Executive Summary

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1. SEA-LEVEL RISE IN THE MID-ATLANTIC

Global sea level is rising and is expected to accelerate. Global sea level is primarily affected by the proportion of water that exists in ocean basins and the amount that is held in glaciers and ice sheets. Sea level has risen and declined as the climate has cooled (producing ice ages) and warmed (melting ice sheets) over the past several million years. Sea level has risen about 120 m (390 ft) since the peak of the last ice age approximately 21,000 years ago. During the last 10,000 years, by contrast, global sea level has been relatively stable, enabling development of human civilization along the coasts.

Recent assessments have indicated that the rate of sea-level rise increased between the mid-19th and mid-20th centuries. Global sea level rose at an average rate of 1.7 mm/yr over the 20th century, with an increased rate of 3.1 mm/yr from 1993 to 2003. In the mid-Atlantic region from New York to North Carolina, tide gauge observations indicate that relative sea-level rise rates have exceeded the global rate due to a combination of land subsidence and global sea-level rise. In this region, relative sea-level rise rates ranged between 3 to 4 mm per year (~1ft per century) over the 20th century.

Rising water levels are submerging low-lying lands, eroding beaches, converting wetlands to open water, exacerbating coastal flooding, and increasing the salinity of estuaries and freshwater aquifers. In undeveloped or less-developed coastal areas where the human influence is less, sea-level rise could be accommodated more readily as ecosystems and geological systems are often more capable of shifting upward and landward with the rising water levels than are human systems.

All of the effects may be increased if the rate of sea-level rise accelerates in the future. Rising global temperatures are likely to accelerate the rate of sea-level rise by further expanding ocean water, melting mountain glaciers, and increasing the rate at which Greenland and Antarctic ice sheets melt or discharge ice into the oceans. If the sea rises more rapidly than the rate with which a particular system can keep pace, it could fundamentally change the state of the coast. Wetlands, beaches, coastal barriers, and estuarine systems have always contended with sea-level changes, but accelerated rates of rise may create more difficult conditions for survivability, and continued coastal development may impose additional challenges.

At the current rate of sea-level rise, over recent decades, coastal residents and businesses have been responding by moving out of harm’s way, holding back the sea, or some combination of both approaches. Wildlife species, particularly in areas affected by coastal development and the armoring of coastlines, have been reacting to their changing habitats in a variety of ways: *e.g.*, moving to other, often less suitable areas, or by having fewer offspring.

This report examines the sensitivity of the Mid-Atlantic coast and its inhabitants to continued and accelerated sea-level rise. It does not estimate how much the sea may rise; instead, it relies upon scenarios that broadly represent information in recent scientific literature. This report explores the implications of three future sea-level rise scenarios:

- Scenario 1 is the 20th century mid-Atlantic trend (3-4 mm/yr; 0.1-0.2 in/yr), and would result in a rise in sea level of 30-40 cm (12-16 in) by 2100.
- Scenarios 2 is an acceleration over the 20th century trend by 2 mm/yr (0.1 in/yr), and would result in a rise in sea level of 50-60 cm (20-24 in) by 2100.
- Scenario 3 is an acceleration over the 20th century trend by 7 mm/yr (0.3 in/yr), and would result in a rise in sea level of 100-110 cm (39-43 in) by 2100.

We also discuss the implications of a 2 meter rise in sea level, which may be possible in the next 100 years or longer.

A rise in sea level implies that land that is now barely above sea level will end up below sea level if no shore protection measures are taken to prevent it from being submerged. However, the reality of how the coast will respond to sea-level rise is more complicated than simple inundation. Storms are major forces in causing coastal change and may increase in intensity as the climate warms. Erosion can cause land to be lost even if the sea does not rise enough to inundate it; sediments eroded from one place can accrete the shoreline elsewhere or be transported offshore; and sometimes wetlands can rise along with the sea rather than become inundated, if sediment inputs are sufficient to compensate for the rise in sea level.

Species that rely on coastal habitat may be adversely affected as sea level rises. A key uncertainty and possible determinant of habitat and species loss is whether or not coastal landforms and present-day habitats will have space to migrate inland in response to sea-level rise. As coastal development continues, the ability for habitats to migrate inland along the rest of the coast will depend on how policies evolve.

2. KEY FINDINGS

This report examines what is potentially at risk from sea-level rise, what adaptation actions are available in response to sea-level rise, and which decisions may change the path forward. The information contained in this report was obtained through synthesis and assessment of the current scientific literature, mapping analyses, expert panel assessments, and information from topical experts.

2.1 Sea-Level Rise and the Physical Environment

2.1.1 Coastal Elevations

Approximately one-sixth of the nation's land close to sea level is in the mid-Atlantic. Sea-level rise is **virtually certain** to cause some areas of dry land to become inundated. Approximately 900-2100 km^2 (350-800 mi^2) of dry land, half of which is in North Carolina, would be flooded during spring high tides if sea level rises 50 cm (20 in), assuming no shore protection measures are taken. For a larger rise, the amount of vulnerable dry land is roughly proportional to the rise in sea level (Chapter 1).

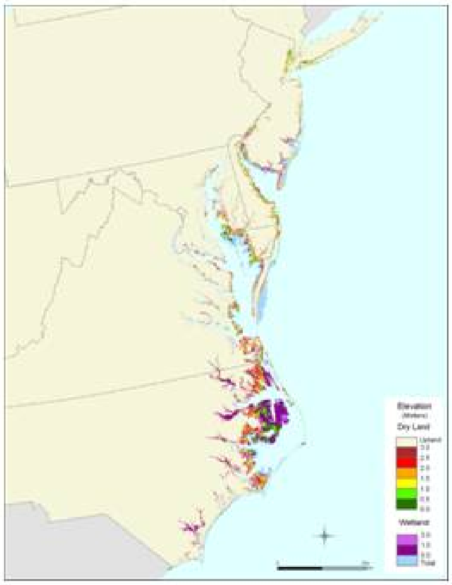

Figure ES.1 Dry land and nontidal wetlands within three meters above the tides in the Mid-Atlantic region.

2.1.2 Ocean Coasts

Nationally, it is **very likely** that erosion will increase in response to sea-level rise, especially in sandy shore environments which comprise all of the mid-Atlantic coast. Within the mid-Atlantic region, it is **virtually certain** that coastal headlands, spits, and barrier islands will also erode in response to future sea-level rise. For the higher sea-level rise scenarios, it is **likely** that some barrier islands in this region will cross a threshold where barrier island migration, segmentation, or disintegration will occur (Chapter 2).

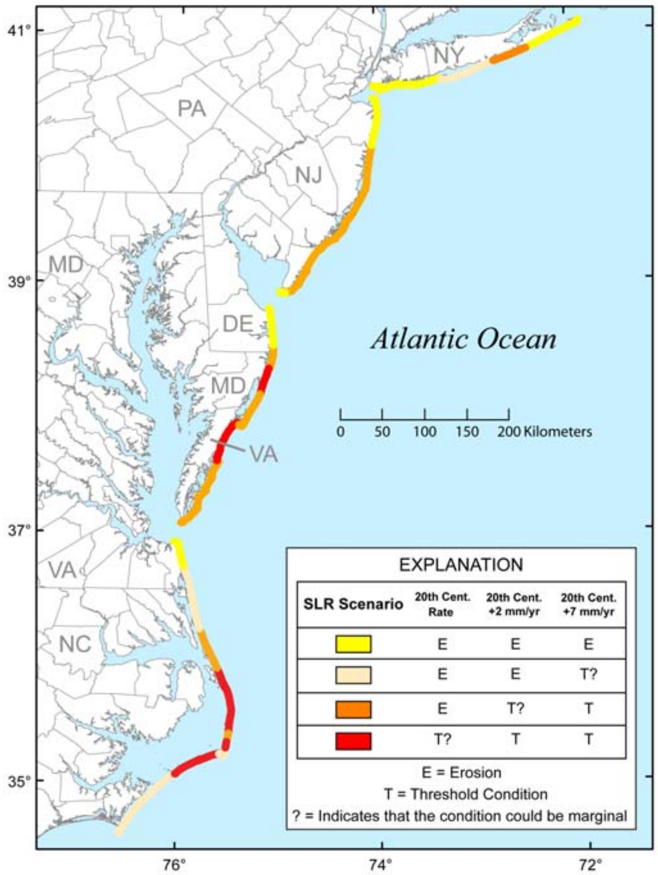

Figure ES.2 Potential coastal landform responses to the three sea-level rise scenarios. Many of the shaded areas are currently experiencing erosion which is expected to increase with future sea-level rise. Coastal segments denoted with a "T" are also expected to undergo erosion and may cross a threshold where barrier island migration, segmentation, or disintegration will occur.

2.1.3 Wetlands

It is **virtually certain** that the Nation's tidal wetlands already experiencing submergence by sea-level rise and associated high rates of loss (*e.g.*, Mississippi River Delta in Louisiana, Blackwater River marshes in Maryland) will continue to lose area under the influence of future accelerated rates of sea-level rise and changes in other climate and environmental drivers (Chapter 3).

It is **very unlikely** that there will be a net increase in tidally influenced wetland area on a national scale over the next 100 years, given current wetland loss rates and the few occurrences of new tidal wetland expansion (*e.g.*, Atchafalaya Delta in Louisiana) (Chapter 3).

For the mid-Atlantic region, an acceleration in sea-level rise of +2 mm/yr will cause many wetlands to become stressed, and it is **likely** that most wetlands would not survive an acceleration in sea-level rise of +7 mm/yr. Excluding North Carolina, the mid-Atlantic has 4200 km^2 (1600 mi^2) of tidal wetlands, but only 300-1000 km^2 (390 mi^2) of dry land within 50 cm above the tides; therefore, the potential area for wetland migration or formation is small compared to the area of wetlands that may be at risk (chapter 3).

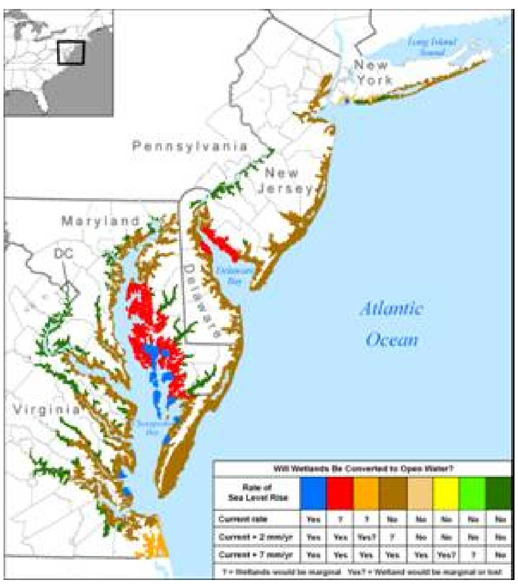

Figure ES.3 Areas where wetlands would be marginal or lost (i.e., converted to open water) under three sea-level rise scenarios.

2.1.4 Vulnerable Species

The quality, quantity, and spatial distribution of coastal habitats will change as a result of shoreline erosion, salinity changes, and wetland loss. Species that rely on these habitats include both terrestrial and aquatic plants and animals (Chapter 4).

Depending on local conditions, habitat may be lost or migrate inland in response to sea-level rise. A key uncertainty and determinant of habitat and species loss is whether or not coastal landforms and present-day habitats will have space to migrate inland (Chapter 4)

Loss of tidal marshes would seriously threaten coastal ecosystems, causing fish and birds to move or produce less offspring. Many estuarine beaches may also be lost, threatening species such as the terrapin and horseshoe crab (Chapter 4).

2.2 Societal Impacts and Implications

2.2.1 Population, Land Use and Infrastructure

The coastal zone has competing interests of increasing population and development building of the necessary supporting infrastructure, while preserving natural coastal wetlands and buffer zones. Increasing sea level will put increasing stress onto the ability to manage these competing interests effectively (Chapter 6).

The available data is sufficient to estimate the number of people who live in the immediate vicinity of land potentially inundated by rising sea level. In the mid-Atlantic, between approximately 900,000 and 3,400,000 people (between 3% and 10% of the total population in the defined region) live on parcels of land or city blocks with at least some land less than 100 cm above spring high water. Approximately 40% of this population is along the Atlantic Ocean or adjacent coastal bays (Chapter 6).

Among the various potential impacts of sea-level rise on infrastructure, the mid-Atlantic transportation infrastructure possibly at risk include ports, highways and rails. For example, in the Port of Wilmington, DE, there is evidence to suggest that for an approximate 50 cm sea-level rise, 70 percent (320 acres) of the port property may be impacted. For the coastal states of Maryland, Virginia, and North Carolina, plus Washington, DC, approximately 3,500 km of our National Highway System, Interstates and other major arterials could be at risk for regular inundation given a sea level rise of 50 cm. Approximately 1,390 km of railway for these same states could be affected for the same scenario (Chapter 6).

2.2.2 Public Access to the Shore

Responses to sea-level rise can increase or decrease public access to the shore. Shoreline armoring generally eliminates public-trust wetlands and beaches, decreasing public access along the shore. Beach nourishment using public funds may increase access to the shore if statutes are in place requiring permanent access (Chapter 7).

2.2.3 Coastal Flooding and Management

Rising sea level increases the vulnerability of coastal floodplains to flooding. Higher sea level provides an elevated base for storm surges to build upon. Sea level rise also diminishes the rate at which low-lying areas drain, thereby increasing the risk of flooding from rainstorms. Increases in shore erosion also contributes to greater flood damages by removing protective dunes, beaches, and wetlands and by leaving particular properties closer to the water's edge (Chapter 8).

In addition to flood damages, many of the other effects, responses, and decisions discussed in this report are likely to occur during or in the immediate aftermath of severe storms. Beach erosion and wetlands loss often occur during storms, and the rebuilding phase after a severe storm often affords the best opportunity for adapting to sea level rise in developed areas. Currently, although the most modern floodplain maps are generally based upon the latest topographic elevations and recent changes in local mean sea level elevations, they do not take into account future sea-level rise (Chapter 8).

Although the Mid-Atlantic coastal zone management community recognizes sea-level rise as a coastal flooding hazard and states are starting to confront the issue of sea level rise, only a limited number of comprehensive analyses and resulting statewide policy revisions to reflect rising sea level have been undertaken (Chapters 8, 10).

2.3 Preparing for Sea-Level Rise

2.3.1 Decision-Making for the Coastal Zone

The prospect of accelerated sea-level rise generally justifies examining the costs and benefits of taking adaptive actions. Determining whether and what specific actions are justified is difficult, due to uncertainty in the timing and magnitude of impacts, and difficulties in quantifying projected benefits and costs (Chapter 9).

Key opportunities for preparing for sea-level rise may include land use planning to ensure that wetlands can migrate inland, siting, and design decisions such as retrofitting (*e.g.*, elevating buildings and homes), and examining whether and how changing risk due to sea-level rise is reflected in flood insurance rates (Chapter 9).

2.3.2 Institutional Barriers

Institutional inertia is a key barrier to change. Responding to sea-level rise requires careful consideration regarding whether and how particular areas will be protected with structures, elevated above the tides, relocated landward, or left alone and potentially given up to the rising sea (Chapter 11).

Today, as people become increasingly interested in more environmentally sensitive shore protection, they are dealing with institutions that have historically responded to requests for hard shoreline structures to hold the coast in a fixed location, and are just beginning to determine how to manage the development of soft shore protection measures (Chapter 11).

3. MEASURES TO IMPROVE UNDERSTANDING

An integrated scientific program of sea-level studies is recommended to reduce gaps in our knowledge and the uncertainty about the potential responses of coasts, estuaries, and wetlands to sea-level rise. This program should focus on insights from the historic and geologic past, monitor ongoing physical and environmental changes, and develop tools and datasets to support and promote sound coastal zone planning. Some measures that are identified in this report include:

Exploit and integrate coastal information from the historic and geologic past and incorporate into computer models to promote improved understanding of coastal processes.

This includes information pertaining to: Past interglacial environmental conditions, barrier island formation and landward migration since the last Ice Age, and thresholds in coastal systems that, if crossed, could lead to rapid changes to coastal and wetland systems.

Further development of a robust monitoring program for all coastal regions, leveraging the existing network of site observations, as well as the growing array of coastal observing systems.

This could be achieved by: expanding and enhancing the network of basic observations and systems, enhanced use of new technologies and nationwide collection of higher resolution data (such as LIDAR), developing homogenous time series data to monitor environmental and landscape changes over time, and assembling and updating baseline data for the coastal zone.

Studies of the past history of sea-level rise and coastal response, combined with extensive monitoring of present conditions, will enable more robust predictions of future sea-level rise impacts.

In order to provide more robust predictions, it will be necessary to develop quantitative assessment methods that identify high-priority areas (geographic or topical) needing useful predictions, and to integrate studies of past and present coastal behavior into predictive models

Develop tools, datasets, and other land management information to support and promote coastal decisions, planning, and policy making.

This includes: providing easy access to data and information resources from this study and forthcoming efforts and applying this information in an integrated framework using such tools as Geographic Information Systems (GIS). There is also a need to develop integrated assessments linking physical vulnerability with economic analyses and planning options, and to assemble and assess coastal zone planning adaptation options to facilitate their use by federal, state and local decision makers.