U.S. Climate Change Science Program

Synthesis and Assessment Product 4.1

Coastal Sensitivity to Sea Level Rise:
A Focus on the Mid-Atlantic Region

Lead Agency:
U.S. Environmental Protection Agency

Other Key Participating Agencies:
U.S. Geological Survey
National Oceanic and Atmospheric Administration

Contributing Agencies:
Department of Transportation

RECOMMENDED CITATIONS

Entire report:
CCSP, 2009: *Coastal Sensitivity to Sea-Level Rise: A Focus on the Mid-Atlantic Region*. A report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. [James G. Titus (Coordinating Lead Author), K. Eric Anderson, Donald R. Cahoon, Dean B. Gesch, Stephen K. Gill, Benjamin T. Gutierrez, E. Robert Thieler, and S. Jeffress Williams (Lead Authors)], U.S. Environmental Protection Agency, Washington D.C., USA.

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Chapter 1:
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Chapter 4 includes results based on a panel assessment. The panel consisted of: Denise Reed, University of New Orleans; Dana Bishara, USGS; Jeffrey Donnelly, Woods Hole Oceanographic Institution; Michael Kearney, University of Maryland; Alexander Kolker, Louisiana Universities Marine Consortium; Lynn Leonard, University of North Carolina-Wilmington; Richard Orson, Orson Environmental Consulting, J. Court Stevenson, University of Maryland. The panel was conducted under contract to EPA, with James G. Titus as the project officer. Jeff DeBlieux of The Nature Conservancy also contributed to portions of Chapter 4.

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Preface

The U.S. Climate Change Science Program (CCSP) was launched in February 2002 as a collaborative federal interagency program, under a new cabinet-level organization designed to improve the government-wide management and dissemination of climate change science and related technology development. The mission of the CCSP is to "facilitate the creation and application of knowledge of the Earth's global environment through research, observations, decision support, and communication". This Product is one of 21 synthesis and assessment products (SAPs) identified in the 2003 *Strategic Plan for the U.S. Climate Change Science Program*, written to help achieve this mission. The SAPs are intended to support informed discussion and decisions by policymakers, resource managers, stakeholders, the media, and the general public. The products help meet the requirements of the Global Change Research Act of 1990, which directs agencies to "produce information readily usable by policymakers attempting to formulate effective strategies for preventing, mitigating, and adapting to the effects of global change" and to undertake periodic scientific assessments.

One of the major goals within the mission is to understand the sensitivity and adaptability of different natural and managed ecosystems and human systems to climate and related global changes. This SAP (4.1), *Coastal Sensitivity to Sea-Level Rise: A Focus on the Mid-Atlantic Region*, addresses this goal by providing a detailed assessment of the effects of sea-level rise on coastal environments and presenting some of the challenges that need to be addressed in order to adapt to sea-level rise while protecting environmental resources and sustaining economic growth. It is intended to provide the most current knowledge regarding the implications of rising sea level and possible adaptive responses, particularly in the mid-Atlantic region of the United States.

P.1 SCOPE AND APPROACH OF THIS PRODUCT

The focus of this Product is to identify and review the potential impacts of future sea-level rise based on present scientific understanding. To do so, this Product evaluates several aspects of sea-level rise impacts to the natural environment and examines the impact to human land development along the coast. In addition, the Product addresses the connection between sea-level rise impacts and current adaptation strategies, and assesses the role of the existing coastal management policies in identifying and responding to potential challenges.

As with other SAPs, the first step in the process of preparing this Product was to publish a draft prospectus listing the questions that the product would seek to answer at the local and mid-Atlantic scale. After public comment, the final prospectus listed ten questions. This Product addresses those ten questions, and answers most of them with specificity. Nevertheless, development of this Product has also highlighted current data and analytical capacity limitations. The analytical presentation in this Product focuses on what characterizations can be provided with sufficient accuracy to be meaningful. For a few questions, the published literature was insufficient to answer the question with great specificity. Nevertheless, the effort to answer the question has identified what information is needed or desirable, and current limitations with regard to available data and tools.

This Product focuses on the U.S. mid-Atlantic coast, which includes the eight states from New York to North Carolina. The Mid-Atlantic is a region where high population density and extensive coastal development is likely to be at increased risk due to sea-level rise. Other coastal regions in the United States, such as the Gulf of Mexico and the Florida coast, are potentially more vulnerable to sea-level rise and have been the focus of other research and assessments, but are outside the scope of this Product.

During the preparation of this Product, three regional meetings were held between the author team and representatives from relevant local, county, state, and federal agencies, as well non-governmental organizations. Many of the questions posed in the prospectus for SAP 4.1 were discussed in detail and the feedback has been incorporated into the Product. However, the available data are insufficient to answer all of the questions at both the local and regional scale. Therefore, the results of this Product are best used as a "starting point" for audiences seeking information about sensitivity to and implications of sea-level rise.

Many of the findings included in this Product are expressed using common terms of likelihood (*e.g.*, very likely, unlikely), similar to those used in the 2007 Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report, *Climate Change 2007: The Physical Science Basis*. The likelihood determinations used in this Product were established by the authors and modeled after other CCSP SAPs such as CCSP SAP 1.1, *Temperature Trends in the Lower Atmosphere: Steps for Understanding* *and Reconciling Differences.* However, characterizations of likelihood in this Product are largely based on the judgment of the authors and uncertainties from published peer-reviewed literature (Figure P.1). 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. Nevertheless, being able to characterize current understanding—and the uncertainty associated with that information—is important. In the main body of this Product, any use of the terms in Figure P.1 reflect qualitative assessment of potential changes based on the authors' review and understanding of available published coastal science literature and of governmental policies (the appendices do not contain findings). Statements that do not use these likelihood terms either have an insufficient basis for assessing likelihood or present information provided in the referenced literature which was not accompanied by assessments of likelihood.

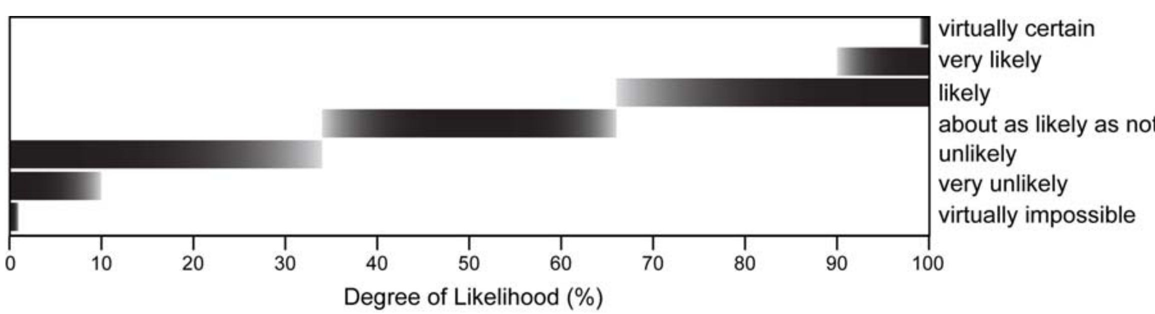

Figure P.1 Likelihood terms and related probabilities used for this Product (with the exception of Appendix 1).

The International System of Units (SI) have been used in this Product; with English units often provided in parentheses. Where conversions are not provided, some readers may wish to convert from SI to English units using the following table:

Table P.1 Conversion from the International System of Units (SI) to English units

Multiply	By	To obtain
Length		
centimeter (cm)	0.3937	inch (in)
millimeter (mm)	0.0394	inch (in)
meter (m)	3.2808	foot (ft)
kilometer (km)	0.6214	mile (mi)
meter (m)	1.0936	yard (yd)
Area		
square meter (sq m)	0.000247	acres
hectare (ha)	2.47	acres
square kilometer (sq km)	247	acres
square meter (sq m)	10.7639	square foot (sq ft)
hectare (ha)	0.00386	square mile (sq mi)
square kilometer (sq km)	0.3861	square mile (sq mi)
Rate of Change		
meters per year (m per year)	3.28084	foot per year (ft per year)
millimeters per year (mm per year)	0.03937	inch per year (in per year)
meters per second (m per sec)	1.943	knots

P.2 FUTURE SEA-LEVEL SCENARIOS ADDRESSED IN THIS PRODUCT

In this Product, the term "sea level" refers to mean sea level or the average level of tidal waters, generally measured over a 20-year period. These measurements generally indicate the water level relative to the land, and thus incorporate changes in the elevation of the land (*i.e.*, subsidence or uplift) as well as absolute changes in sea level (*i.e.*, rise in sea level caused by increasing its volume or adding water). For clarity, scientists often use two different terms:

- "Global sea-level rise" is the average increase in the level of the world's oceans that occurs due to a variety of factors, the most significant being thermal expansion of the oceans and the addition of water by melting of land-based ice sheets, ice caps, and glaciers.

- “Relative sea-level rise” refers to the change in sea level relative to the elevation of the adjacent land, which can also subside or rise due to natural and human-induced factors. Relative sea-level changes include both global sea-level rise and changes in the vertical elevation of the land surface.

In this Product, both terms are used. Global sea-level rise is used when referring to the worldwide average increase in sea level. Relative sea-level rise, or simply sea-level rise, is used when referring to the scenarios used in this Product and effects on the coast.

This Product does not provide a forecast of future rates of sea-level rise. Rather, it evaluates the implications of three relative sea-level rise scenarios over the next century developed from a combination of the twentieth century relative sea-level rise rate and either a 2 or 7 millimeter per year increase in global sea level:

- Scenario 1: the twentieth century rate, which is generally 3 to 4 millimeters per year in the mid-Atlantic region (30 to 40 centimeters total by the year 2100);
- Scenario 2: the twentieth century rate plus 2 millimeters per year acceleration (up to 50 centimeters total by 2100);
- Scenario 3: the twentieth century rate plus 7 millimeters per year acceleration (up to 100 centimeters total by 2100).

The twentieth century rate of sea-level rise refers to the local long-term rate of relative sea-level rise that has been observed at NOAA National Ocean Service (NOS) tide gauges in the mid-Atlantic study region. Scenario 1 assesses the impacts if future sea-level rise occurs at the same rate as was observed over the twentieth century at a particular location. Scenarios 1 and 2 are within the range of those reported in the recent IPCC Report *Climate Change 2007: The Physical Science Basis,* specifically in the chapter *Observations: Oceanic Climate Change and Sea Level*, while Scenario 3 exceeds the IPCC scenario range by up to 40 centimeters by 2100. Higher estimates, as suggested by some recent publications, are the basis for Scenario 3. In addition to these three scenarios, some chapters refer to even higher sea-level rise scenarios, such as a 200 centimeter rise over the next few hundred years (a high but plausible estimate if ice sheet melting on Greenland and West Antarctica exceeds IPCC model estimates).

P.3 PRODUCT ORGANIZATION

This Product is divided into four parts:

Part I first provides context and addresses the effects of sea-level rise on the physical environment. Chapter 1 provides the context for sea-level rise and its effects. Chapter 2 discusses the current knowledge and limitations in coastal elevation mapping. Chapter 3 describes the physical changes at the coast that will result in changes to coastal landforms (*e.g.*, barrier islands) and shoreline position in response to sea-level rise. Chapter 4 considers the ability of wetlands to accumulate sediments and survive in response to rising sea level. Chapter 5 examines the habitats and species that will be vulnerable to sea-level rise related impacts.

Part II describes the societal impacts and implications of sea-level rise. Chapter 6 provides a framework for assessing shoreline protection options in response to sea-level rise. Chapter 7 discusses the extent of vulnerable population and infrastructure, and Chapter 8 addresses the implications for public access to the shore. Chapter 9 reviews the impact of sea-level rise to flood hazards.

Part III examines strategies for coping with sea-level rise. Chapter 10 outlines key considerations when making decisions to reduce vulnerability. Chapter 11 discusses what organizations are currently doing to adapt to sea-level rise, and Chapter 12 examines possible institutional barriers to adaptation.

Part IV examines national implications and a science strategy for moving forward. Chapter 13 discusses sea-level rise impacts and implications at a national scale and highlights how coasts in other parts of the United States are vulnerable to sea-level rise. Chapter 14 presents opportunities for future efforts to reduce uncertainty and close gaps in scientific knowledge and understanding.

Finally, this Product also includes two appendices: 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. The Appendix also describe 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 Appendix is provided as background information and does not include findings or an independent assessment of likelihood.

Appendix 2 reviews some of the basic approaches that have been used to conduct shoreline change or land loss assessments in the context of sea-level rise and some of the difficulties that arise in using these methods.

Technical and scientific terms are used throughout this Product. To aid readers with these terms, a Glossary and a list of Acronyms and Abbreviations are included at the end of the Product.

Executive Summary

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Global sea level is rising, and there is evidence that the rate is accelerating. Increasing atmospheric concentrations of greenhouse gases, primarily from human contributions, are very likely warming the atmosphere and oceans. The warmer temperatures raise sea level by expanding ocean water, melting glaciers, and possibly increasing the rate at which ice sheets discharge ice and water into the oceans. Rising sea level and the potential for stronger storms pose an increasing threat to coastal cities, residential communities, infrastructure, beaches, wetlands, and ecosystems. The potential impacts to the United States extend across the entire country: ports provide gateways for transport of goods domestically and abroad; coastal resorts and beaches are central to the U.S. economy; wetlands provide valuable ecosystem services such as water filtering and spawning grounds for commercially important fisheries. How people respond to sea-level rise in the coastal zone will have potentially large economic and environmental costs.

This Synthesis and Assessment Product examines the implications of rising sea level, with a focus on the mid-Atlantic region of the United States, where rates of sea-level rise are moderately high, storm impacts occur, and there is a large extent of critical habitat (marshes), high population densities, and infrastructure in low-lying areas. Although these issues apply to coastal regions across the country, the mid-Atlantic region was selected as a focus area to explore how addressing both sensitive ecosystems and impacts to humans will be a challenge. Using current scientific literature and expert panel assessments, this Product examines potential risks, possible responses, and decisions that may be sensitive to sea-level rise.

The information, data, and tools needed to inform decision-making with regard to sea-level rise are evolving, but insufficient to assess the implications at scales of interest to all stakeholders. Accordingly, this Product can only provide a starting point to discuss impacts and examine possible responses at the regional scale. The Product briefly summarizes national scale implications and outlines the steps involved in providing information at multiple scales (*e.g.*, local).

ES.1 WHY IS SEA LEVEL RISING? HOW MUCH WILL IT RISE?

During periods of climate warming, two major processes cause global mean sea-level rise: (1) as the ocean warms, the water expands and increases its volume and (2) land reservoirs of ice and water, including glaciers and ice sheets, contribute water to the oceans. In addition, the land in many coastal regions is subsiding, adding to the vulnerability to the effects of sea-level rise.

Recent U.S. and international assessments of climate change show that global average sea level rose approximately 1.7 millimeters per year through the twentieth century, after a period of little change during the previous two thousand years. Observations suggest that the rate of global sea-level rise may be accelerating. In 2007, the Intergovernmental Panel on Climate Change (IPCC) projected that global sea level will likely rise between 19 and 59 centimeters (7 and 23 inches) by the end of the century (2090 to 2099), relative to the base period (1980 to 1999), excluding any rapid changes in ice flow from Greenland and Antarctica. According to the IPCC, the average rate of global sea-level rise during the twenty-first century is *very likely* to exceed the average rate over the last four decades. Recently observed accelerated ice flow and melting in some Greenland outlet glaciers and West Antarctic ice streams could substantially increase the contribution from the ice sheets to rates of global sea-level rise. Understanding of the magnitude and timing of these processes is limited and, thus, there is currently no consensus on the upper bound of global sea-level rise. Recent studies suggest the potential for a meter or more of global sea-level rise by the year 2100, and possibly several meters within the next several centuries.

In the mid-Atlantic region from New York to North Carolina, tide-gauge observations indicate that relative sea-level rise (the combination of global sea-level rise and land subsidence) rates were higher than the global mean and generally ranged between 2.4 and 4.4 millimeters per year, or about 0.3 meters (1 foot) over the twentieth century.

ES.2 WHAT ARE THE EFFECTS OF SEA-LEVEL RISE?

Coastal environments such as beaches, barrier islands, wetlands, and estuarine systems are closely linked to sea level. Many of these environments adjust to increasing water level by growing vertically, migrating inland, or expanding laterally. If the rate of sea-level rise accelerates significantly, coastal environments and human populations will be affected. In some cases, the effects will be limited in scope and similar to those observed during the last century. In other cases, thresholds may be crossed, beyond which the impacts would be much greater. If the sea rises more rapidly than the rate with which a particular coastal system can keep pace, it could fundamentally change the state of the coast. For example, rapid sea-level rise can cause rapid landward migration or segmentation of some barrier islands, or disintegration of wetlands.

Today, rising sea 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. Other impacts of climate change, coastal development, and natural coastal processes also contribute to these impacts. In undeveloped or less-developed coastal areas where human influence is minimal, ecosystems and geological systems can sometimes shift upward and landward with the rising water levels. Coastal development, including buildings, roads, and other infrastructure, are less mobile and more vulnerable. Vulnerability to an accelerating rate of sea-level rise is compounded by the high population density along the coast, the possibility of other effects of climate change, and the susceptibility of coastal regions to storms and environmental stressors, such as drought or invasive species.

ES.2.1 Sea-Level Rise and the Physical Environment

The coastal zone is dynamic and the response of coastal areas to sea-level rise is more complex than simple inundation. Erosion is a natural process from waves and currents and can cause land to be lost even with a stable sea level. Sea-level rise can exacerbate coastal change due to erosion and accretion. While some wetlands can keep pace with sea-level rise due to sediment inputs, those that cannot keep pace will gradually degrade and become submerged. Shore protection and engineering efforts also affect how coasts are able to respond to sea-level rise.

For coastal areas that are vulnerable to inundation by sea-level rise, elevation is generally the most critical factor in assessing potential impacts. The extent of inundation is controlled largely by the slope of the land, with a greater area of inundation occurring in locations with more gentle gradients. Most of the currently available elevation data do not provide the degree of confidence that is needed for making quantitative assessments of the effects of sea-level rise for local planning and decision making. However, systematic collection of high-quality elevation data (*i.e.*, lidar) will improve the ability to conduct detailed assessments (Chapter 2).

Nationally, coastal erosion will probably increase as sea-level rises at rates higher than those that have been observed over the past century. The exact manner and rates at which these changes are likely to occur will depend on the character of coastal landforms (*e.g.*, barrier islands, cliffs) and physical processes (Part I). Particularly in sandy shore environments which comprise the entire mid-Atlantic ocean coast (Figure ES.1), it is *virtually certain* that coastal headlands, spits, and barrier islands will erode at a faster pace in response to future sea-level rise. For sea-level rise scenarios greater than 7 millimeters per year, it is *likely* that some barrier islands in this region will cross a threshold where rapid barrier island migration or segmentation will occur (Chapter 3).

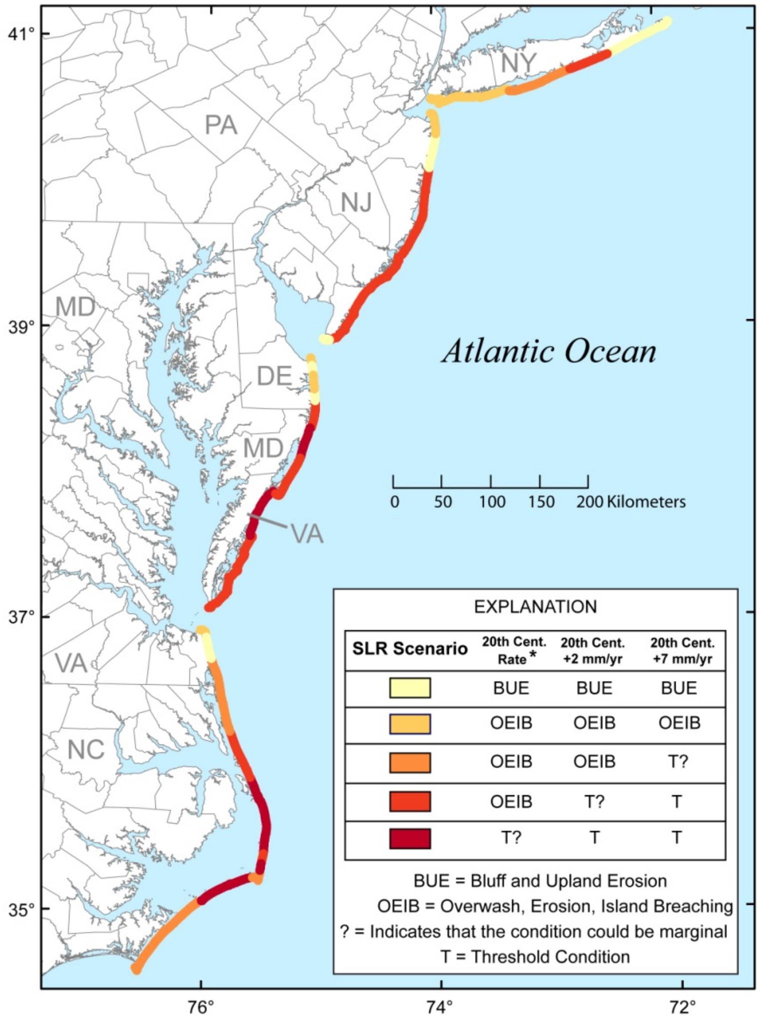

Figure ES.1 Potential mid-Atlantic coastal landform responses to three sea-level rise scenarios. Most coastal areas are currently experiencing erosion, which is expected to increase with future sea-level rise. In addition to undergoing erosion, coastal segments denoted with a "T" may also cross a threshold where rapid barrier island migration or segmentation will occur.

Tidal wetlands in the United States, such as the Mississippi River Delta in Louisiana and Blackwater River marshes in Maryland, are already experiencing submergence by relative sea-level rise and associated high rates of wetland loss.

For the mid-Atlantic region (Figure ES.2), acceleration in sea-level rise by 2 millimeters per year will cause many wetlands to become stressed; it is *likely* that most wetlands will not survive acceleration in sea-level rise by 7 millimeters per year. Wetlands may expand inland where low-lying land is available but, if existing wetlands cannot keep pace with sea-level rise, the result will be an overall loss of wetland area in the Mid-Atlantic. The loss of associated wetland ecosystem functions (*e.g.*, providing flood control, acting as a storm surge buffer, protecting water quality buffer, and serving as a nursery area) can have important societal consequences, such as was seen with the storm surge impacts associated with Hurricanes Katrina and Rita in southern Louisiana, including New Orleans, in 2005. Nationally, tidal wetlands already experiencing submergence by sea-level rise and associated land loss (*e.g.*, Mississippi River delta in Louisiana, and Blackwater River marshes in Maryland) will continue to lose area in response to future accelerated rates of sea-level rise and changes in other climate and environmental drivers.

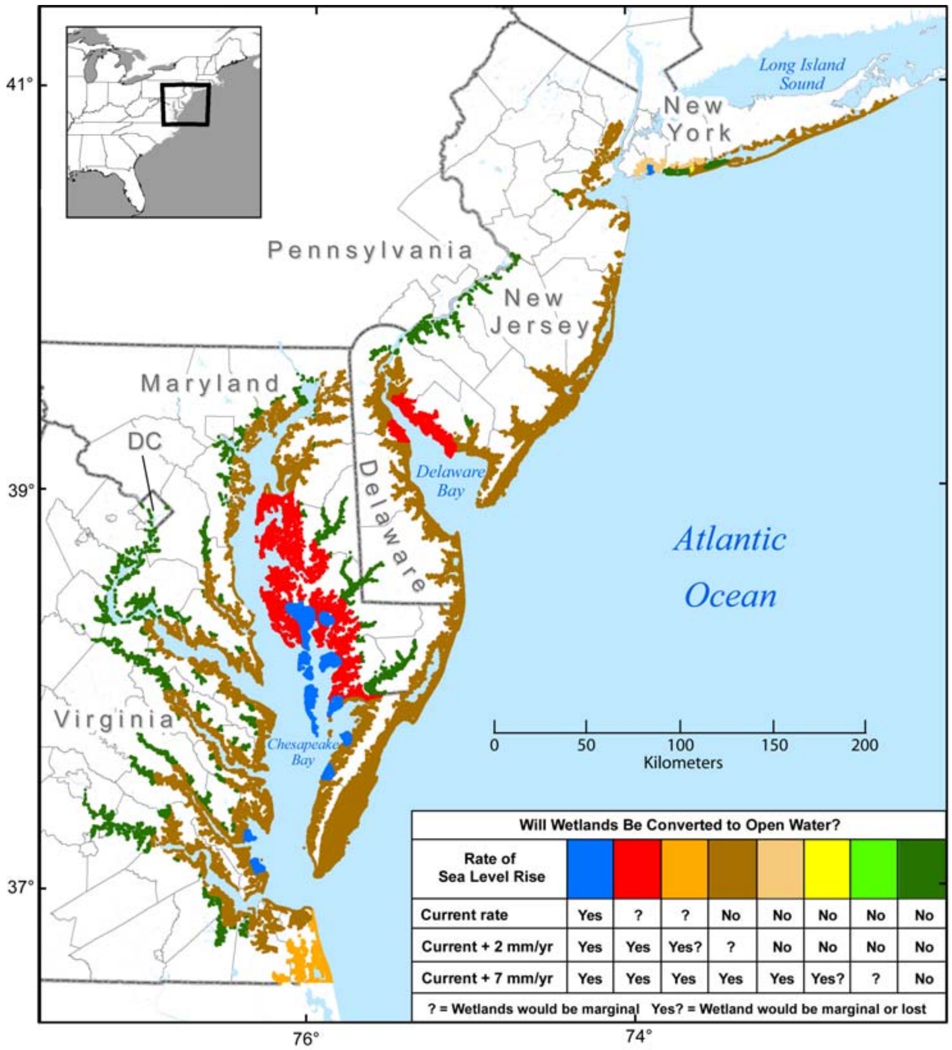

Figure ES.2 Areas where wetlands would be marginal or lost (*i.e.*, converted to open water) under three sea-level rise scenarios.

Terrestrial and aquatic plants and animals that rely on coastal habitat are likely to be stressed and adversely affected as sea level rises. The quality, quantity, and spatial distribution of coastal habitats will change as a result of erosion, salinity changes, and wetland loss. Depending on local conditions, habitat may be lost or migrate inland in response to sea-level rise. Loss of tidal marshes would seriously threaten coastal ecosystems, causing fish and birds to move or produce fewer offspring. Many estuarine beaches may also be lost, threatening numerous species (Chapter 5).

Sea-level rise is just one of many factors affecting coastal habitats: sediment input, nutrient runoff, fisheries management, and other factors are also important. Under natural conditions, habitats are continually shifting, and species generally have some flexibility to adapt to varied geography and/or habitat type. Future habitat and species loss will be determined by factors that include rates of wetland submergence, coastal erosion, and whether coastal landforms and present-day habitats have space to migrate inland. As coastal development continues, the ability for habitats to change and migrate inland along the rest of the coast will not only be a function of the attributes of the natural system, but also of the coastal management policies for developed and undeveloped areas.

ES.2.2 Societal Impacts and Implications

Increasing population, development, and supporting infrastructure in the coastal zone often compete with the desire to maintain the benefits that natural ecosystems (*e.g.*, beaches, barrier islands, and wetlands) provide to humans. Increasing sea level will put additional stress on the ability to manage these competing interests effectively (Chapter 7). In the Mid-Atlantic, for example, movement to the coast and development continues, despite the growing vulnerability to coastal hazards.

Rising sea level increases the vulnerability of development on coastal floodplains. Higher sea level provides an elevated base for storm surges to build upon and diminishes the rate at which low-lying areas drain, thereby increasing the risk of flooding from rainstorms. Increases in shore erosion also contribute to greater flood damages by removing protective dunes, beaches, and wetlands and by leaving some properties closer to the water's edge (Chapter 9).

ES.3 HOW CAN PEOPLE PREPARE FOR SEA-LEVEL RISE?

ES.3.1 Options for Adapting to Sea-level Rise

At the current rate of sea-level rise, coastal residents and businesses have been responding by rebuilding at the same location, relocating, holding back the sea by coastal engineering, or some combination of these approaches. With a substantial acceleration of sea-level rise, traditional coastal engineering may not be economically or environmentally sustainable in some areas (Chapter 6).

Nationally, most current coastal policies do not accommodate accelerations in sea-level rise. Floodplain maps, which are used to guide development and building practices in hazardous areas, are generally based upon recent observations of topographic elevation and local mean sea-level. However, these maps often do not take into account accelerated sea-level rise or possible changes in storm intensity (Chapter 9). As a result, most shore protection structures are designed for current sea level, and development policies that rely on setting development back from the coast are designed for current rates of coastal erosion, not taking into account sea level rise.

ES.3.2 Adapting to Sea-level Rise

The prospect of accelerated sea-level rise underscores the need to rigorously assess vulnerability and examine the costs and benefits of taking adaptive actions. Determining whether, what, and when specific actions are justified is not simple, due to uncertainty in the timing and magnitude of impacts, and difficulties in quantifying projected costs and benefits. Key opportunities for preparing for sea-level rise include: provisions for preserving public access along the shore (Chapter 8); land-use planning to ensure that wetlands, beaches, and associated coastal ecosystem services are preserved (Chapter 10); siting and design decisions such as retrofitting (*e.g.*, elevating buildings and homes) (Chapter 10); and examining whether and how changing risk due to sea-level rise is reflected in flood insurance rates (Chapter 10).

However, the time, and often cultural shift, required to make change in federal, state, and local policies is sometimes a barrier to change. In the mid-Atlantic coastal zone, for example, although the management community recognizes sea-level rise as a coastal flooding hazard and state governments are starting to face the issue of sea-level rise, only a limited number of analyses and resulting statewide policy revisions to address rising sea level have been undertaken (Chapters 9, 11). Current policies in some areas are now being adapted to include the effects of sea-level rise on coastal environments and infrastructure. 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 12).

Many coastal management decisions made today have implications for sea-level rise adaptation. Existing state policies that restrict development along the shore to mitigate hazards or protect water quality (Appendix 1) could preserve open space that may also help coastal ecosystems adapt to rising sea level. On the other hand, efforts to fortify coastal development can make it less likely that such an area would be abandoned as sea level rises (Chapter 6). A prime opportunity for adapting to sea-level rise in developed areas may be in the aftermath of a severe storm (Chapter 9).

ES.4 HOW CAN SCIENCE IMPROVE UNDERSTANDING AND PREPAREDNESS FOR FUTURE SEA-LEVEL RISE?

This Product broadly synthesizes physical, biological, social, and institutional topics involved in assessing the potential vulnerability of the mid-Atlantic United States to sea-level rise. This includes the potential for landscape changes and associated geological and biological processes; and the ability of society and its institutions to adapt to change. Current limitations in the ability to quantitatively assess these topics at local, regional, and national scales may affect whether, when, and how some decisions will be made.

Scientific syntheses and assessments such as this have different types and levels of uncertainty. Part I of this Product describes the physical settings and processes in the Mid-Atlantic and how they may be impacted by sea-level rise. There is uncertainty regarding coastal elevations and the extent to which some areas will be inundated. In some areas, coastal elevations have been mapped with great detail and accuracy, and thus the data have the requisite high degree of certainty for local decision making by coastal managers. In many other areas, the coarser resolution and limited vertical accuracy of the available elevation data preclude their use in detailed assessments, but the uncertainty can be explicitly quantified (Chapter 2). The range of physical and biological processes associated with coastal change is poorly understood at some of the time and space scales required for decision making. For example, although the scope and general nature of the changes that can occur on ocean coasts in response to sea-level rise are widely recognized, how these changes occur in response to a specific rise in sea level is difficult to predict (Chapter 3). Similarly, current model projections of wetland vulnerability on regional and national scales are uncertain due to the coarse level of resolution of landscape-scale models. While site-specific model projections are quite good where local information has been acquired on factors that control local accretionary processes in specific wetland settings, such projections cannot presently be generalized so as to apply to larger regional or national scales with high confidence (Chapter 4). The cumulative impacts of physical and biological change due to sea-level rise on the quality and quantity of coastal habitats are not well understood.

Like the uncertainties associated with the physical settings, the potential human responses to future sea-level rise described in Part II of this Product are also uncertain. Society generally responds to changes as they emerge. The decisions that people make to respond to sea-level rise could be influenced by the physical setting, the properties of the built environment, social values, the constraints of regulations and economics, as well as the level of uncertainty in the form and magnitude of future coastal change. This Product examines some of the available options and assesses actions that federal and state governments and coastal communities could take in response to sea-level rise. For example, as rising sea level impacts coastal lands, a fundamental choice is whether to attempt to hold back the sea or allow nature to takes its course. Both choices have important costs and uncertainties (Chapter 6).

Part III of this Product focuses on what might be done to prepare for sea-level rise. As discussed above, the rate, timing, and impacts of future sea-level rise are uncertain, with important implications for decision-making. For example, planning for sea-level rise requires examining the benefits and costs of such issues as coastal wetland protection, existing and planned coastal infrastructure, and management of floodplains in the context of temporal and spatial uncertainty (Chapter 10). In addition, institutional barriers can make it difficult to incorporate the potential impacts of future sea-level rise into coastal planning (Chapter 12).

ES.4.1 Enhance Understanding

An integrated scientific program of sea-level studies would reduce gaps in current knowledge and the uncertainty about the potential responses of coasts, estuaries, wetlands, and human populations to sea-level rise. This program should focus on expanded efforts to monitor ongoing physical and environmental changes, using new technologies and higher resolution elevation data as available. Insights from the historic and geologic past also provide important perspectives. A key area of uncertainty is the vulnerability of coastal landforms and wetlands to sea-level rise; therefore, it is important to understand the dynamics of barrier island processes and wetland accretion, wetland migration, and the effects of land-use change as sea-level rise continues. Understanding, predicting, and responding to the environmental and societal effects of sea-level rise would require an integrated program of research that includes both natural and social sciences. Social science research is a necessary component as sea-level rise vulnerability, sea-level rise impacts, and the success of many adaptation strategies will depend on characterizing the social, economic, and political contexts in which management decisions are made (Chapter 14).

ES.4.2 Enhance Decision Support

Decision making on regional and local levels in the coastal zone can be supported by improved understanding of vulnerabilities and risks of sea-level rise impacts. Developing tools, datasets, and other coastal management information is key to supporting and promoting sound coastal planning, policy making, and decisions. This includes providing easy access to data and information resources and applying this information in an integrated framework using such tools as geographic information systems. Integrated assessments linking physical vulnerability with economic analyses and planning options will be valuable, as will efforts to assemble and assess coastal zone planning adaptation options for federal, state, and local decision makers. Stakeholder participation in every phase of this process is important, so that decision makers and the public have access to the information that they need and can make well-informed choices regarding sea-level rise and the consequences of different management decisions. Coastal planning and policies that are consistent with the reality of a rising sea could enable U.S. coastal communities to avoid or adapt to its potential environmental, societal, and economic impacts.