastal environment as sea level rises throughout the coming century and beyond (see Sections 6.1.3, 6.2, 10.3). To the west, by contrast, the City of Chesapeake is encouraging development in the rural areas, particularly along major corridors. Comprehensive plans in the more rural counties such as Isle of Wight and James City tend to focus less on preserving open space and more on encouraging growth in designated areas (Isle of Wight, 2001; James City County, 2003). Therefore, these more remote areas may present the best opportunity for long-range planning to minimize coastal hazards and preserve the ability of ecosystems to migrate inland.

Vulnerable Habitat

Much of the tidal wetlands in the area are within Poquoson’s Plum Tree Island National Wildlife Refuge. Unlike most mid-Atlantic wetlands, these wetlands are unlikely to keep pace with the current rate of sea-level rise (Shellenbarger Jones and Bosch, 2008c, interpreting the findings of Reed *et al*., 2008). The relative isolation of the area has made it a haven for over 100 different species of birds. The refuge has substantial forested dune hummocks (CPCP, 1999), and a variety of mammals use the higher ground of the refuge. Endangered sea turtles, primarily the loggerhead, use the near shore waters. Oyster, clams, and blue crabs inhabit the shallow waters and mudflats, and striped bass, mullet, spot, and white perch have been found in the near shore waters and marsh (USFWS, undated[b]).

The wetlands in York County appear able to keep pace with the current rate of sea-level rise. Assuming that they are typical of most wetlands on the western side of Chesapeake Bay, they are likely to become marginal with a modest acceleration and be lost if sea-level rise accelerates to 1 cm per year (Shellenbarger Jones and Bosch, 2008c, interpreting the findings of Reed *et al*., 2008). Bald eagles currently nest in the Goodwin Islands National Estuarine Research Reserve (Watts and Markham, 2003). This reserve includes intertidal flats, 100 ha (300 ac) of eelgrass and widgeon grass (VIMS, undated), and salt marshes dominated by salt marsh cordgrass and salt meadow hay.

A1.F.1.2 York River to Potomac River

Two planning districts lie between the York and Potomac rivers. The Middle Peninsula Planning District includes the land between the York and Rappahannock rivers. The Northern Neck is between the Rappahannock and Potomac rivers.

Development and Shore Protection

A large portion of the necks along Mobjack Bay has a conservation zoning that allows only low-density residential development "in a manner which protects natural resources in a sensitive environment[97]. The intent is to preserve contiguous open spaces and protect the surrounding wetlands[98]. The county also seeks to maintain coastal ecosystems important for crabbing and fishing. As a result, existing land use would not prevent wetlands and beaches along Mobjack Bay from migrating inland as sea level rises.

Gloucester County also has suburban country side zoning, which allows for low density residential development, including clustered sub-developments[99] along part of the Guinea Neck and along the York River between Carter Creek and the Catlett islands. These developments often leave some open space that might convert to wetlands as sea level rises even if the development itself is protected. The county plan anticipates development along most of the York River. Nevertheless, a number of areas are off limits to development. For example, the Catlett islands are part of the Chesapeake Bay National Estuarine Research Reserve in Virginia, managed as a conservation area[100].

Along the Northern Neck, shoreline armoring is already very common, especially along Chesapeake Bay and the Rappahannock Rivers shores of Lancaster County. Above Lancaster County, however, development is relatively sparse along the Rappahannock

[97] Gloucester County Code of Ordinances, accessed through Municode Online Codes: <http://livepublish.municode.com/22/lpext.dll?f = templates&fn = main-j.htm&vid = 10843>: "The intent of the SC-1 district is to allow low density residential development….Cluster development is encouraged in order to protect environmental and scenic resources."
[98] Gloucester County Code of Ordinances, accessed through Municode Online Codes; <http://livepublish.municode.com/22/lpext.dll?f = templates&fn = main-j.htm&vid = 10843>
[99] Definition of suburban countryside in Gloucester County Code of Ordinances, accessed through Municode Online Codes: <http://livepublish.municode.com/22/lpext.dll?f = templates&fn = main-j.htm&vid = 10843>: "The intent of the SC-1 district is to allow low density residential development….Cluster development is encouraged in order to protect environmental and scenic resources."
[100] See the Research Reserve's web page at <http://www.vims.edu/cbnerr/about/index.htm>.

River and shoreline armoring is not common. Development and shoreline armoring are proceeding along the Potomac River.

Vulnerable Habitat

Like the marshes of Poquoson to the south, the marshes of the Guinea Neck and adjacent islands are not keeping pace with the current rates of sea-level rise (Shellenbarger Jones and Bosch, 2008a, interpreting the findings of Reed *et al*., 2008). For more than three decades, scientists have documented their migration onto farms and forests (Moore, 1976). Thus, the continued survival of these marshes depends on land-use and shore protection decisions.

Upstream from the Guinea Neck, sea-level rise is evident in the York River's tributaries, not because wetlands are converting to open water but because the composition of wetlands is changing. Along the Pamunkey and Mattaponi Rivers, dead trees reveal that tidal hardwood swamps are converting to brackish or freshwater marsh as the water level rises (Rheinhardt, 2007). Tidal hardwood swamps provide nesting sites for piscivorous (fish eating) species such as ospreys, bald eagles, and double-crested cormorants (Robbins and Blom, 1996).

In Mathews County, Bethel Beach (a natural area preserve separating Winter Harbor from Chesapeake Bay) is currently migrating inland over an extensive salt marsh area (Shellenbarger Jones and Bosch, 2008a). The beach is currently undergoing high erosion (Berman *et al*., 2000), and is home to a population of the Northeastern beach tiger beetle (federally listed as threatened) and a nesting site for rare least terns, which scour shallow nests in the sand (VA DCR, 1999). In the overwash zone extending toward the marsh, a rare plant is present, the sea-beach knotweed (*Polygonum glaucum*) (VA DCR, 1999). The marsh is also one of few Chesapeake Bay nesting sites for northern harriers (*Circus cyaneus*), a hawk that is more commonly found in regions further north (VA DCR, 1999). As long as the shore is able to migrate, these habitats will remain intact; but eventually, overwash and inundation of the marsh could reduce habitat populations (Shellenbarger Jones and Bosch, 2008a).

A1.F.1.3 The Potomac River

Virginia Side. Many coastal homes are along bluffs, some of which are eroding (Bernd-Cohen and Gordon, 1999). Lewisetta is one of the larger vulnerable communities along the Potomac. Water in some ditches rise and fall with the tides, and some areas drain through tide gates. With a fairly modest rise in sea level, one could predict that wetlands may begin to take over portions of people’s yards, the tide gates could close more often, and flooding could become more frequent. Somewhat higher in elevation than Lewisetta, Old Town Alexandria and Belle Haven (Fairfax County) both flood occasionally from high levels in the Potomac River.

Maryland Side. Much of the low-lying land is concentrated around St. George Island and Piney Point in St. Mary’s County, and along the Wicomico River and along Neal Sound opposite Cobb Island in Charles County. Relatively steep bluffs, however, are also common.

Development and Shore Protection

West of Chesapeake Bay, the southwestern shoreline of the Potomac River is the border between Maryland and Virginia[101]. As a result, islands in the Potomac River, no matter how close they are to the Virginia side of the river, are part of Maryland or the District of Columbia. Moreover, most efforts to control erosion along the Virginia shore take place partly in Maryland (or the District of Columbia) and thus could potentially be subject to Maryland (or Washington, D.C.) policies[102].

Development is proceeding along approximately two-thirds of the Potomac River shore. Nevertheless, most shores in Charles County, Maryland are in the resource conservation area defined by the state's Critical Areas Act (and hence limited to one home per 20 ac) (MD DNR, 2007). A significant portion of Prince George's County's shoreline along the Potomac and its tributaries are owned by the National Park Service and other conservation entities that seek to preserve the coastal environment (MD DNR, 2000).

In Virginia, parks also account for a significant portion of the shore (ESRI, 1999). In King George County, several developers have set development back from low-lying marsh areas, which avoids problems associated with flooding and poor drainage. Water and sewer regulations that only apply for lot sizes less than 10 acres may provide an incentive for larger lot sizes. In Stafford County, the CSX railroad line follows the river

[101] See Maryland v. Virginia, 540 US (2003)
[102] The Virginia Shore across from Washington, D.C. is mostly owned by the federal government, which would be exempt from District of Columbia policies.

for several miles, and is set back to allow shores to erode, but not so far back as to allow for development between the railroad and the shore (ADC, 2008).

Vulnerable Habitat

The Lower Potomac River includes a diverse mix of land uses and habitat types. *Freshwater tidal marshes* in the Lower Potomac are found in the upper reaches of tidal tributaries. In general, freshwater tidal marshes in the Lower Potomac are keeping pace with sea-level rise through sediment and peat accumulation, and are likely to continue to do so, even under higher sea-level rise scenarios (Strange and Shellenbarger Jones, 2008a, interpreting the findings of Reed *et al*., 2008).

Brackish tidal marshes are a major feature of the downstream portions of the region's rivers. In general, these marshes are keeping pace with sea-level rise today, but are likely to be marginal if sea level rise accelerates by 2 mm per year, and be lost if sea level accelerates 7 mm per year (Strange and Shellenbarger Jones, 2008a, interpreting the findings of Reed *et al*., 2008). Loss of brackish tidal marshes would eliminate nesting, foraging, roosting, and stopover areas for migrating birds (Strange and Shellenbarger Jones, 2008a). Significant concentrations of migrating waterfowl forage and overwinter in these marshes in fall and winter. Rails, coots, and migrant shorebirds are transient species that feed on fish and invertebrates in and around the marshes and tidal creeks. (Strange and Shellenbarger Jones, 2008a). The rich food resources of the tidal marshes also support rare bird species such as bald eagle and northern harrier (White, 1989).

Unnourished *beaches and tidal flats* of the Lower Potomac are likely to erode as sea levels rise. Impacts on beaches are highly dependent on the nature of shoreline protection measures selected for a specific area. For example, the developed areas of Wicomico Beach and Cobb Island are at the mouth of the Wicomico River in Maryland. Assuming that the shores of Cobb Island continue to be protected, sea-level rise is likely to eliminate most of the island's remaining beaches and tidal flats (Strange and Shellenbarger Jones, 2008a).

Finally, where the *cliffs and bluffs* along the Lower Potomac are not protected (*e.g.*, Westmoreland State Park, Caledon Natural Area), natural erosional processes will generally continue, helping to maintain the beaches below (Strange and Shellenbarger Jones, 2008a).

Above Indian Head, the Potomac River is fresh. Tidal wetlands are likely to generally keep pace with rising sea level in these areas (see Chapter 4 of this Product). Nevertheless, the Dyke Marsh Preserve faces an uncertain future. Its freshwater tidal marsh and adjacent mud flats are one of the last major remnants of the freshwater tidal marshes of the Upper Potomac River (Johnston, 2000). A recent survey found 62 species of fish, nine species of amphibians, seven species of turtles, two species of lizards, three species of snakes, 34 species of mammals, and 76 species of birds in Dyke Marsh (Engelhardt *et al.*, 2005). Many of the fish species present (*e.g.*, striped bass, American shad, yellow perch, blueback herring) are important for commercial and recreational fisheries in the area (Mangold *et al.*, 2004).

Parklands on the Mason Neck Peninsula are managed for conservation, but shoreline protection on adjacent lands may result in marsh loss and reduced abundance of key bird species (Strange and Shellenbarger Jones, 2008b). The Mason Neck National Wildlife Refuge hosts seven nesting bald eagle pairs and up to 100 bald eagles during winter, has one of the largest great blue heron colonies in Virginia, provides nesting areas for hawks and waterfowl, and is a stopover for migratory birds.

A1.F.1.4 District of Columbia

Within the downtown area, most of the lowest land is the area filled during the 1870s, such as Hains Point and the location of the former Tiber and James Creeks, as well as the Washington City Canal that joined them (See Box 5.2 in Chapter 5). The largest low area is the former Naval Air Station, now part of Bolling Air Force Base, just south of the mouth of the Anacostia River, which was part of the mouth of the Anacostia River during colonial times. A dike protects this area, where most of the low land between Interstate-295 and the Anacostia River was open water when the city of Washington was originally planned.

Development and Shore Protection

The central city is not likely to be given up to rising sea level; city officials are currently discussing the flood control infrastructure necessary to avoid portions of the downtown area from being classified as part of the 100-year floodplain. Nevertheless, natural areas in the city account for a substantial portion of the city's shore, such as Roosevelt Island and the shores of the Potomac River within C&O Canal National Historic Park.

As part of the city's efforts to restore the Anacostia River, District officials have proposed a series of environmental protection buffers along the Anacostia River with widths between 15 and 90 m (50 and 300 ft). Bulkheads are being removed except where they are needed for navigation, in favor of natural shores in the upper part of the river and bioengineered "living shorelines" in the lower portion (DCOP, 2003).

Vulnerable Habitat

The Washington, D.C. area features sensitive wetland habitats potentially vulnerable to sea-level rise. Several major areas are managed for conservation or are the target of restoration efforts, making ultimate impacts uncertain. The wetlands around the Anacostia River are an example. Local organizations have been working to reverse historical modifications and restore some of the wetlands around several heavily altered lakes. Restoration of the 13-ha (32-ac) Kenilworth Marsh was completed in 1993; restoration of the Kingman Lake marshes began in 2000 (USGS, undated). Monitoring of the restored habitats demonstrates that these marshes can be very productive. A recent survey identified 177 bird species in the marshes, including shorebirds, gulls, terns, passerines, and raptors as well as marsh nesting species such as marsh wren and swamp sparrow (Paul *et al.*, 2004).

Roosevelt Island is another area where sea-level rise effects are uncertain. Fish in the Roosevelt Island marsh provide food for herons, egrets, and other marsh birds (NPS, undated). The ability of the tidal marshes of the island to keep pace with sea-level rise will depend on the supply of sediment, and increased inundation of the swamp forest could result in crown dieback and tree mortality (Fleming *et al*., 2006).

A1.F.1.5 Western Shore: Potomac River to Susquehanna River

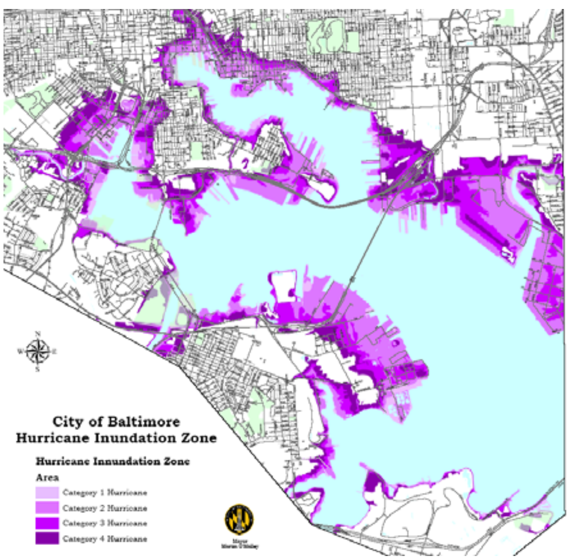
The Western Shore counties have relatively little low land, unlike the low counties across the Bay. The Deal/Shady Side peninsula (Anne Arundel County) and Aberdeen Proving Grounds (Harford County) are the only areas with substantial amounts of low-lying land. The block closest to the water, however, is similarly low in many of the older communities, including parts of Baltimore County, Fells Point in Baltimore (see Box A1.6), downtown Annapolis, North Beach, and Chesapeake Beach, all of which flooded during Hurricane Isabel.

Between the Potomac and the Patuxent Rivers, the bay shore is usually a sandy beach in front of a bank less than 3 m (10 ft) high. Cliffs and bluffs up to 35 m (115 ft) above the water dominate the shores of Calvert County (Shellenbarger Jones and Bosch, 2008b). The shores north of Calvert County tend to be beaches; but these beaches become narrower as one proceeds north, where the wave climate is milder.

BOX A1.6: Planning for Sea-level Rise in Baltimore

Only 3.2 percent of the City of Baltimore's 210 sq km (81 sq mi) of land is currently within the coastal floodplain. This land, however, includes popular tourist destinations such as Inner Harbor and the Fells Point Historic District, as well as industrial areas, some of which are being redeveloped into mixed use developments with residential, commercial, and retail land uses. The map below depicts the areas that the city expects to be flooded by category 1, 2, 3 and 4 hurricanes, which roughly correspond to water levels of 1.78 m (6 ft), 3.0 m (10 ft), 4.2 m (14 ft), and 5.5 m (18 ft) above North Amercan Vertical Datum (NAVD88). Approximately 250 homes are vulnerable to a category 1, while 700 homes could be flooded by a category 2 hurricane (Baltimore, 2006). As Hurricane Isabel passed in September 2003, water levels in Baltimore Harbor generally reached approximately 2.4 m (8 ft) above NAVD, flooding streets and basements, but resulting in only 16 flood insurance claims (Baltimore, 2006).

The city's All Hazards Plan explicitly includes rising sea level as one of the factors to be considered in land use and infrastructure planning. The All Hazards Plan has as an objective to "develop up-to-date research about hazards" and a strategy under that objective to "study the threat, possible mitigation and policy changes for sea-level rise." As a first step toward accurate mapping of possible sea-level rise scenarios, the city is exploring options for acquiring lidar. Policies developed for floodplain management foreshadow the broad methods the city is likely to use in its response.



Box Figure A1.6 Inundation Zone for Baltimore Harbor under category 1,2,3, and 4 hurricanes.

Property values are high, and there is a long-standing practice of armoring shores to facilitate port-related activities and more recently, protect waterfront structures from shore erosion. In most areas, there is not enough room between the harbor and waterfront buildings to fit a dike. Even where there is room, the loss of waterfront views would be unacceptable in tourist and residential areas (see Section 6.5 in Chapter 6; Titus, 1990). In addition, storm sewers, which drain by gravity into the harbor, would have to be fit with pumping systems.

Fells Point Historic District This historic community has 24 ha (60 ac) within the 100-year flood plain. Fells Point is a Federal Historic District and pending approval as a Local Historic District. The row houses here were built predominantly in the early to mid-nineteenth century and cannot be easily elevated. Elevating brick and stone structures is always more difficult than elevating a wood frame structure. But because row houses are, by definition, attached to each other, elevating them one at a time is not feasible. Many of these homes have basements, which already flood. FEMA regulations do not permit basements in new construction in the floodplain and treats (44 CFR §60.3[c] [2]) existing basements as requiring mitigation. Possible mitigation for basements includes relocation of utilities, reinforcement of walls, and filling.

In theory, homes could be remodeled to add stairways and doors to convert what is now the second floor to a first floor and convert the first floors to basements. But doing so would reduce the livable space. Moreover, federal and local preservation laws, as well as community sensibilities, preclude adding third stories to these homes. Elevating streets is also problematic because below-grade utilities need to be elevated. In the last decade only one street (one block of Caroline Street) has been elevated specifically to reduce flooding.

FEMA Flood Hazard Mapping and Sea-level Rise

Baltimore City is a participating jurisdiction in the National Flood Insurance Program through its regulation of development in the floodplain and through overall floodplain management. The city is currently funded through the Cooperative Technical Partnership (CTP) to update its flood maps. Federal flood mapping policies require that Flood Insurance Rate Maps be based on existing conditions (see Section 10.7.5.3 in Chapter 10). Therefore, the floodplain maps do not consider future sea level rise. As a result, the city will be permitting new structures with effective functional lifespan of 50 to 100 years but elevated only to current flood elevations. One strategy to surmount this limitation is to add "freeboard," or additional elevation to the effective BFE. Baltimore already requires one additional foot of freeboard.

The City of Baltimore is concerned, however, that 0.3 to 0.6 additional meters of freeboard is inequitable and inefficient. If flood levels will be, for example, 1 meter higher than the flood maps currently assume, then lands just outside the current flood boundary are also potentially vulnerable. If the city were to add 1 meter of freeboard to property in the floodplain, without addressing adjacent properties outside the floodplain, then adjacent property owners would have divergent requirements that city officials would find difficult to justify. (see Figure 10.6.)

Infrastructure

Baltimore has two regional sewerage plants. One of them, the Patapsco Wastewater Treatment Plant, sits on ground that is less than two meters above mean sea level and floods occasionally (see Box Figure A1.6). The facility itself is elevated and currently drains by gravity into the Patapsco River (USGS 7.5-minute map series). With a significant rise in sea level, however, pumping will be needed and possibly additional protections against storms (Smith, 1998: Titus *et al*., 1987, . Numerous streets, with associated conduits and utility piping, are within the existing coatal floodplain and would potentially be affected by sea-level rise (see Box Figure A1.6).

Development and Shore Protection

The Western Shore was largely developed before the Maryland's Critical Areas Act was passed. Stone revetments are common along the mostly developed shores of Anne Arundel and Baltimore Counties. Yet Calvert County has one of the only shore protection policies in the nation that prohibits shore protection along an estuary, even when the prohibition means that homes will be lost. Calvert County's erosion policy is designed to preserve unique cliff areas that border Chesapeake Bay.

The county allows shoreline armoring in certain developed areas to protect property interests, but also bans armoring in other areas to protect endangered species and the unique landscape[103]. Cliffs in Calvert County are separated into categories according to the priority for preservation of the land. Although a county policy prohibiting shore protection would appear to run counter to the state law granting riparian owner the right to shore protection, to date no legal challenges to the cliff policy have been made. The state has accepted the county's policy, which is embodied in the county's critical areas plan submitted to the state under the Critical Areas Act. Recognizing the potential environmental implications, living shoreline protection is becoming increasingly commonplace along the Western Shore.

Vulnerable Habitat

A range of sea-level rise impacts are possible along the western shore of Chesapeake Bay, including potential loss of key habitats. First, marshes are expected to be marginal with mid-range increases in sea-level rise, and to be lost with high-range increases in sea-level rise (Shellenbarger Jones and Bosch, 2008b, interpreting the findings of Reed *et al*., 2008). The ability to migrate is likely to determine coastal marsh survival as well as the survival of the crustaceans, mollusks, turtles, and birds that depend on the marshes. In upper reaches of tributaries, however, marsh accretion is likely to be sufficient to counter sea-level rise (Shellenbarger Jones and Bosch, 2008b, interpreting the findings of Reed *et al*., 2008). Several key locations warrant attention:

[103]See also Nationwide Permits 3 (Maintenance), 31 (Maintenance of Existing Flood Control Facilities) and 45 (Repair of Uplands Damaged by Discrete Events). 72 Federal Register 11092-11198 (March 12, 2007).

- In the Jug Bay Sanctuary, along the upper Patuxent River, marsh inundation is causing vegetation changes, compounding stress on local bird species (Shellenbarger Jones and Bosch, 2008b).
- Cove Point Marsh in Calvert County is a 60-ha (150-ac) freshwater, barrier-beach marsh. Numerous state-defined rare plant species are present, including American frog's-bit, silver plumegrass, various ferns, and unique wetland communities (Steury, 2002), as well as several rare or threatened beetle species. With current rates of sea-level rise, the marsh is continuing to migrate, but will soon hit the northern edge of local residential development.
- The potential loss of the wide mudflats at Hart-Miller Island would eliminate major foraging and nesting areas for several high conservation priority species (Shellenbarger Jones and Bosch, 2008b).
- Given the extent of development and shoreline armoring in Anne Arundel County and Baltimore City/County, both intertidal areas and wetlands are likely to be lost with even a modest acceleration in sea-level rise (Shellenbarger Jones and Bosch, 2008b).

Beach loss, particularly in St. Mary's, Calvert, and Anne Arundel Counties along Chesapeake Bay, may occur in areas without nourishment. In general, beach loss will lead to habitat loss for resident insects (including the Northeastern beach tiger beetle, federally listed as threatened) and other invertebrates, as well as forage loss for larger predators such as shorebirds (Lippson and Lippson, 2006)[104].

[104] For more detail on beach habitats and the species that occur in the mid-Atlantic region, see Shellenbarger Jones (2008a).

The Calvert County cliffs represent unique habitat that could be degraded by sea-level rise; however, the cliffs are not likely to be lost entirely. The Puritan tiger beetle and Northeastern beach tiger beetle, both federally listed, are present in the area (Shellenbarger Jones and Bosch, 2008b). While natural erosion processes are allowed to continue in the protected cliff areas in the southern portion of the county, shoreline protections in the more northern developed areas are increasing erosion rates in adjacent areas (Wilcock *et al.*, 1998).

A1.F.1.6 Upper Eastern Shore

The Eastern Shore above Rock Hall is dominated by bluffs and steep slopes rising to above 6 m (20 ft). Tolchester Beach, Betterton Beach, and Crystal Beach are typical in that regard. From Rock Hall south to around the middle of Kent Island, all of the land within a few kilometers of the Chesapeake Bay or its major tributaries consists of low-lying land.

Between the Choptank River and Ocohannock Creek along the Eastern Shore of Chesapeake Bay lies one of the largest concentrations of land close to sea level. Water levels in roadside ditches rise and fall with the tides in the areas west of Golden Hill in Dorchester County and several necks in Somerset County. Many farms abut tidal wetlands, which are gradually encroaching onto those farms. Some landowners have responded by inserting makeshift tide gates over culverts, decreasing their own flooding but increasing it elsewhere. Throughout Hoopers Island, as well as the mainland nearby, there are: numerous abandoned driveways that once led to a home but are now ridges flooded at high tide and surrounded by low marsh or open water; recently abandoned homes that are still standing but surrounded by marsh; and dead trees still standing in areas where marsh has invaded a forest.

Development and Shore Protection

Along the Chesapeake Bay, recent coastal development has not placed a high value on the beach. The new bayfront subdivisions often provide no public access to the beach, and as shores erode, people erect shore-protection structures that eventually eliminate the beach (see Chapter 6 of this Product; Titus, 1998). Some traditional access points have been closed (Titus, 1998). Maintaining a beach remains important to some of the older bay resort communities where residents have long had a public beach—but even communities with "beach" in the name are seeing their beaches replaced with shore protection structures.

Maryland's Critical Areas Act, however, is likely to restrict the extent of additional development along the Eastern Shore of Chesapeake Bay to a greater extent than along the Western Shore. The resource conservation areas where development is discouraged include half of the Chesapeake Bay shoreline between the Susquehanna and Choptank Rivers. Among the major tributaries, most of the Sassafras, Chester, and Choptank Rivers are similarly preserved; the Act did not prevent development along most of the Wye, Elk, and North East Rivers. Existing development is most concentrated in the northern areas near Interstate-95, Kent Island, and the various necks near Easton and St. Michaels.

Vulnerable Habitat

Above Kent Island. The environmental implications of sea-level rise effects in the upper Chesapeake Bay are likely to be relatively limited. The Susquehanna River provides a large (though variable) influx of sediment to the upper Chesapeake Bay, as well as almost half of Chesapeake Bay's freshwater input (CBP, 2002). This sediment generally is retained above the Chesapeake Bay Bridge and provides material for accretion in the tidal wetlands of the region (CBP, 2002). The other upper Chesapeake Bay tributaries characteristically have large sediment loads as well, and currently receive sufficient sediment to maintain wetlands and their ecological function. As such, the upper Chesapeake Bay will continue to provide spawning and nursery habitat for crabs and fish, as well as nesting and foraging habitat for migratory and residential birds, including bald eagles and large numbers of waterfowl. Likewise, while some of the beaches may require nourishment for retention, the general lack of shoreline protections will minimize interferences with longshore sediment transport. Hence, beaches are likely to remain intact throughout much of the region (Shellenbarger Jones, 2008b).

Two areas in the upper bay—Eastern Neck and Elk Neck—appear most vulnerable to sea-level rise effects. First, Eastern Neck Wildlife Refuge lies at the southern tip of Maryland's Kent County. Ongoing shoreline protection efforts seek to reduce erosion of habitats supporting many migratory waterfowl and residential birds, as well as turtles, invertebrates, and the Delmarva fox squirrel, federally listed as endangered. In many marsh locations, stands of invasive common reed are the only areas retaining sufficient sediment (Shellenbarger Jones, 2008b). Local managers have observed common reed migrating upland into forested areas as inundation at marsh edges increases, although widespread marsh migration of other species has not been observed (Shellenbarger Jones, 2008b). The three-square bulrush marshes on Eastern Neck have been largely inundated, as have the black needle rush marshes on Smith Island and other locations, likely causes of reductions in black duck counts (Shellenbarger Jones, 2008b).

Other sea-level rise impacts are possible in Cecil County, in and around the Northeast and Elk Rivers. The headwaters of the rivers are tidal freshwater wetlands and tidal flats, spawning and nursery areas for striped bass and a nursery area for alewife, blueback herring, hickory shad, and white perch, as well as a wintering and breeding area for waterfowl (USFWS, 1980). Accretion is likely to be sufficient in some areas due to the large sediment inputs in the Upper Bay. Where accretion rates are not sufficient, wetland migration would be difficult due to the upland elevation adjacent to the shorelines. These conditions increase the chances of large tidal fresh marsh losses (Shellenbarger Jones, 2008b). Other sensitive Cecil County habitats exist such as the cliffs at Elk Neck State Park and the Sassafras River Natural Resource Management Area, which will be left to erode naturally losses (Shellenbarger Jones, 2008b). Finally, marsh loss is possible in and around the Aberdeen Proving Ground in Harford County. The Proving Ground is primarily within 5 m of sea level and contains 8000 ha (20,000 ac) of tidal wetlands.

Kent Island to Choptank River. The central Eastern Shore region of Chesapeake Bay contains diverse habitats, and sea-level rise holds equally diverse implications, varying greatly between subregions. Large expanses of marsh and tidal flats are likely to be lost, affecting shellfish, fish, and waterfowl populations (Shellenbarger Jones, 2008c). Several subregions merit consideration:

- Marshes along the Chester River are likely to be marginal with moderate sea-level rise rate increases (Shellenbarger Jones, 2008c, interpreting the findings of Reed *et al*., 2008; see Chapter 4 of this Product).
- Loss of the large tidal flats exist at the mouth of the Chester River (Tiner and Burke, 1995) may result in a decline in the resident invertebrates and fish that use the shallow waters as well as the birds that feed on the flats (Shellenbarger Jones, 2008c; Robbins and Blom, 1996).
- The Eastern Bay side of nearby Kent Island has several tidal creeks, extensive tidal flats, and wetlands. Existing marshes and tidal flats are likely to be lost (see Chapter 4) (although some marsh may convert to tidal flat). Increasing water depths are likely to reduce the remaining SAV; a landward migration onto existing flats and marshes will depend on sediment type and choice of shoreline structure (Shellenbarger Jones, 2008c).
- Portions of the Wye River shore are being developed. If these shores are protected and the marshes and tidal flats in these areas are lost, the juvenile fish nurseries will be affected and species that feed in the marshes and SAV will lose an important food source (MD DNR, 2004).

Certain key marsh areas are likely to be retained. The upper reaches of tributaries, including the Chester and Choptank Rivers, are likely to retain current marshes and the associated ecological services. Likewise, Poplar Island will provide a large, isolated marsh and tidal flat area (USACE, undated[b]). In addition, the marshes of the Wye Island Natural Resource Management Area support a large waterfowl population (MD DNR, 2004). Maryland DNR will manage Wye Island to protect its biological diversity and structural integrity, such that detrimental effects from sea-level rise acceleration are minimized (MD DNR, 2004).

Beach loss is also possible in some areas. The Chesapeake Bay shore of Kent Island historically had narrow sandy beaches with some pebbles along low bluffs, as well as some wider beaches and dune areas (*e.g.*, Terrapin Park). As development continues, however, privately owned shores are gradually being replaced with stone revetments. The beaches will be unable to migrate inland, leading to habitat loss for the various resident invertebrates, including tiger beetles, sand fleas, and numerous crab species (Shellenbarger Jones, 2008c). Shorebirds that rely on beaches for forage and nesting will face more limited resources (Lippson and Lippson, 2006). Likewise, on the bay side of Tilghman Island, the high erosion rates will tend to encourage shoreline protection measures, particularly following construction of waterfront homes (MD DNR, undated). Beach loss, combined with anticipated marsh loss in the area, will eliminate the worms, snails, amphipods, sand fleas, and other invertebrates that live in the beach and intertidal areas and reduce forage for their predators (Shellenbarger Jones, 2008c).

A1.F.1.7. Lower Eastern Shore

Approximately halfway between Crisfield on the Eastern Shore and the mouth of the Potomac River on the Western Shore, are the last two inhabited islands in Chesapeake

Bay unconnected by bridges to the mainland: Smith (Maryland) and Tangier (Virginia). Both islands are entirely below the 5-ft elevation contour on a USGS topographic map. Along the Eastern Shore of Northampton County, by contrast, elevations are higher, often with bluffs of a few meters.

Development and Shore Protection

Along Chesapeake Bay, islands are threatened by a combination of erosion and inundation. Wetlands are taking over portions of Hoopers and Deal Islands, but shore erosion is the more serious threat. During the middle of the nineteenth century, watermen who made their living by fishing Chesapeake Bay made their homes on various islands in this region. Today, Bloodsworth and Lower Hoopers Islands are uninhabitable marsh, and the erosion of Barren and Poplar Islands led people to move their homes to the mainland (Leatherman, 1992). Smith Island is now several islands, and has a declining population. Hoopers and Deal Islands are becoming gentrified, as small houses owned by watermen are replaced with larger houses owned by wealthier retirees and professionals.

Virtually all of the beaches along Chesapeake Bay are eroding. Shore erosion of beaches and clay shores along the Chester, Nanticoke, and Chester Rivers is slower than along the Bay but enough to induce shoreline armoring along most developed portions. The lower Eastern Shore has a history of abandoning lowlands to shore erosion and rising sea level to a greater extent than other parts of the state (Leatherman, 1992).

Today, Smith and Tangier are the only inhabited islands without a bridge connection to the mainland. Government officials at all levels are pursuing efforts to prevent the loss of these lands, partly because of their unique cultural status and—in the case of Tangier—a town government that works hard to ensure that the state continues to reinvest in schools and infrastructure. The USACE has several planned projects for halting shore erosion, but to date, no efforts are underway to elevate the land (USACE, 2001b; Johnson, 2000). The replacement of traditional lifestyles with gentrified second homes may increase the resources available to preserve these islands.

The mainland of Somerset County vulnerable to sea-level rise is mostly along three necks. Until recently, a key indicator of the cost-effectiveness of shore protection was the availability of a sewer line[105]. As sea level rises, homes without sewer may be condemned as septic systems fail. The incorporated town of Crisfield, in the southernmost neck, has long had sewer service, which has been recently expanded to nearby areas. The town itself is largely encircled by an aging dike. Deal Island, no longer the thriving fishing port of centuries gone by, still has moderate density housing on most of the dry land.

Wicomico County's low-lying areas are along both the Wicomico and Nanticoke Rivers. Unlike Somerset, Wicomico has a large urban/suburban population, with the Eastern Shore's largest city, Salisbury. Planners accept the general principals of the state's Critical Areas Act, which discourages development along the shore.

[105] The mounds systems have made it possible to inhabit low areas with high water tables.

Much of coastal Dorchester County is already part of Blackwater Wildlife Refuge. The very low land south of Cambridge that is not already part of the refuge is farmland. Because most of the low-lying lands west of Cambridge are within Resource Conservation Areas (CBCAC, 2001), significant development would be unlikely under the state's Critical Areas Act (see Section A1.F.2). On the higher ground along the Choptank River, by contrast, many waterfront parcels are being developed. In July 2008, the State of Maryland Board of Public Works approved the purchase of 295 ha (729 ac) of land along the Little Blackwater River, near the town to Cambridge in Dorchester County. Funded by the state's Program Open Space, the purchase will allow for the preservation and restoration of more than two-thirds of a 434-ha (1,072-ac) parcel that was previously slated for development[106].

Vulnerable Habitat

On the lower Eastern Shore of Chesapeake Bay in Maryland, habitats vulnerable to sea-level rise are diverse and include beaches, various types of tidal marsh, non-tidal marshes, and upland pine forests.

Narrow sandy beaches exist along discrete segments of shoreline throughout the region, particularly in Somerset County. Given the gradual slope of the shoreline, one might infer that these habitats could accommodate moderate sea-level rise by migrating upslope, assuming no armoring or other barriers exist. Many of the beaches provide critical nesting habitat for the diamondback terrapin (*Malaclemys terrapin*), and proximity of

[106] See <http://www.dnr.state.md.us/dnrnews/pressrelease2007/041807.html>

these nesting beaches to nearby marshes provides habitat for new hatchlings (see Box A1.7)

BOX A1.7: The Diamondback Terrapin, *Malaclemys terrapin*

The diamondback terrapin, *Malaclemys terrapin*, comprising seven subspecies, is the only turtle that is fully adapted to life in the brackish salt marshes of estuarine embayments, lagoons, and impoundments (Ernst and Barbour, 1972). Its range extends from Massachusetts to Texas in the narrowest of coastal strips along the Atlantic and Gulf coasts of the United States (Palmer and Cordes, 1988). Extreme fishing pressure on the species resulted in population crashes over much of their range so that by 1920 the catch in Chesapeake Bay had fallen to less than 900 pounds. The Great Depression put a halt to the fishery, and during the mid-twentieth century, populations began to recover (CBP, 2006). Although a modest fishery has been reestablished in some areas, stringent harvest regulations are in place in several states. In some instances, states have listed the species as endangered (Rhode Island), threatened (Massachusetts), or as a "species of concern" (Georgia, Delaware, New Jersey, Louisiana, North Carolina, and Virginia). In Maryland, the status of the northern diamondback subpopulation is under review (MD DNR, 2006).

Effects of Sea-level Rise

The prospect of sea-level rise, along with land subsidence at many coastal locations, increasing human habitation of the shore zone and shoreline stabilization, places the habitat of terrapins at increasing risk. Loss of prime nesting beaches remains a major threat to the diamondback terrapin population in Chesapeake Bay (MD DTTF, 2001).Because human infrastructure (*i.e.*, roadways, buildings, and impervious surfaces) leaves tidal salt marshes with little or no room to transgress inland, one can infer that the ecosystem that terrapins depend on may be lost with concomitant extirpation of the species.

Of the 87,000 ha (340 sq mi) of tidal marsh in the Chesapeake Bay, a majority is located in the three-county lower Eastern Shore region (Darmondy and Foss, 1979). The marshes are critical nursery grounds for commercially important fisheries (*e.g.*, crabs and rockfish); critical feeding grounds for migratory waterfowl; and home to furbearers (*e.g.*, muskrat and nutria).

Areas of Virginia's Eastern Shore are uniquely vulnerable to sea-level rise since large portions of Northampton and Accomack counties lie near sea level. Because most of the land in the two counties is undeveloped or agricultural, the area also has a high potential for wetland creation relative to other Virginia shorelines.

Most notably, the bay side of northern Accomack County is primarily tidal salt marsh, with low-lying lands extending several kilometers inland. Unprotected marshes are already migrating inland in response to sea-level rise, creating new wetlands in agricultural areas at a rate of 16 ha (40 ac) per year (Strange, 2008e). Given the anticipated lack of shoreline protection and insufficient sediment input, the seaward boundaries of these tidal wetlands are likely to continue retreating (Strange, 2008e, interpreting the findings of Reed *et al*., 2008). The upland elevations are higher in southern than northern Accomack County, however, making wetland migration more difficult.

The salt marshes of Accomack County support a variety of species, including rare bird species such as the seaside sparrow, sharp-tailed sparrow, and peregrine falcon (VA DCR, undated [a][b]). Growth and survival of these species may be reduced where shores are hardened, unless alternative suitable habitat is available nearby. Furthermore, long-term tidal flooding will decrease the ability of nekton (*i.e.*, free-swimming finfish and decapod crustaceans such as shrimps and crabs) to access coastal marshes.

A1.F.2 Baywide Policy Context

Chesapeake Bay's watershed has tidal shores in Virginia, Maryland, the District of Columbia, and Delaware. Because the shores of Delaware and the District of Columbia. account for a small portion of the total, this subsection focuses on Virginia and Maryland.

(The federal Coastal Zone Management Act's definition of "coastal state" excludes the District of Columbia[107].)

Coastal management officials of Maryland have cooperated with the U.S. EPA since the 1980s in efforts to learn the ramifications of accelerated sea-level rise for their activities (AP, 1985). Increased erosion from sea-level rise was one of the factors cited for the state's decision in 1985 to shift its erosion control strategy at Ocean City from groins to beach nourishment (AP, 1985). The state also developed a planning document for rising sea level (Johnson, 2000), and sea-level rise was a key factor motivating Maryland to become the second mid-Atlantic state to obtain lidar elevation data for the entire coastal floodplain.

Neither Maryland nor Virginia has adopted a comprehensive policy to explicitly address the consequences of rising sea level. Nevertheless, the policies designed to protect wetlands, beaches, and private shorefront properties are collectively an implicit policy. Both states prevent new buildings within 30.5 m (100 ft) of most tidal shores; Maryland also limits the density of new development in most areas to one home per 8 ha (20 ac) within 305 m (1,000 ft) of the shore. Virginia allows most forms of shore protection. Maryland encourages shore protection[108], but discourages new bulkheads in favor of revetments or nonstructural measures (MD DNR, 2006). Both states have programs to inform property owners of nonstructural options and have created programs and educational outreach efforts to train marine contractors on "living shoreline" design and

[107] 16 USC §1453 (4)
[108] Code of Maryland Regulations§ 27.01.04.02.02-03

installation techniques. Both states work with the federal government to obtain federal funds for beach nourishment along their respective ocean resorts (Ocean City and Virginia Beach); Virginia also assists local governments in efforts to nourish public beaches along Chesapeake Bay and its tributaries. Summaries of these land use, wetlands, and beach nourishment policies follow.

During 2007, both states established climate change commissions to inform policy makers about options for responding to sea level rise and other consequences of changing climate[109]. The Maryland Commission on Climate Change is charged with developing a climate action plan to address both the causes and consequences of climate change[110]. Its interim report (MCCC, 2008) recommends that the state (1) protect and restore natural shoreline features (*e.g.*, wetlands) and (2) reduce growth and development in areas vulnerable to sea-level rise and its ensuing coastal hazards. The Virginia commission has an Adaptation Subgroup.

A1.F.2.1 Land Use

The primary state policies related to land use are Maryland's Chesapeake and Atlantic Coastal Bays Critical Area Protection Act, Virginia's Chesapeake Bay Preservation Act, and Virginia's Coastal Primary Sand Dunes & Beaches Act.

Maryland Chesapeake Bay and Atlantic Coastal Bays Critical Area Protection Act. The Maryland General Assembly enacted the Chesapeake Bay Critical Area Protection Act in

[109] Maryland Executive Order (01.01.2007.07); Virginia Executive Order 59 (2007).
[110] Maryland Executive Order (01.01.2007.07).

1984 to reverse the deterioration of the Bay[111]. (The statute now applies to Atlantic coastal bays as well; see Section A1.E.2) The law seeks to control development in the coastal zone and preserve a healthy bay ecosystem. The jurisdictional boundary of the Critical Area includes all waters of Chesapeake and Atlantic Coastal Bays, adjacent wetlands[112], dry land within 305 m (1,000 ft) of open water[113], and in some cases dry land within 305 m inland of wetlands that are hydraulically connected to the bays[114].

The act created a Critical Areas Commission to set criteria and approve local plans[115]. The commission has divided land in the critical area into three classes: intensely developed areas (IDAs), limited development areas (LDAs), and resource conservation areas (RCAs)[116]. Within the RCAs, new development is limited to an average density of one home per 8 ha (20 ac)[117] and set back at least 61 m (200 ft)[118], and the regulations encourage communities to "consider cluster development, transfer of development rights, maximum lot size provisions, and/or additional means to maintain the land area necessary to support the protective uses"[119]. The program limits future intense development activities to lands within the IDAs, and permits some additional low-intensity development in the LDAs. However, the statute allows up to 5 percent of the RCAs in a

[111] Chesapeake Bay Critical Areas Protection Act, Maryland Code Natural Resources §8-1807.
[112] *i.e.* all state and private wetlands designated under Natural Resources Article, Title 9 (now Title 16 of the Environment Article).
[113] Maryland Code Natural Resources §8-1807(c)(1)(i)(2).
[114] Lands that are less than 1,000 ft from open water *may* be excluded from jurisdiction if the lands are more than 1,000 ft from open water, and the wetlands between that land and the open water are highly functional and able to protect the water from adverse effects of developing the land. Maryland Code Natural Resources §8-1807(c)(1)(i)(2) and §8-1807(a)(2).
[115] Maryland Code Natural Resources §8-1808.
[116] Code of Maryland Regulations §27.01.02.02(A).
[117] Code of Maryland Regulations §27.01.02.05(C)(4).
[118] Maryland Code Natural Resources §8-1808.10 The required setback is only 100 feet for new construction on pre-existing lots.
[119] Code of Maryland Regulations §27.01.02.05(C)(4).

county to be converted to an IDA[120], although a 61-m (200-ft) buffer applies in those locations.

The three categories were originally delineated based on the land uses of 1985. Areas that were dominated by either agriculture, forest, or other open space, as well as residential areas with densities less than one home in 2 ha (5 acres), were defined as RCAs[121]. Thus, the greatest preservation occurs in the areas that had little development when the act was passed, typically lands that are far from population centers and major transportation corridors—particularly along tributaries (as opposed to the Bay itself). The boundary of the critical area was based on wetland maps created in 1972. MCCC (2008) pointed out that rising sea level and shoreline erosion had made that boundary obsolete in some locations. As a result, the Legislature directed the Critical Areas Commission to update the maps based on 2007 to 2008 imagery, and thereafter at least once every 12 years[122].

The Critical Areas Program also established a 30.5-m (100-ft) natural buffer adjacent to tidal waters, which applies to all three land categories[123]. No new development activities are allowed within the buffer[124], except water-dependent facilities. By limiting development in the buffer, the program prevents additional infrastructure from being located in the areas most vulnerable to sea-level rise. In some cases, the 30.5-m buffer provides a first line of defense against coastal erosion and flooding induced by sea-level

[120] Code of Maryland Regulations §27.01.02.06.
[121] Code of Maryland Regulations §27.01.02.05.
[122] Maryland House Bill 1253 (2008) §3.
[123] Code of Maryland Regulations §27.01.00.01 (C)(1).
[124] Code of Maryland Regulations §27.01.00.01 (C)(2).

rise. But the regulations also encourage property owners to halt shore erosion[125]. Nonstructural measures are preferred, followed by structural measures[126], with an eroding shore the least preferable (Titus, 1998).

Virginia Chesapeake Bay Preservation Act. The Chesapeake Bay Preservation Act[127] seeks to limit runoff into the bay by creating a class of land known as Chesapeake Bay Preservation Areas. The act also created the Chesapeake Bay Local Assistance Board to implement[128] and enforce[129] its provisions. Although the act defers most site-specific development decisions to local governments[130], it lays out the broad framework for the preservation areas[131] and provides the Board with rulemaking authority to set overall criteria[132]. The Board has issued regulations[133] defining the programs that local governments must develop to comply with the act[134].

All localities must create maps that define the locations of the preservation areas, which are subdivided into resource management areas[135] and resource protection areas

[125] Code of Maryland Regulations§ 27.01.04.02. 02
[126] Code of Maryland Regulations§ 27.01.04.02. 03.
[127] Code VA §10.1-2100 et seq. As of August 8, 2003, the Act was posted on the Virginia Legislative Information System website as part of the Code of Virginia at: <http://leg1.state.va.us/cgi-bin/legp504.exe?000+cod+TOC10010000021000000000000>.
[128] Code VA §10.1-2102.
[129] Code VA §10.1-2104.
[130] Code VA §10.1-2109.
[131] Code VA §10.1-2107(B).
[132] Code VA §10.1-2107(A).
[133] Chesapeake Bay Preservation Area Designation and Management Regulations (9 VAC 10-20-10 et. seq.).
[134] 9 Virginia Administrative Code §10-20-50.
[135] The act also provides for Resource Management Areas (RMAs) which are lands that, if improperly used or developed, have the potential to diminish the functional value of RPAs. Finally, areas in which development is concentrated or redevelopment efforts are taking place may be designated as Intensely Developed Areas (IDAs) and become subject to certain performance criteria for redevelopment. Private landowners are free to develop IDA and RMA lands, but must undergo a permitting process as well to prove that these actions will not harm the RPAs.

(RPAs)[136]. RPAs include areas flooded by the tides, as well as a 30.5 m (100-ft) buffer inland of the tidal shores and wetlands[137]. Within the buffer, development is generally limited to water dependent uses, redevelopment, and some water management facilities. Roads may be allowed if there is no practical alternative. Similarly, for lots subdivided before 2002, new buildings may encroach into the 30.5 m buffer if necessary to preserve the owner's right to build; but any building must still be at least 15.2 m (50 ft) from the shore[138]. Property owners, however, may still construct shoreline defense structures within the RPA. The type of shoreline defense installed is not regulated (beyond certain engineering considerations). Consequently, hard structures can be installed anywhere along Virginia's shoreline.

Virginia Coastal Primary Sand Dunes & Beaches Act. Virginia's Dunes and Beaches Act preserves and protects coastal primary sand dunes while accommodating shoreline development. The act identifies eight counties and cities that can adopt a coastal primary sand dune zoning ordinance, somewhat analogous to a Tidal Wetlands ordinance: Accomack, Northampton, Virginia Beach, Norfolk, Hampton, Mathews, Lancaster, and Northumberland (Hardaway *et al.*, 2001); all but Hampton and Accomack have done so. The act defines beaches as (1) the shoreline zone of unconsolidated sandy material; (2) the land extending from mean low water landward to a marked change in material composition or in physiographic form (*e.g.*, a dune, marsh, or bluff); and (3) if a marked change does not occur, then a line of woody vegetation or the nearest seawall, revetment, bulkhead or other similar structure.

[136] 9 Virginia Administrative Code §10-20-70.
[137] 9 Virginia Administrative Code §10-20-80 (B).
[138] 9 Virginia Administrative Code §10-20-130 (4).

A1.F.2.2 Wetlands and Erosion Control Permits

Virginia. The Tidal Wetlands Act seeks to "…preserve and prevent the despoliation and destruction of wetlands while accommodating necessary economic development in a manner consistent with wetlands preservation" (VA Code 28.2-1302). It provides for a Wetlands Zoning ordinance that any county, city, or town in Virginia may adopt to regulate the use and development of local wetlands. Under the ordinance, localities create a wetlands board consisting of five to seven citizen volunteers. The jurisdiction of these local boards extends from mean low water (the Marine Resources Commission has jurisdiction over bottom lands seaward of mean low water) to mean high water where no emergent vegetation exists, and slightly above spring high water[139] where marsh is present. The board grants or denies permits for shoreline alterations within their jurisdiction (Trono, 2003). The Virginia Marine Resources Commission has jurisdiction over the permitting of projects within state-owned subaqueous lands and reviews projects in localities that have no local wetlands board by virtue of not having adopted a wetland zoning ordinance[140].

Maryland. The Wetlands and Riparian Rights Act[141] gives the owner of land bounding on navigable water the right to protect their property from the effects of shore erosion. For example, property owners who erect an erosion control structure in Maryland can obtain

[139] The act grants jurisdiction to an elevation equal to 1.5 times the mean tide range, above mean low water.
[140] Virginia Administrative Code §28.2.
[141] Maryland Environmental Code §16-101 to §16-503.

a permit to fill vegetated wetlands[142] and fill beaches and tidal waters up to 3 m (10 ft) seaward of mean high water[143]. In addition, Maryland's statute allows anyone whose property has eroded to fill wetlands and other tidal waters to reclaim any land that the owner has lost since the early 1970s[144]. (USACE has delegated most wetland permit approval to the state[145].) Although the state has long discouraged bulkheads, much of the shore has been armored with stone revetments (Titus, 1998).

Shore protection structures tend to be initially constructed landward of mean high water, but neither Virginia nor Maryland[146] require their removal once the shore erodes to the point where the structures are flooded by the tides. Nor has either state prevented construction of replacement bulkheads within state waters, although Maryland encourages revetments.

For the last several years, Maryland has encouraged the "living shorelines" approach to halting erosion (*e.g.*, marsh planting and beach nourishment) over hard structures and revetments over bulkheads[147]. Few new bulkheads are built for erosion control, and existing bulkheads are often replaced with revetments. Nevertheless, obtaining permits for structural options has often been easier (NRC, 2007; Johnson and Luscher, 2004). For

142 See MD. CODE ANN., ENVIR. § 16-201 (1996); See Baltimore District (1996), app. at I-24, I-31. Along sheltered waters, the state encourages property owners to control erosion by planting vegetation. For this purpose, one can fill up to 35 feet seaward of mean high water. See MD. CODE ANN., ENVIR. § 16-202(c)(3)(iii) (Supp. 1997). Along Chesapeake Bay and other waters with significant waves, hard structures are generally employed.
143 MD. CODE ANN., ENVIR. § 16-202(c)(2).
144 MD. CODE ANN., ENVIR. § 16-201.
145 See Baltimore District (1996) §§ 1-5
146 The Maryland/Virginia border along the Potomac River is the low water mark. Courts have not ruled whether Maryland or Virginia environmental rules would govern a structure in Maryland waters attached to Virginia land.
147 Maryland General Permit at 56, § A1(A)(1)(g).

example, in the aftermath of Hurricane Isabel, many property owners sought expedited permits to replace shore protection structures that had been destroyed by storms. Maryland wanted to make obtaining a permit to replace a destroyed bulkhead with a living shoreline as easy as obtaining a permit to rebuild the bulkhead; but the state was unable to obtain federal approval. The permits issued by USACE authorized replacement of the damaged structures with new structures of the same kind, but they did not authorize owners to replace lost revetments and bulkheads with living shoreslines, or even to replace lost bulkheads with revetments (Johnson and Luscher, 2004).

Recognizing the environmental consequences of continued shoreline armoring, the Living Shoreline Protection Act of 2008[148]. Under the act, the Department of Environment will designate certain areas as appropriate for structural shoreline measures (*e.g.*, bulkheads and revetments). Outside of those areas, only nonstructural measures (*e.g.*, marsh creation, beach nourishment) will be allowed unless the property owner can demonstrate that nonstructural measures are infeasible[149].

A1.F.2.3 Beach Nourishment and Other Shore Protection Activities

Virginia. Until 2003, the Board on Conservation and Development of Public Beaches promoted maintenance, access, and development along the public beaches of Virginia. The largest beach nourishment projects have been along the 21 km (13 mi) of public beach along the Atlantic Ocean in Virginia Beach. During the last 50 years, the state has

[148] MD H.B. 273 (2008).
[149] MD Code Environment §16-201(c)

provided three percent of the funding for beach nourishment at Virginia Beach, with the local and federal shares being 67 percent and 30 percent, respectively (VA PBB, 2000).

Virginia has made substantial efforts to promote beach nourishment (and public use of beaches) along Chesapeake Bay and its tributaries. Norfolk's four guarded beaches serve 160,000 visitors each summer (VA PBB, 2000). When shore erosion threatened property, the tourist economy, and local recreation, the Beach Board helped the city construct a series of breakwaters with beachfill and a terminal groin at a cost of $5 million (VA PBB, 2000). State and local partnerships have also promoted beach restoration projects in several other locations along Chesapeake Bay and the Potomac and York rivers. (see Table A1.3).

Maryland. Maryland's primary effort to protect shores along the bay is through the Department of Natural Resource's Shore Erosion Control Program. Until 2008, the program provided interest-free loans and technical assistance to Maryland property owners to resolve erosion problems through the use of both structural and nonstructural shore erosion control projects; the program is now limited to "living shoreline" (see Box 5.3 in Chapter 5) approaches. The program provides contractor and homeowner training to support the installation of "living shorelines". The Department of Natural Resources has been involved in several beach nourishment projects along Chesapeake Bay (see Table A1.3), many of which include breakwaters or groins to retain sand within the area nourished.

The Maryland Port Administration and the USACE have also used dredge spoils to restore Poplar and Smith Islands (USACE, 2001b). Preliminary examinations are under way to see if dredged materials can be used to restore other Chesapeake Bay islands such as James and Barren Islands (Federal Register, 2006), or to protect valuable environmental resources such as the eroding lands of the U.S. Fish and Wildlife Service (USFWS) Blackwater National Wildlife Refuge (USFWS, 2008).

Table A1.3. Selected State Funded Beach Nourishment Projects Along Estuarine Shores in Maryland and Virginia

Location	City or County	$Cost (Millions)
Maryland (2001 to 2008)		
North Beach	Calvert	n.a.
Sandy Point	Anne Arundel	n.a.
PT Lookout State Park	St Mary’s	n.a.
Choptank River Fishing Pier	Talbot	n.a.
Jefferson Island.	St. Mary's	n.a.
Tanners Creek	St. Mary's	n.a.
Bay Ridge	Anne Arundel	n.a.
Hart and Mlllers Island.	Baltimore County Co.	n.a.
Rock Hall Town Park	Kent	n.a.
Claiborne Landing	Talbot	n.a.
Terrapin Beach,	Queen Anne’s	n.a.
Jefferson Is. Club - St Catherine Island	St. Mary's	n.a.
Elms Power Plant Site	St. Mary's	n.a.
Virginia (1995 to 2005)		
Bay Shore	Norfolk	5.0
Parks along James River	Newport News	1.0
Buckroe Beach	Hampton	1.3
Cape Charles	Northampton	0.3
Colonial Beach	Westmoreland	0.3
Aquia Landing	Stafford	0.2

Source: Maryland Department of Natural Resources; Virginia Board on Conservation and Development of Public Beaches

A1.G North Caroina

A1.G.1 Introduction

North Carolina's coastline is outlined by a barrier island system, with approximately 500 km (300 mi) of shoreline along the Atlantic Ocean. North Carolina's winding estuarine shorelines extend a total of approximately 10,000 linear km (6,000 mi) (Feldman, 2008). There are three well-known capes along the coastline: Cape Hatteras, Cape Lookout, and Cape Fear, in order from north to south. The "Outer Banks" of North Carolina include the barrier islands and barrier spits from Cape Lookout north to the Virginia state line. Much of this land is owned by the federal government, including Cape Lookout National Seashore, Cape Hatteras National Seashore, Pea Island National Wildlife Refuge, and Currituck National Wildlife Refuge. The Outer Banks also include several towns, including Kitty Hawk, Nags Head, Rodanthe, and Ocracoke (see Section A1.G.4.2). North and east of Cape Lookout, four rivers empty into the Albemarle and Pamlico Sounds. Albemarle Sound, Pamlico Sound, and their tidal tributaries, sometimes collectively called the Albemarle-Pamlico Estuarine System, comprise the second largest estuarine system in the United States.

Previous assessments of North Carolina's estuarine regions have divided the state's coastal regions into two principal provinces (geological zones), each with different characteristics (*e.g.*, Riggs and Ames, 2003). The zone northeast of a line drawn between Cape Lookout and Raleigh (located about 260 km west of the cape) is called the Northern Coastal Province, which includes the Outer Banks and most of the land bordering the

Albemarle and Pamlico Sounds. It has gentle slopes, three major and three minor inlets, and long barrier islands with a moderately low sediment supply, compared to barrier islands worldwide (Riggs and Ames, 2003). The rest of the state's coastal zone—the Southern Coastal Province—has steeper slopes, an even lower sediment supply, short barrier islands, and many inlets.

The Albemarle-Pamlico Peninsula is the land between Albemarle and Pamlico Sounds, to the west of Roanoke Island. The potential vulnerability of this 5,500 sq km (2,100 sq mi) peninsula (Henman and Poulter, 2008) is described in Box A1.8. The majority of Dare and Hyde counties are less than 1 m (approximately 3 ft) above sea level, as is a large portion of Tyrell County (Poulter and Halpin, 2007). Along the estuarine shorelines of North Carolina, wetlands are widespread, particularly in Hyde, Tyrell, and Dare counties. North Carolina's Division of Coastal Management mapped a total of more than 11,000 sq km (4,400 sq mi) of wetlands in the 20 coastal counties in North Carolina (Sutter, 1999). Wetlands types present include marshes, swamps, forested wetlands, pocosins (where evergreen shrubs and wetland trees occupy peat deposits), and many other types (Sutter, 1999).

Where the land is flat, areas a few meters above sea level drain slowly—so slowly that most of the lowest land is nontidal wetland (Richardson, 2003). Because rising sea level decreases the average slope between nearby coastal areas and the sea, it slows the speed at which these areas drain. Some of the dry land within a few meters above the tides could convert to wetland from even a small rise in sea level; and nontidal wetlands at these elevations would be saturated more of the time (McFadden *et al*., 2007; Moorhead and Brinson, 1995). Wetland loss could occur if dikes and drainage systems are built to prevent dry land from becoming wet (McFadden *et al*., 2007).

The very low tide range in some of the sounds is another possible source of vulnerability. Albemarle Sound, Currituck Sound, and much of Pamlico Sound have a very small tide range because inlets to the ocean are few and far between (NOAA, 2008b). Some of the inlets are narrow and shallow as well. Although Oregon and Ocracoke inlets are more than 10 m (over 30 ft) deep, the inlets are characterized by extensive shoals on both the ebb and flood sides, and the channels do not maintain depth for long distances before they break into shallower finger channels. Like narrow channels, this configuration limits the flow of water between the ocean and sounds (NOAA, 2008c). Thus, although the astronomic tide range at the ocean entrances is approximately 90 cm (3 ft), it decreases to 30 cm (1 ft) just inside the inlets, and a few centimeters in the centers of the estuaries. It is possible that rising sea level combined with storm-induced erosion will cause more, wider, and/or deeper inlets in the future (Riggs and Ames, 2003; see Chapter 3 of this Product). If greater tide ranges resulted, more lands would be tidally inundated.

The configuration of the few inlets within the Northern Coastal Province reduces tidal flushing and keeps salinity levels relatively low in most of the estuaries in this area (Riggs and Ames, 2003). Salinity is relatively high at the inlets, but declines as one proceeds upstream or away from the inlets. Also, there can be a strong seasonal variation with lower salinities during the periods of maximum river discharge and higher salinities during periods of drought (Buzzelli *et al*., 2003). The salinity in Albemarle-Pamlico Sound generally ranges from 0 to 20 parts per thousand (ppt), with the upper reaches of the Neuse and Pamlico Rivers, Albemarle Sound and Currituck Sound having salinities usually below 5 ppt (Caldwell, 2001; Tenore, 1972). (The typical salinity of the ocean is 35 ppt [Caldwell, 2001]). Some tidal marshes (which are irregularly flooded by the winds rather than regularly flooded by astronomical tides) are thus unable to tolerate salt water (Bridgham and Richardson, 1993; Poulter, 2005). In some areas, the flow of shallow groundwater to the sea is also fresh, so the soils are unaccustomed to salt water, and hence potentially vulnerable to increased salinity.

BOX A1.8: Vulnerability of the Albemarle-Pamlico Peninsula and Emerging Stakeholder Response

Vulnerability to sea-level rise on the diverse Albemarle-Pamlico Peninsula is very high: about two-thirds of the peninsula is less than 1.5 m (5 ft) above sea level (Heath, 1975), and approximately 30 percent is less than 0.9 m (3 ft) above sea level (Poulter, 2005). Shoreline retreat rates in parts of the peninsula are already high, up to 7.6 m (25 ft) per year (Riggs and Ames, 2003). The ecosystems of the Albemarle-Pamlico Peninsula have long been recognized for their biological and ecological value. The peninsula is home to four national wildlife refuges, the first of which was established in 1932. In all, about one-third of the peninsula has been set aside for conservation purposes.

The Albemarle-Pamlico Peninsula is among North Carolina's poorest areas. Four of its five counties are classified as economically distressed by the state, with high unemployment rates, along with low average household incomes (NC Department of Commerce, 2008). However, now that undeveloped waterfront property on the Outer Banks is very expensive and very scarce, developers have discovered the small fishing villages on the peninsula and begun acquiring property in several areas—including Columbia (Tyrrell County), Engelhard (Hyde County) and Bath (Beaufort County). The peninsula is being marketed as the "Inner Banks" (Washington County, 2008). Communities across the peninsula are planning infrastructure, including wastewater treatment facilities and desalination plants for drinking water, to enable new development. Columbia and Plymouth (Washington County) have become demonstration sites in the North Carolina Rural Economic Development Center's STEP (Small Towns Economic Prosperity) Program, which is designed to support revitalization and provide information vital to developing public policies that support long-term investment in small towns (NC REDC, 2006).

There are already signs that sea-level rise is causing ecosystems on the Albemarle-Pamlico Peninsula to change. For example, at the Buckridge Coastal Reserve, a 7,547-ha (18,650-ac) area owned by the North Carolina Division of Coastal Management, dieback is occurring in several areas of Atlantic white cedar. Other parts of the cedar community are beginning to show signs of stress. Initial investigations suggest the dieback is associated with altered hydrologic conditions, due to canals and ditches serving as conduits that bring salt and brackish water into the peat soils where cedar usually grows. Storms have pushed estuarine water into areas that are naturally fresh, affecting water chemistry, peatland soils, and vegetation intolerant of saline conditions (Poulter and Pederson, 2006). There is growing awareness on the part of residents and local officials about potential vulnerabilities across the landscape (Poulter, *et al*., 2009). Some farmers acknowledge that salt intrusion and sea- level rise are affecting their fields (Moorhead and Brinson, 1995). Researchers at North Carolina State University are using Hyde County farms to experiment with the development of new varieties of salt-tolerant soybeans (Lee *et al*., 2004). Hyde County is building a dike around Swan Quarter, the county seat (Hyde Country, 2008).

A variety of evidence has suggested to some stakeholders that the risks to the Albemarle-Pamlico Peninsula merit special management responses. In fact, because so much of the landscape across the peninsula has been transformed by humans, some have expressed concern that the ecosystem may be less resilient and less likely to be able to adapt when exposed to mounting stresses (Pearsall *et al*., 2005). Thus far, no comprehensive long-term response to the effects of sea-level rise on the peninsula has been proposed. In 2007, The Nature Conservancy, U.S. Fish and Wildlife Service, National Audubon Society, Environmental Defense, Ducks Unlimited, the North Carolina Coastal Federation and others began working to build an Albemarle-Pamlico Conservation and Communities Collaborative (AP3C) to develop a long-term strategic vision for the peninsula. Although this initiative is only in its infancy, sea-level rise will be one of the first and most important issues the partnership will address (Nature Conservancy, 2008).

The Nature Conservancy and other stakeholders have already identified several adaptive responses to sea-level rise on the Peninsula. Many of these approaches require community participation in conservation efforts, land protection, and adaptive management (Pearsall and Poulter, 2005). Specific management strategies that The Nature Conservancy and others have recommended include: plugging drainage ditches and installing tide gates in agricultural fields so that sea water does not flow inland through them, establishing cypress trees where land has been cleared in areas that are expected to become wetlands in the future, reestablishing brackish marshes in hospitable areas that are likely to become wetlands in the future, creating conservation corridors that run from the shoreline inland to facilitate habitat migration, reducing habitat fragmentation, banning or restricting hardened structures along the estuarine shoreline, and establishing oyster reefs and submerged aquatic vegetation beds offshore to help buffer shorelines (Pearsall and DeBlieu, 2005; Pearsall and Poulter, 2005).

More than other areas in the Mid-Atlantic, the Albemarle-Pamlico Sound region appears to be potentially vulnerable to the possibility that several impacts of sea-level rise might compound to produce an impact larger than the sum of the individual effects (Poulter and Halpin, 2007; Poulter *et al*., 2008). If a major inlet opened, increasing the tide range and salinity levels, it is possible that some freshwater wetlands that are otherwise able to keep pace with rising sea level would be poisoned by excessive salinity and convert to open water. Similarly, if a pulse of salt water penetrated into the groundwater, sulfate reduction of the organic-rich soil and peat that underlies parts of the region could cause the land surfaces to subside (Hackney and Yelverton, 1990; Henman and Poulter, 2008; Mitsch and Gosselink, 2000; Portnoy and Giblin, 1997). Moreover, a substantial acceleration in the rate of sea-level rise storms of the type described below could cause barrier islands to be breached (see Chapter 3). Pamlico Sound (and potentially Albemarle Sound) could be transformed from a protected estuary into a semi-open embayment with saltier waters, regular astronomical tides, and larger waves (Riggs and Ames, 2003).

A1.G.2 Shore Processes

A1.G.2.1 Ocean Coasts

North Carolina receives the highest wave energy along the entire east coast of the United States and the northwest Atlantic margin (Riggs and Ames 2003). The coast of North Carolina has shifted significantly over time due to storms, waves, tides, currents, rising sea level, and other natural and human activities. These factors have caused variable sediment transport, erosion, and accretion, along with the opening and closing of inlets (see, *e.g.*, Everts *et al.*, 1983).

The North Carolina Division of Coastal Management (NCDCM) has calculated long-term erosion rates along the coastline adjacent to the ocean by comparing the location of shorelines in 1998 with the oldest available maps of shoreline location, mostly from the 1940s. The average erosion rate was 0.8 m (2.6 ft) per year. Approximately 18 percent of the ocean coastline retreated by more than 1.5 m per year (5 ft per year), 20 percent eroded at an annual rate of 0.6 to 1.5 m (2 to 5 ft) per year, and 30 percent of the coastaline eroded by 0.6 m (2 ft) per year or less. However, 32 percent of the coastline accreted (NC DCM, 2003). The NCDCM recalculates long-term erosion rates about every five years to better track the dynamic shoreline trends and establish the setback line that determines where structures may be permitted on the oceanfront (NC DCM, 2005).

An analysis of shoreline change between approximately 1850 and 1980 in the area between the northern border of North Carolina and the point 8 km west of Cape Hatteras has been published. Data were averaged over 2 km reaches (stretches of coastline). Across the areas where data were available during this time period, approximately 68 percent of the ocean shoreline retreated towards the mainland, while approximately 28 percent advanced (or accreted) away from the mainland, and 4 percent did not change position (Everts *et al.*, 1983). On average, the parts of the coastline between Ocracoke Inlet and Cape Hatteras eroded an average of 4.5 m (14.8 ft) per year over 1852 to 1917, 8.3 m (27.2 ft) per year over 1917 to 1949, and 2.0 m (6.6 ft) per year over 1949 to 1980. The average erosion rate over the study period along the parts of the coastline facing east (between Cape Hatteras and Cape Henry, in Virginia) was 0.8 m (2.6 ft) per year. However, the study indicates that the coastline from Cape Hatteras to Oregon Inlet accreted slightly (an average of 0.4 m [1.3 ft] per year) over 1852 to 1917, eroded an average of 2.9 m (9.5 ft) per year over 1917 to 1949, and eroded an average of 1.3 m (4.3 ft) per year over 1949 to 1980. North of Oregon Inlet, the coastline was stable, on average, over 1852 to 1917; however, there was an average of 1.2 m (3.9 ft) per year of erosion over 1917 to 1949 and an average of 0.3 m (1.0 ft) per year of erosion in 1949 to1980 (Everts *et al*., 1983).

The report cautions against predicting future shoreline change based on the limited data available from surveys conducted since 1850. The authors observe that shoreline change can be influenced by local features, such as inlets, capes, and shoals (Everts *et al.*, 1983).

For example, shorelines north of the ridges of three offshore shoals intersecting North Carolina's ocean coast have retreated, whereas shorelines south of the ridges have generally advanced (Everts *et al.*, 1983). Everts *et al*. also point out that while geological evidence indicates that the barrier islands have migrated landward over thousands of years, the islands are presently narrowing from both sides, in part because overwash processes cannot carry sand to the estuarine side due to island width and development (Everts *et al.*, 1983).

More recently, researchers have used models to predict the amount of shoreline change that might result from future sea-level rise, above and beyond the shoreline change caused by other factors. For example, one analysis of statewide erosion rates over the past 100 years led researchers to estimate that a 1 m sea-level rise would cause the shore to retreat an average of 88 m (289 ft), in addition to the erosion caused by other factors (excluding inlets) (Leatherman *et al.*, 2000a). Another study estimated that a rise in sea level of 0.52 m between 1996 and 2050 would cause the shoreline at Nags Head to retreat between 33 and 43 m, or between 108 and 144 ft (Daniels, 1996).

Some researchers are concerned that the barrier islands themselves may be in jeopardy if sea-level rise accelerates. According to Riggs and Ames (2003), about 40 km (25 mi) of the Outer Banks are so sediment-starved that they are already in the process of "collapsing". Within a few decades, they estimate, portions of Cape Hatteras National Seashore could be destroyed by: (1) sea-level rise (at current rates or higher); (2) storms of the magnitude experienced in the 1990s; or (3) one or more Category 4 or 5 hurricanes hitting the Outer Banks (Riggs and Ames, 2003). Most of the Outer Banks between Nags Head and Ocracoke is vulnerable to barrier island segmentation and disintegration over the next century if the rate of sea-level rise accelerates by 2 mm per year—and portions may be vulnerable even at the current trend (see Chapter 3.)

A1.G.3 Vulnerable Habitats and Species

Some wetland systems are already at the limit of their ability to vertically keep pace with rising sea level, such as the remnants of the tidal marshes that connected Roanoke Island to the mainland of Dare County until the nineteenth century. The pocosin wetlands can vertically accrete by about 1 to 2 mm per year with or without rising sea level—when they are in their natural state (Craft and Richardson, 1998; Moorhead and Brinson, 1995). The human-altered drainage patterns, however, appear to be limiting their vertical accretion—and saltwater intrusion could cause subsidence and conversion to open water (Pearsall and Poulter, 2005).

A1.G.3.1 Estuarine Shoreline Retreat

The Pamlico and Albemarle Sounds, North Carolina's smaller sounds, and the lower reaches of the Chowan, Roanoke, Tar, and Neuse Rivers are affected by rising sea level (Brinson *et al.*, 1985). Rising sea level is not the primary cause of shoreline retreat along estuarine shores in North Carolina. Storm waves cause shorelines to recede whether or not the sea is rising. A study of 21 sites estimated that shoreline retreat—caused by "the intimately coupled processes of wave action and rising sea level"—is already eliminating wetlands at a rate of about 3 sq km (800 ac) per year, mostly in zones of brackish marsh habitat, such as on the Albemarle-Pamlico Peninsula (Riggs and Ames, 2003).

Riggs and Ames (2003) compiled data collected across North Carolina shorelines, both those that are adjacent to wetlands and those that are not. These data show that the vast majority of estuarine shores in the region are eroding, except for the sound sides of barrier islands (which one might expect to advance toward the mainland). Shores have retreated almost 2 m (7 ft) per year, over periods as long as 30 years. Annual averages for most shoreline types are less than 1 m per year, (Table A1.4) but annual maxima exceed the average many-fold and can reach 8 m (26 ft) per year where the shoreline is characterized by sediment bluffs or high banks. One or a few individual storm events contribute disproportionately to average annual shoreline recession rates (Riggs and Ames, 2003).

Table A1.4 Estuarine shoreline erosion rates by shoreline type and the percent of total shoreline for each type. From Riggs and Ames (2003).

Shoreline type	Percent of shoreline	Maximum rate per year (m)	Average rate per year (m)
Sediment Bank	38		
Low bank	30	2.7	1.0
Bluff/high bank	8	8.0	0.8
Back-barrier strandplain beach	<1	0.6	-0.2[1]
Organic Shoreline	62		
Mainland marsh	55	5.6	0.9
Back-barrier marsh	<1	5.8	0.4
Swamp forest	7	1.8	0.7
Human Modified	Unknown	2.0	0.2
Weighted Average[2]			2.7

[1] The negative erosion rate listed refers to this shoreline type, on average, accreting.
[2] This weighted average excludes strandplain beaches and human-modified shorelines.

An analysis of estuarine shoreline change is also included in Everts *et al.* (1983). The authors calculated average erosion rates for the periods around 1850 to 1915 and 1915 to

1980. Between Nags Head and Oregon Inlet, the estuarine points analyzed between 1850 and 1915 showed both advance rates greater than 4 m (13 ft) per year and retreat rates of close to 3 m (10 ft) per year. However, between 1915 and 1980, the estuarine points analyzed in this region showed a range of approximately 1 m per year of retreat to less than 1 m per year of advance. Study authors did not analyze the area adjacent to Oregon Inlet or along most of Pea Island. Just north of Rodanthe, the earlier dataset shows dramatic shoreline advance averaging 4 m per year, but the later dataset shows a relatively stable shoreline. Just south of Rodanthe, there was slow advance during the earlier period and slow retreat (of approximately 1 m per year or less) in the later period. Between Avon and Salvo, both datasets show shoreline retreat at rates not exceeding 2 m per year, with a slightly higher average rate of retreat in the later period than the earlier period (taken from Figure 34, Everts *et al*., 1983).

The study indicates that the average retreat rate across all the estuarine points analyzed from 1852 to 1980 was 0.1 m (4 in) per year. However, this average masks an important trend seen both north and south of Oregon Inlet. The rate of shoreline change gradually changed from shoreline advance (movement towards the sounds) to shore retreat. The rate of advance was almost 2.0 m per year from 1852 to 1917. Shores were generally stable from 1917 to 1949, but they retreated over the period from 1949 to 1980. Erosion was greater along estuarine shores facing west (an average of 1.2 m per year over 1852 to 1980) than those facing north or south (averaging 0.1 m per year over 1852 to 1980). The authors observed that these data indicate that the North Carolina barrier islands in the study region did not appear to be migrating landward during the study period, but instead they narrowed from both sides. The present rate of island narrowing averages 0.9 m (3.0 ft) per year. Available data indicate that sand washed over the barrier islands to the estuarine side of islands (overwash) did not significantly affect shoreline change along the estuary, particularly after the artificial dunes were constructed, a process that might itself have caused erosion from the sound side because it removed sand from the estuarine system (Everts *et al*., 1983). Away from the inlets connecting the Albemarle-Pamlico Estuarine System to the ocean, the authors conclude that the retreat of the estuarine shoreline "can be accounted for mostly by sea level rise" (Everts *et al*., 1983).

A1.G.3.2 Potential for Wetlands to Keep Pace with Rising Sea Level

Sections 4.3, 4.4, and 4.6 in Chapter 4 discuss wetland vertical and horizontal development. In North Carolina, vertical accretion rates have, for the most part, matched the rate of sea-level rise (see Section 4.6.2 in Chapter 4; Cahoon, 2003; Erlich, 1980; Riggs *et al.*, 2000). Vertical accretion rates as high as 2.4 to 3.6 mm per year have been measured, but the maximum rate at which wetlands can accrete is not well understood (Craft e*t al.*, 1993). Further, relative sea-level rise in North Carolina in recent years has ranged from approximately 1.8 to 4.3 mm per year at different points along the North Carolina coast (Zervas, 2004). As discussed in Section 4.6.2.2, wetland drowning could result in some areas if rates of global sea-level rise increase by 2 mm per year and is likely if rates increase by 7 mm per year. Day *et al.* (2005) suggest that brackish marshes in the Mississippi Delta region cannot survive 10 mm per year of relative sea-level rise. Under this scenario, fringe wetlands of North Carolina's lower coastal plain would drown. However, swamp forest wetlands along the piedmont-draining rivers are likely to sustain themselves where there is an abundant supply of mineral sediments (*e.g.*, river floodplains, but not river mouths) (Kuhn and Mendelssohn, 1999). As sea level rises further and waters with higher salt content reach the Albemarle-Pamlico peninsula, the ability of peat-based wetlands to keep up is doubtful, where the peat, root map, and vegetation would first be killed by brackish water (Poulter, 2005; Portnoy and Giblin, 1997; Pearsall and Poulter, 2005).

Finally, as described in Chapter 3, in a scenario where there are high rates of sea-level rise, more inlets would likely be created and segmentation or disintegration of some of the barrier islands is possible. This would cause a state change from a non-tidal to tidal regime as additional inlets open, causing the Albemarle and Pamlico Sounds to have a significant tide range and increased salinity, which would greatly disrupt current ecosystems. In this scenario, wave activity in the sounds could change erosion patterns and could impact wetlands (Riggs and Ames, 2003).

A1.G.3.3 Environmental Implications of Habitat Loss and Shore Protection

Ecological/habitat processes and patterns. Some wetland functions are proportional to size. Other functions depend on the wetland's edges, that is, the borders between open water and wetland. Many irregularly flooded marshes in coastal North Carolina are quite large. In the absence of tidal creeks and astronomical tidal currents, pathways for fish and invertebrate movement are severely restricted, except when wind tides are unusually high or during storm events. By contrast, the twice-daily inundation of tidal marshes by astronomical tides increases connections across the aquatic-wetland edge, as does the presence of tidal creeks, which allow fish and aquatic invertebrates to exploit intertidal areas (Kneib and Wagner, 1994). Mobility across ecosystem boundaries is less prevalent in irregularly flooded marshes, where some fish species become marsh "residents" because of the long distances required to navigate from marshes to subtidal habitats (Marraro *et al.*, 1991). Where irregularly flooded marshes are inundated for weeks at a time, little is known about how resident species adapt. These include, among other species, several types of fish (*e.g.*, killifish and mummichogs), brown water snakes, crustaceans (various species of crabs), birds (yellowthroat, marsh wren, harrier, swamp sparrow, and five species of rails), and several species of mammals (nutria, cotton rat, and raccoon). North Carolina's coastal marshes are also home to a reintroduced population of red wolves, and sea-level rise could affect this population (see Box A1.9).

Effects of human activities. Levees associated with waterfowl impoundments have isolated large marsh areas in the southern Pamlico Sound from any connection with estuarine waters. Impoundments were built to create a freshwater environment conducive to migratory duck populations and thus eliminated most other habitat functions mentioned above for brackish marshes. Further, isolation from sea level influences has likely disconnected the impoundments from pre-existing hydrologic gradients that would promote vertical accretion of marsh soil. If the impoundments were opened to an estuarine connection after decades of isolation, they would likely become shallow, open-water areas incapable of reverting to wetlands (Day *et al.*, 1990).

Drainage ditches, installed to drain land so that it would be suitable for agriculture and timber harvesting, are prevalent in North Carolina. By the 1970s, on the Albemarle-Pamlico Peninsula, there were an estimated 32 km (20 mi) of streams and artificial drainage channels per square mile of land, while the ratio in other parts of North Carolina ranged from 1.4:1 to 2.8:1 (Heath, 1975). In Dare County, there are currently an estimated 4 km of drainage ditch features per sq km (Poulter *et al.*, 2008). In many cases, ditches, some of which were dug more than a century ago to drain farmland (Lilly, 1981), now serve to transport brackish water landward, a problem that could become increasingly prevalent as sea level rises. Saltwater intrusion into agricultural soils and peat collapse are major consequences of this process.

BOX IV.9: Reintroduced population of red wolves in North Carolina

***Red Wolf** (Canus rufus)*

Photograph credit: U.S. Fish and Wildlife Service. Red Wolf Recovery Project. Photos. Accessed at: <http://www.fws.gov/alligatorriver/red wolf/rwpics.html>. Photo: Greg Koch

Habitat: The red wolf (*Canus rufus*) is federally listed as endangered and was formerly extinct in the wild. Red wolves were hunted and trapped aggressively in the early 1900s as the Southeast became increasingly developed, and the remaining wolf populations then suffered further declines with the extensive clearing of forest and hardwood river bottoms that formed much of the prime red wolf habitat (USFWS, 1993; USFWS, 2004c). The last wild red wolves were found in coastal prairie and marsh habitat, having been pushed to the edges of their range in Louisiana and Texas. The red wolf is elusive and most active at dawn and dusk. It lives in packs of five to eight animals, and it feeds on white-tailed deer, raccoon, rabbit, nutria, and other rodents. In addition to food and water in a large home range area (65 to 130 sq km), red wolves require heavy vegetation cover (USFWS, 1993).

Locations: Through a captive breeding program and reintroduction of the species, there are now an estimated total of 100 red wolves living in the wild in coastal areas of North Carolina. In the wild, the red wolf currently occupies approximately 1.7 million acres on three national wildlife refuges and other public and private lands in eastern North Carolina. Principal among these areas is the Alligator River National Wildlife Refuge (NWR), the site of the red wolf's reintroduction to the wild in 1987 (USFWS, 2006). This low-lying refuge is surrounded on three sides by coastal waters and connected to the mainland by a largely developed area. Red wolves have also been reintroduced to the Pocosin Lakes NWR, slightly inland from Alligator River NWR, and are occasionally sighted on the Mattamuskeet NWR. The last wild red wolves were found in Louisiana and Texas coastal marsh areas, but their historic range extended from southern Pennsylvania throughout the Southeast and west as far as central Texas (USFWS, 2004c). Despite their potential for survival in numerous habitat types throughout the southeastern United States, the small current population could face serious threats from sea-level rise.

Impact of Sea Level Rise: In a 2006 report, the Defenders of Wildlife (an environmental advocacy organization) characterized Alligator River NWR, the red wolf's primary population center, as one of the ten NWRs most gravely at risk due to sea level rise. The effects of sea-level rise can already be seen on the habitat in Alligator River NWR, where pond pine forest has transitioned into a sawgrass marsh in one area, and the peat soils of canal banks are eroding near the sounds (Stewart, 2006). Areas of hardwood forest and pocosin will be replaced by expanding grass-dominated freshwater marshes currently occupying the edges of the sounds. Bald cypress and swamp tupelo forests will also replace the hardwood areas (USFWS, 2006). While it is too early to be certain, the Alligator River NWR biologist projects that the red wolf is not likely to adapt to the marsh habitat given the rate at which habitat conversion is already taking place (Stewart, 2006). Ultimately, the low-lying refuge risks being flooded by sea level rise, in addition to its forests being converted to marsh. Furthermore, developed areas inland of the peninsular refuge limit habitat migration potential.

A number of tide gates have been installed on the Albemarle-Pamlico Peninsula to reduce brackish water intrusion, but these will serve their purpose only temporarily, given continued sea-level rise. One analysis indicates that plugging ditches in selected places to reduce saltwater flow inland would be effective for local stakeholders. Another option is to install new water control structures, such as tide gates, in selected locations (Poulter *et al*., 2008). Plugging ditches would also help restore natural drainage patterns to the marshes.

A1.G.4 Development, Shore Protection, and Coastal Policies

A1.G.4.1 Statewide Policy Context

Several North Carolina laws and regulations have an impact on response to sea-level rise within the state. First, setback rules encourage retreat by requiring buildings being constructed or reconstructed to be set back a certain distance from where the shoreline is located when construction permits are issued. Second, North Carolina does not allow "hard" shoreline armoring [150] such as seawalls and revetments on oceanfront shorelines[151], preventing property owners from employing one possible method of holding back the sea to protect property[152]. Along estuarine shores, however, shoreline armoring is allowed landward of any wetlands. The North Carolina Coastal Resources Commission (CRC) is preparing new state regulations for the location and type of estuarine shoreline stabilization structures to help encourage alternatives to bulkheads

[150] See Chapter 6 for an explanation of various shore protection options.
[151] 15A NCAC 07H.0101.
[152] Some hard structures exist along North Carolina's oceanfront shoreline (*e.g.*, adjacent to inlets). Many were built before 1985 when the statute was enacted to ban new hard structures, or were covered by exception in the rules. The Legislature regularly considers additional exceptions, such as terminal groins for beach nourishment projects and jetties for stabilizing inlets. *e.g.* North Carolina SB599 (2007-2008).

(NC CRC, 2008b; Feldman, 2008). The goals are similar to the “living shorelines” legislation recently enacted in Maryland (see Section A1.F.2.2). Adding sand to beaches (*i.e.*, beach nourishment) is the preferred method in North Carolina to protect buildings and roads along the ocean coastline.

The state’s Coastal Area Management Act (CAMA) has fostered land use planning in the 20 coastal counties to which it applies. Regulations authorized by CAMA require local land use plans to “[d]evelop policies that minimize threats to life, property, and natural resources resulting from development located in or adjacent to hazard areas, such as those subject to erosion, high winds, storm surge, flowing, or sea level rise”. However, the state’s technical manual for coastal land use planning (NC DCM, 2002) does not mention sea-level rise. Accordingly, local land use plans either do not mention sea-level rise at all, mention it only in passing, or explicitly defer decisions about vulnerable areas until more information is available in the future (Feldman, 2008; Poulter *et al.*, in press). Nevertheless, the regulatory requirement to consider sea-level rise may eventually encourage local jurisdictions to consider how the communities most vulnerable to sea-level rise should prepare and respond (Feldman, 2008). Land-use plans are updated regularly and are an important tool for increasing public awareness about coastal hazards.

CAMA and the state’s Dredge and Fill Law authorize the CRC to regulate certain aspects of development within North Carolina’s 20 coastal counties. For example, the CRC issues permits for development and classifies certain regions as Areas of Environmental Concern (AECs, *e.g.*, ocean hazard zones and coastal wetlands) where special rules governing development apply. Land use plans are binding in AECs. In response to the threat of damage to coastal structures from the waves, since 1980 North Carolina has required new development to be set back from the oceanfront. The setbacks are measured from the first line of stable natural vegetation[153]. Single-family homes of any size—as well as multi-family homes and non-residential structures with less than 5,000 sq ft of floor area—must be set back by 60 ft or 30 times the long-term rate of erosion as calculated by the state, whichever is greater. Larger multi-family homes and non-residential structures must be set back by 120 ft or the erosion-based setback distance, whichever is greater. The setback distance for these larger structures is set as either 60 times the annual erosion rate or 105 ft plus 30 times the erosion rate, whichever is less[154]. North Carolina is considering changes to its oceanfront setback rules, including progressively larger setback factors for buildings with 10,000 sq ft of floor area or more (NC CRC, 2008a). Along estuarine shorelines, North Carolina has a 30-ft setback[155] and restricts development between 30 and 75 ft from the shore[156]. As the shore moves inland, these setback lines move inland as well.

As of 2000, the U.S. Army Corps of Engineers (USACE) participated in beach nourishment projects along more than 51 km (32 mi) of North Carolina's shoreline (including some nourishment projects that occurred as a result of nearby dredging projects), and nourishment along an additional 137 km (85 mi) of coastline had been

[153] Local governments can request that an alternative vegetation line be established under certain conditions. Additional rules also apply when there is a sand dune between the home and the shoreline, to protect the integrity of the dune.
[154] 15A NCAC 07H. 0305 - 0306.
[155] 15A NCAC 07H.0306.
[156] 15A NCAC 07H.0209

proposed (USACE, 2000)[157]. If necessary, property owners can place large geotextile sandbags in front of buildings to attempt to protect them from the waves. Standards apply to the placement of sandbags, which is supposed to be temporary (to protect structures during and after a major storm or other short-term event that causes erosion, or to allow time for relocation)[158]. Buildings are supposed to be moved or removed within two years of becoming "imminently threatened" by shoreline changes[159].

North Carolina officials are in the process of reassessing certain state policies in light of the forces of shoreline change and climate change. Policy considerations have been affected by numerous studies that researchers have published on the potential effects of sea-level rise on North Carolina (Poulter *et al.*, in press). The state legislature appointed a Legislative Commission on Global Climate Change to study and report on potential climate change effects and potential mitigation strategies, including providing recommendations that address impacts on the coastal zone[160]. The Commission's recommendations have not yet been finalized, but an initial draft version offered such suggestions as creating a mechanism to purchase land or conservation easements in low-lying areas at great risk from sea-level rise; providing incentives for controlling erosion along estuarine shorelines using ecologically beneficial methods; creating a commission to study adaptation to climate change and make recommendations about controversial

[157] Although beach nourishment has been a common response to sea level rise in many areas along the coast, there has been a decline in the availability of suitable sand sources for nourishment, particularly along portions of the coast (Bruun, 2002, Finkl *et al*. 2007). In addition, the availability of substantial federal funds allocated for beach nourishment has become increasingly questionable in certain areas, particularly in Dare County (Dare County, 2007; Coastal Science and Engineering, 2004).
[158] 15A NCAC 07H.0308
[159] 15A NCAC 7H.0306 (l)
[160] See the "North Carolina Global Warming Act," Session Law 2005-442.

issues; and inventorying, mapping, and monitoring the physical and biological characteristics of the entire shoreline (Feldman, 2008; Riggs *et al*., 2007).

The CRC is also considering the potential effects of sea-level rise and whether to recommend any changes to its rules affecting development in coastal areas (Feldman, 2008). In addition, NCDCM is developing a Beach and Inlet Management Plan to define beach and inlet management zones and propose preliminary management strategies given natural forces, economic factors, limitations to the supply of beach-quality sand, and other constraints (Moffatt and Nichol, 2007).

A1.G.4.2 Current Land Use

Ocean Coast (from north to south). North Carolina's ocean coast, like the coasts of most states, includes moderate and densely developed communities, as well as undeveloped roadless barrier islands. Unlike other mid-Atlantic states, North Carolina's coast also includes a major lighthouse (at Cape Hatteras) that has been relocated landward, a roadless coastal barrier that is nevertheless being developed (described below), and densely populated areas where storms, erosion, and sea-level rise have caused homes to become abandoned or relocated.

The northern 23 km (14 mi) of the state's coastline is a designated undeveloped coastal barrier under the Coastal Barrier Resources Act (CBRA) and hence ineligible for most federal programs (USFWS, undated[c]) This stretch of barrier island includes two sections of Currituck National Wildlife Refuge, each about 2 km (1 mi) long, which are both off-limits to development. Nevertheless, the privately owned areas are gradually being developed, even though they are accessible only by boat or four-wheel drive vehicles traveling along the beach. The CBRA zones are ineligible for federal beach nourishment and flood insurance (USFWS, undated[c]).

Along the Dare County coast from Kitty Hawk south to Nags Head, federal legislation has authorized shore protection, and USACE (2006b) has concluded that the proposed project would be cost-effective. In some areas, homes have been lost to shoreline erosion (Pilkey *et al.*, 1998) (see Figure 12.6). Continued shore erosion has threatened some of the through-streets parallel to the shore, which had been landward of the lost homes. Given the importance of those roads to entire communities (see Section 12.2 in Chapter 12) small sand replenishment projects have been undertaken to protect the roads (Town of Kitty Hawk, 2005). The planned beach nourishment project does not extend along the coast to the north of Kitty Hawk. Those beaches are generally not open to the public and are currently ineligible for publicly funded beach nourishment.

From Nags Head to the southwestern end of Hatteras Island, most of the coast is part of Cape Hatteras National Seashore. A coastal highway runs the entire length, from which one can catch a ferry to Ocracoke Island, carrying through traffic to both Ocracoke and Carteret County. Therefore, the National Park Service must balance its general commitment to allowing natural shoreline processes to function (see Chapter 12.1; NRC 1988) with the needs to manage an important transportation artery. In most cases, the approach is a managed retreat, in which shores generally migrate but assets are relocated rather than simply abandoned to the sea. Congress appropriated $9.8 million to move the Cape Hatteras Lighthouse 1,600 ft (468 m) inland in 1999 (NPS, 2000) (see Figure 11.1a). The coastal highway has been relocated inland in places. Because it is essential infrastructure, its protection would probably require maintaining the barrier island itself, for example, by filling inlets after severe storms. A possible exception is where the highway runs through Pea Island National Wildlife Refuge on the northern end of Hatteras Island, just south of the bridge over Oregon Inlet. The federal and state governments are considering the possibility that when a new bridge is built over Oregon Inlet, it would bypass the National Wildlife Refuge and extend over Pamlico Sound just west of Hatteras Island as far as Rodanthe (USDOI, 2007).

The undeveloped Portsmouth Island and Core Banks constitute Cape Lookout National Sea Shore and lack road access. Cape Lookout is located on Core Banks. Shackleford Banks, immediately adjacent to the southwest, is also roadless and uninhabited. Southwest of Cape Lookout, the coast consists mostly of developed barrier islands, conservation lands, and designated “undeveloped coastal barriers” that are nevertheless being developed. Bogue Banks includes five large communities with high dunes and dense forests (Pilkey *et al.*, 1998). Bogue Banks also receives fill to widen its beaches regularly.

To the west of Bogue Banks are the barrier islands of Onslow County and then Pender County. Some islands are only accessible by boat, and most of these are undeveloped. North Topsail Beach, on Topsail Island, has been devastated by multiple hurricanes, in part due to its low elevation and the island's narrow width. Erosion has forced multiple roads on the island to be moved. While some parts of North Topsail Beach are part of a unit under the CBRA system, making them ineligible for federal subsidies, development has occurred within them nonetheless (Pilkey *et al.*, 1998).

Further to the southwest are the barrier islands of New Hanover County, including Figure Eight Island, which is entirely privately-owned with no public access to the beach, and hence ineligible for public funding for beach nourishment (see Chapter 8). Wrightsville Beach, like many other communities southwest of Cape Lookout, has an inlet on each side. It is the site of a dispute to protect a hotel from being washed away due to inlet migration (Pilkey *et al.*, 1998). The USACE has made a long-term commitment to regular beach renourishment to maintain the place of the shoreline in Wrightsville Beach and Carolina Beach (USACE, 2006a). An exception to North Carolina's rules forbidding hardened structures has been granted in Kure Beach, west of Carolina Beach, where stone revetments have been placed on the oceanfront to protect Fort Fisher (which dates back to the Civil War). These structures also protect a highway that provides access to the area (Pilkey *et al.*, 1998). Most of the beach communities in New Hanover County are extensively developed.

Some of the barrier islands in Brunswick County, close to the South Carolina state line, are heavily forested with high elevations, making them more resilient to coastal hazards (Pilkey *et al.*, 1998). Holden Beach and Ocean Isle Beach, however, contain many dredge-and-fill finger canals. Historically, at least two inlets ran through Holden Beach; and storms could create new inlets where there are currently canals (Pilkey *et al.*, 1998).

Estuarine Shores. Significant urbanization was slow to come to this region for many reasons. Most of the area is farther from population centers than the Delaware and Chesapeake Estuaries. The Outer Banks were developed more slowly than the barrier islands of New Jersey, Delaware, and Maryland. Most importantly, the land is mostly low and wet.

Unlike the Delaware Estuary, North Carolina does not have a long history of diking tidal wetlands to reclaim land from the sea for agricultural purposes[161]. However, the state is starting to gain experience with dikes to protect agricultural lands from flooding. In Tyrrell County, the Gum Neck has been protected with a dike for four decades. A dike is under construction for the town and farms around Swan Quarter (Allegood, 2007), the county seat of Hyde County (which includes Ocracoke Island). Hurricanes Fran and Floyd led to federally-sponsored purchases of thousands of properties across North Carolina's eastern counties, facilitating the demolition or relocation of associated structures. Pamlico County has encouraged people to gradually abandon Goose Creek Island in the eastern portion of the county, by working with FEMA to relocate people rather than rebuild damaged homes and businesses (Barnes, 2001). By contrast, in other areas (*e.g.*, parts of Carteret County), people took the opposite approach and elevated homes.

[161] Nevertheless, it has had a few short-lived projects, most notably Lake Matamuskeet.

Geography, coastal features, and community characteristics vary greatly along North Carolina's coast. Thus, one can assume that a variety of different planning and adaptation strategies related to shoreline change and sea-level rise would be needed, particularly over the long term. Scientists, managers, and community members in North Carolina have undertaken a variety of efforts to better understand and begin to address potential sea-level rise vulnerabilities and impacts. These research and collaborative efforts may increase awareness, receptivity, and readiness to make informed coastal management decisions in the future (Poulter *et al*., in press).

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