Context: Sea-Level Rise and Its Effects on the Coast

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The accumulation of scientific evidence over the past several decades unequivocally demonstrates that the global climate is changing, largely due to carbon dioxide emissions from human activities (IPCC, 2001; 2007). Sea-level rise is one effect of climate warming that will have profound impacts on all coastal regions of the United States and around the world. The geologic record shows that sea level and the global climate have been relatively stable over the past 10,000 years and this stability is a significant factor in enabling the development of human civilizations. The significant changes over the past 200 years in atmospheric carbon dioxide, temperature, ecosystems, and ice-sheet melting follow a six-fold increase in global population (Zalasiewicz et al., 2008). Along the ocean and estuarine coasts of most of the United States, sea level has risen over the last century and will continue to do so in the future. The effects are evident in many areas, as shores erode and move landward and formerly dry areas become submerged, more frequently flooded by high tides and storm surges. People are responding to these impacts by taking measures to protect threatened property or by relocating development inland to higher ground. The intent of this report is to assess the potential effects and risks of sea-level rise on coastal regions and provide information needed to understand the implications and options for dealing with sea-level rise.

The effects of sea-level rise are likely to intensify and become more pervasive in the coming decades as the Earth's climate warms. Throughout geologic history, climate change has been the main factor driving the evolution of Earth and its inhabitants. Now, climate is changing rapidly, largely in response to human activity (IPCC, 2007). Many impacts of human-induced climate change are already occurring, including, melting glaciers and ice sheets; changes in extreme weather, such as heavy downpours and droughts, and an accelerated rise in sea level. These physical changes are also leading to biologic responses such as changes in the range of species, earlier spring events (such as animal migration), and a loss of habitat, such as coastal wetlands (IPCC, 2007). The rates of warming occurring now and those projected for the future may exceed the ability of many living organisms to adapt without major disruptions and extinctions. With future warming and wide spread ice sheet melting too, sea-level rise could accelerate very rapidly on decadal scales and follow non-linear patterns that would have large impacts on coastal regions.

More extreme weather events and storm activity and a world-wide rise in sea level are two of the most likely, most disruptive, and most costly effects of global warming. Often these two elements of climate change act in concert with each other to impact coastal regions. They have most effect on coastal regions where the land relief is generally low, land forms are susceptible to erosion, and human population and development are highly concentrated. This includes much of the coast around the United States, but the mid-Atlantic region (the main focus of this report) is particularly vulnerable due to high rates of relative sea-level rise and dense coastal development.

This report reviews available scientific literature and presents a scientific consensus on the likely effects of sea-level rise on the mid-Atlantic coast of the United States, the human and environmental impacts, likely responses in the context of current policies and economic trends, and possible options for changing planning and management activities so that society and the environment are better able to cope with an accelerated rise in sea level. A summary of implications on a Nation-wide scale are presented in Part V. The Preface of this report contains further information on the process for developing this report, the nature of the regional focus, and the structure of this report.

C.1 WHY IS GLOBAL SEA LEVEL RISING?

The elevation of global sea level is determined primarily by the balance between the volume of ice on land (in glaciers and ice sheets) and the volume of water in ocean basins. During the last 800,000 years, sea level has risen and fallen in response to the buildup and decline of large ice sheets as climate warmed and cooled in natural cycles of approximately 100,000 years. Figure C.1 shows a record of sea level change over the past 400,000 years.

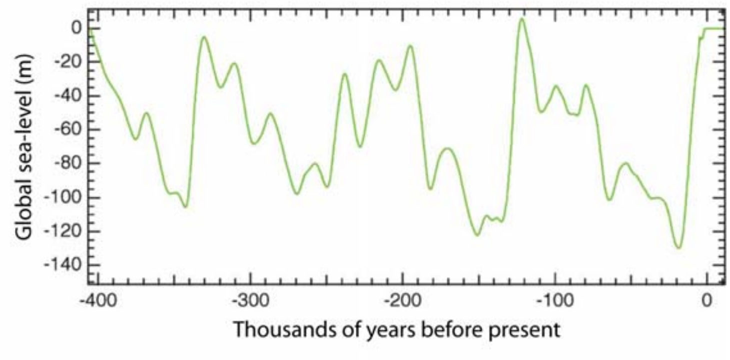

Figure C.1 Sea level change over the last 400,000 years resulting from natural glacial- interglacial cycles. Evidence suggests that sea level was about 4-6 m higher than present during the last interglacial warm period 125,000 years ago, and 120 m lower during the last Ice Age, about 21,000 years ago. Modified from Huybrechts (2002).

In the recent geologic past, sea level has varied from 120 m (400 ft) lower than present during the last Ice Age, when massive glaciers covered much of North America, northern Europe, and Asia, and the shoreline was seaward at the edge of the continental shelf, to about 4 to 6 m (20 ft) higher than present during the previous ‘interglacial’ (non-Ice Age) warm period when the coast was much further inland than present day. As ice sheets melted and climate warmed following the Ice Age, beginning approximately 21,000 years ago, sea level rose. Global sea level reached close to its current position about 3,000 years ago (Figure C.2) and has fluctuated only slightly until the past several decades when tide gauge and satellite data indicate an acceleration in sea-level rise rates. The ocean has absorbed more than 80 percent of the atmospheric warming since 1961, causing sea water to expand, contributing to this recent rise. In addition, rapid melting of land-based glaciers as well as ice sheets on Greenland and Antarctica have very likely increased sea-level rise (IPCC, 2007). The combination of stable sea level and moderate climate during the current interglacial warm period has been a major factor contributing to the growth in human development and our modern civilization (Day *et al.* 2007).

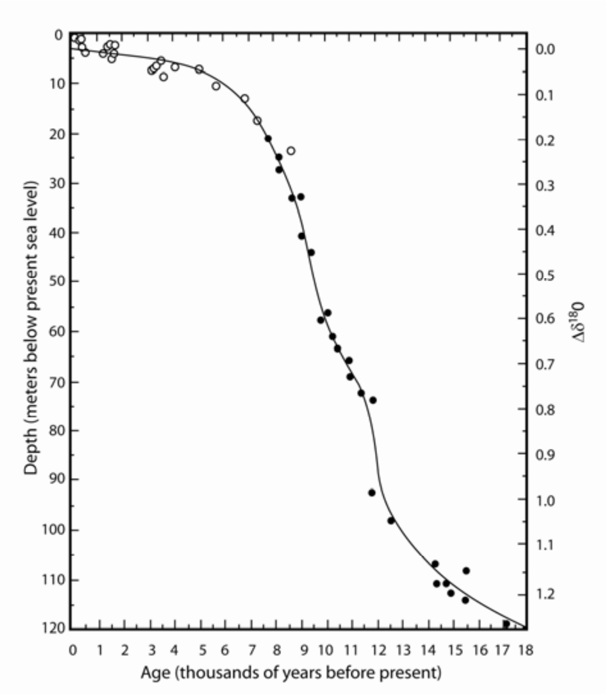

Figure C.2 Rise in global sea-level over the last 18,000 years to the present time reconstructed from oxygen isotope concentrations and radiocarbon dating of geologic samples, shown as data points. (Modified from Fairbanks,1989).

The study of climate change and associated sea-level rise is complex. The most credible and comprehensive body of scientific information on the subject, based on a consensus of approximately 2,500 of the world's scientists, has been compiled by the United Nations' Intergovernmental Panel on Climate Change (IPCC) in a series of reports issued approximately every five years. The most recent IPCC (2007) report, *Climate Change 2007: The Physical Science Basis*, contains a comprehensive review and assessment of climate change trends, expected changes over the next century, and the impacts and challenges that both humans and the natural world are likely to be confronted with during the next century. In addition, the U.S. Climate Change Science Program (CCSP) Synthesis and Assessment Products (SAPs), including this one, are providing detailed climate information for the United States. This SAP, discussing the impacts of sea-level rise on the U.S., relies heavily on IPCC (2007) findings and predictions for sea-level rise. A few key findings of the most recent IPCC reports are summarized in Box C.1

BOX C.1 SELECTED IPCC (2007) FINDINGS ON CLIMATE AND SEA-LEVEL RISE

Recent Global Climate Change:

- Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level

- Carbon dioxide is the most important human-caused greenhouse gas. The atmospheric concentration of carbon dioxide in 2005 exceeds by far the natural range over the last 650,000 years

- Most of the observed increase in global average temperatures since the mid-20th century is *very likely* due to the observed increase in human-caused greenhouse gas concentrations. Discernible human influences now extend to other aspects of climate, including ocean warming, continental-average temperatures, temperature extremes and wind patterns

Recent Sea-Level Rise

- Observations since 1961 show that the average temperature of the global ocean has increased to depths of at least 3000 m and that the ocean has been absorbing more than 80% of the heat added to the climate system. Such warming causes seawater to expand, contributing to sea-level rise

- Mountain glaciers and snow cover have declined on average in both hemispheres. Widespread decreases in glaciers and ice caps have contributed to sea-level rise (ice caps do not include contributions from the Greenland and Antarctic ice sheets)

- New data show that losses from the ice sheets of Greenland and Antarctica have *very likely* contributed to sea-level rise between 1993 and 2003

- Global average sea level rose at an average rate of 1.8 [1.3 to 2.3] mm per year between 1961 and 2003. The rate was faster between 1993 and 2003: about 3.1 [2.4 to 3.8] mm per year. Whether the faster rate for 1993 to 2003 reflects decadal variability or an increase in the longer term trend is unclear. (Figure C.3)

- Global average sea level in the last interglacial period (about 125,000 years ago) was *likely* 4 to 6 m higher than during the 20th century, mainly due to the retreat of polar ice. Ice core data indicate that average polar temperatures at that time were 3°C to 5°C higher than present, because of differences in the Earth's orbit. The Greenland ice sheet and other arctic ice fields *likely* contributed no more than 4 m of the observed sea-level rise. There may also have been contributions from Antarctica ice sheet melting.

Projections of the Future:

- Continued greenhouse gas emissions at or above current rates would cause further warming and induce many changes in the global climate system during the 21st century that would *very likely* be larger than those observed during the 20th century.
- Based on a range of possible greenhouse gas emission scenarios for the next century, the IPCC estimates the global increase in temperature will likely be between 1.1 and 6.4ºC. Estimates of sea-level rise for the same scenarios are 0.18m to 0.59 m, excluding the contribution from accelerated ice discharges from the Greenland and Antarctica ice sheets.

- Extrapolating the recent acceleration of ice discharges from the polar ice sheets would imply an additional contribution up to 20 cm. If melting of these ice caps increases, larger values of sea-level rise cannot be excluded.

- In addition to sea-level rise, the storms that lead to coastal storm surges could become more intense. The IPCC indicate that based on a range of computer models, it is *likely* that hurricanes will become more intense, with larger peak wind speeds and more heavy precipitation associated with ongoing increases of tropical sea surface temperatures, while the tracks of 'winter' or non-tropical storms are projected to shift towards the poles along with some indications of an increase in intensity in the North Atlantic.

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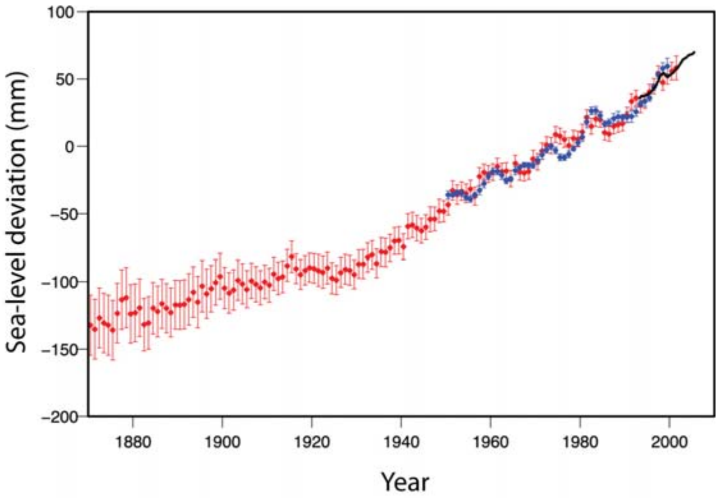

Figure C.3 Annual averages of global mean sea level from IPCC (2007). The red curve shows sea-level fields since 1870 updated from Church and White (2006); the blue curve displays tide gauge data from Holgate and Woodworth (2004), and the black curve is based on satellite altimetry from Leuliette *et al.* (2004). The red and blue curves are deviations from their averages for 1961 to 1990, and the black curve is the deviation from the average of the red curve for the period 1993 to 2001. Error bars show 90% confidence intervals. Modified from Bindoff *et al.* (2007).

Global sea-level rise – resulting from the balance between global ice volume and ocean seawater volume - is a useful measure of the general direction of change; however there are substantial local and regional variations in the rates of sea-level rise. In some locations, subsidence of the land increases the 'effective' or 'relative 'sea-level rise, whereas in other locations, local sea-level rise is less than the global average because the land is still rising (rebounding) from a time when an ice sheet, sometimes a mile thick, covered the area, depressing the Earth's crust. In a few cases, such as in the Pacific Northwest of the U.S., this can lead to a drop in local sea level. In responding to sea-level rise, it is necessary to refer to the local (relative) sea level-rise because it is this combination of global effects and local conditions that impact the coast. Thus in this report, 'sea-level rise' refers to relative sea-level rise. See box C.2 for further discussion.

Box C.2 Relative Sea Level

The term "global sea level", sometimes referred to as eustatic sea level, refers to the average level of tidal waters around the world based on long-term measurements from coastal tide gauges. The most reliable data are from gauges having records of 50 years or longer and are important observation instruments for measuring sea level change trends. Vertical movements of the land surface at the coast can also contribute significantly to sea-level change and the combination of sea level and land-level change is referred to as "relative sea level" (Douglas, 2001). These two terms used by scientists are defined as follows:

- "global sea-level rise" is the worldwide increase in the volume of the world's oceans that occurs as a result of thermal expansion and melting ice caps and glaciers.
- "relative sea-level rise" refers to the change in sea level relative to the elevation of the land, which includes both global sea-level rise and vertical movements of the land.

In this report, the term "sea-level rise" is used to mean "relative sea-level rise."

Vertical changes of the land surface result from many factors including tectonic processes, adjustment of the Earth's crust, compaction of sediments, and extraction of subsurface fluids such as oil, gas, and water. A principal contributor to this change along the Atlantic coast of North America and northern Europe is the plastic-like adjustment of the Earth's crust to changing ice loads since the Ice Age. The thick accumulation of ice on continental landmasses depressed the Earth's surface in ice-covered regions. This displaced the mantle (the layer of the planet beneath the crust) causing a "peripheral bulge" some distance from the edges of the thick continental ice cover. As a result of these crustal adjustments, relative sea level records vary greatly along the coast from glaciated regions in New England southward to North Carolina. These vertical crustal adjustments have persisted for thousands of years and will continue to persist for some time. In addition to glacial adjustments, sediment loading also contributes to regional subsidence of the land surface. Subsidence contributes to high rates of relative sea level (>100 mm/yr) in the Mississippi River delta where thick sediments have accumulated. Likewise, fluid withdrawal from coastal aquifers causes the sediments to locally compact as the water is extracted. In Louisiana, Texas, and the southern California region, oil, gas and ground-water extraction have contributed markedly to subsidence and relative sea level rise (Gornitz and Lebedeff, 1987, Emery and Aubrey, 1991, Galloway *et al.*, 1999; Morton *et al.*, 2004). Last, tectonic uplift affects the rates of relative sea level rise from Alaska to California. In places where the land surface is uplifted due to tectonic activity, rates of relative sea-level rise may be notably smaller than the rate of global sea level rise or in some cases, reversed, with localized relative sea-level fall. In locations where the land surface is subsiding, rates of relative sea-level rise may exceed the rate of global rise (*e.g.*, the central Gulf of Mexico coast and mid-Atlantic coast).

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C.2 SEA-LEVEL RISE AROUND THE UNITED STATES

Sea level has varied greatly throughout the Earth's history due to a variety of geologic, oceanographic, and climatic processes (Douglas, 2001) and is influenced by many factors that operate globally to locally over a wide range of time scales, including days to weeks (tides, storms), seasons, decades, and millennia.

The long-term records from tide gauge stations have been the primary measurements of relative sea level trends over the last century (Douglas, 2001). Figure C.3 shows the variations in relative sea level for U.S. coastal regions. Many parts of the eastern and Gulf shores are showing higher rates of sea-level rise than for the world as a whole. For example, sea level is rising 3-4 mm/yr along the mid-Atlantic region compared to the absolute rate of 1.8 mm/yr for the world (Figures C.3, C.4)

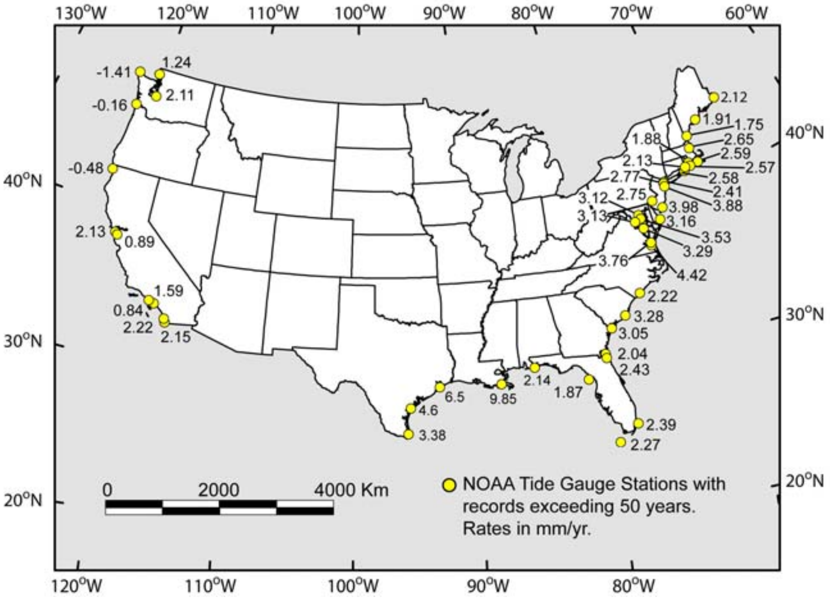

Figure C.4 Map of annual relative sea-level rise rates around the U.S. coast. The high rates for Louisiana (9.9 mm/yr) and the mid-Atlantic region (3-4 mm/yr) are due to land subsidence. Sea level is stable or dropping relative to the land in the Pacific northwest, where the land is tectonically active or rebounding upward in response to the melting of ice sheets (compiled by USGS from Zervas, 2001).

NOAA routinely produces updated estimates of relative sea level trends observed at tide stations around the country and the results show a large variation of trends from very high rates of relative sea level rise in southern Louisiana (+ 9.9 mm/yr (+/- 0.35 mm) at Grand Isle) due to land subsidence, to high rates of relative sea level fall in southeast Alaska (- 16.7 mm/yr (+/- 0.42 mm) at Skagway) due to land rebound as a result of glacier melting (Zervas, 2001). Figure C.5 is an example of the monthly average (mean) sea level record and the computed relative sea-level rise trend at Baltimore, MD. Here, the relative sea level trend is 3.12 mm/yr (+/- 0.08), which, as a result of land subsidence, is nearly 2 times the present rate of global sea-level rise.

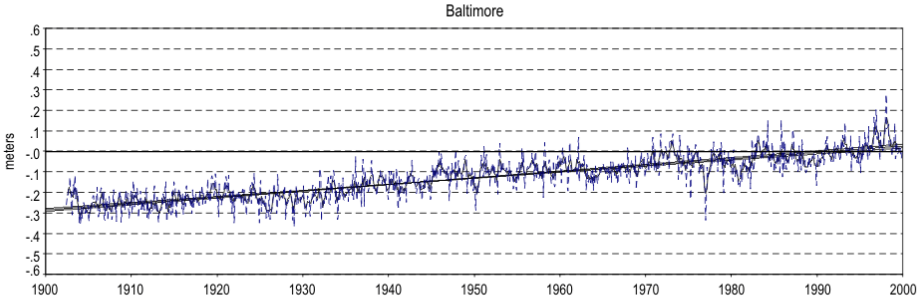

Figure C.5 Sea-level rise for Baltimore, MD from 1900 to 2000. The plot shows the monthly mean sea level with the average seasonal cycle removed (blue dashed line), a 5-month average (black solid line), and the linear trend.

C.2.1 Future Sea-Level Rise Around the United States: Our Approach

This report does not develop new estimates of future sea-level rise. Instead, we use three scenarios of relative sea-level rise along the mid-Atlantic coast:

Scenario 1: Continuation of the 20th century rate (3 mm/yr)

Scenario 2: An acceleration of 2 mm/yr over the 20th century trend (total rate of 5 mm/yr)

Scenario 3: An acceleration of 7 mm/yr over the 20th century trend (total rate of 10 mm/yr)

These three scenarios enable an assessment of the implications of a rise of 30 cm, 50 cm, and 100 cm over the next century.

These scenarios are broadly consistent with recent assessments by the IPCC (2007) and others (see Figure C.6). The IPCC's likely range for a global rise in sea level is 10-59 cm over the next century, excluding the possibility of increased ice melting on Greenland and Antarctica. IPCC also states that extrapolating the central estimate of current accelerated ice discharge would add another 10-20 cm, implying a range of 20-79 cm. The upper end of that range represents a 6 mm/yr acceleration over the 20th century global sea level trend. Scenario 3 is 1mm/yr higher, and substantially less than the high estimates suggested by more recent publications (Rahmstorf, 2007; Rahmstorf *et al.*, 2007; Hansen *et al.*, 2007). Scenario 2 is consistent with the best estimates for the various IPCC emission scenarios, which generally represented an acceleration of 2 mm/yr above the historic rate. Finally, Scenario 1 is consistent with the IPCC's low estimate of future and current sea-level rise.

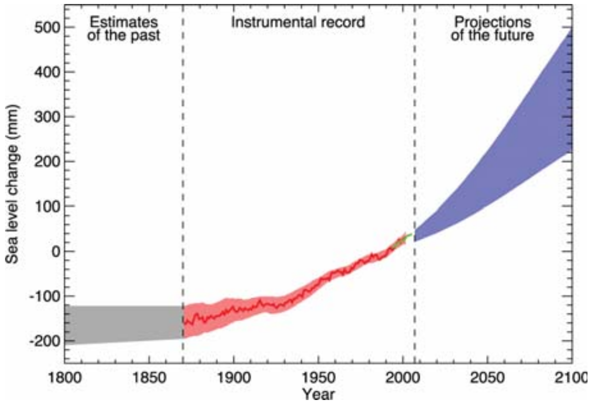

Figure C.6 Past, present, and projected global sea-level rise. Time-series of global mean sea level compiled from the past (grey shading), late 19^{th} and 20th century observations (red and green lines and red shaded region), and future projections (blue shading) determined in the recent IPCC assessment (Bindoff *et al.*, 2007). The grey shading shows the uncertainty in the estimated long-term rate of sea-level change. The red line is a reconstruction of global mean sea level from tide gauges and the shaded area indicates the rage of variations from this line. The green line illustrates the global mean sea level record based on satellite altimeter measurements. The blue shaded region represents the range of model projections complied from the IPCC assessment (Meehl *et al.*, 2007). Figure from Bindoff *et al*.(2007).

The primary focus of this report is over the next century, but the longer term implications are also considered. Recent evaluations of changes in ice cover and glacial melting on Greenland, Antarctica, and smaller glaciers and ice caps from around the world indicate that ice loss could be more rapid than has been measured and predicted (Chen *et al.*, 2006; Shepherd and Wingham, 2007; Meier *et al.*, 2007). If so, this accelerated melting could significantly raise sea-level predictions to levels (~4-6 m) during the last interglacial period over the next several hundred years (Overpeck *et al.*, 2006). The science behind these predictions is not yet well developed, but is worthy of study because of the very significant implications for all coastal regions.

C.3 IMPACTS OF SEA-LEVEL RISE FOR THE UNITED STATES

C.3.1 Coastal Vulnerability Around the United States

Coastal communities and habitats will be increasingly stressed by climate change impacts interacting with development and pollution (Field et al., 2007). Impacts from sea-level rise include: land loss through submergence and erosion of lands in the coastal zone; migration of coastal landforms and changes to coastal environments; increased storm-surge flooding; wetland losses; and increased salinity in estuaries and coastal groundwater aquifers. Each of these effects can have important impacts on both natural ecosystems and human developments and infrastructure. Other impacts of climate change, such as increasingly severe droughts and storm intensity—along with continued rapid coastal development—could amplify the effects of sea-level rise.

Sea-level rise in combination with other factors is already starting to have significant effects on the coastal zone of the United States. Flooding of low lying regions by storm surges and spring tides is becoming more frequent and causing more damage and disruptions. Around the Chesapeake Bay, wetlands are being submerged, fringe forests are dying and being converted to marsh, farm land and lawns are being converted to marsh; and some roads are routinely flooded at high tides (Douglas, 2001). "Ghost forests" of standing dead trees killed by salt water intrusion are becoming increasingly common in southern New Jersey, Maryland, Virginia, Louisiana, and North Carolina (Riggs and Ames, 2003). Rising sea level is gradually intruding into estuaries and threatening fresh-water aquifers (Barlow, 2003).

Rising sea level will affect to varying degrees entire coastal systems from the shoreline to the landward edge of the Coastal Plain. These physical and ecological changes that are likely to occur in the near future will also have impacts on humans and coastal development. In addition, it is uncertain how current practices in managing coastal systems for mitigating erosion and flooding are likely to affect potential future impacts. Climate change implications should be included in planning and decision making to best accommodate climate change.

Continued rapid coastal development exacerbates both the environmental and the human impact of rising sea level. During the 20th century, an expanding proportion of the U.S. population and associated urban development relocated to the land along the Atlantic, Gulf of Mexico, and Pacific coasts. Coastal populations have doubled in the past 30 years and although the coastal population is currently increasing at approximately the same rate as the national population, continued coastal development increasingly conflicts with the natural processes associated with coastal change from storms and sea-level rise. Currently the majority of the U.S. population lives in the coastal zone and movement to the coast and development continues. Fourteen of the Nation's 20 largest urban centers are located along the coast. In addition, these economic and population pressures have transformed sparsely developed coastal areas into high-density year-round urban complexes. With accelerated rise in sea level and increased intensity of storms, the conflicts between development at the coast and the natural processes are likely to increase dramatically unless new coastal management and planning is employed.

C.3.2 Shoreline Change and Coastal Erosion

The diverse landforms comprising the more than 160,000 km of U.S. coast reflect a dynamic interaction between: 1) natural factors and physical processes that act on the coast (*e.g.*, storms, waves, currents, sand sources and sinks, relative sea level), 2) human activity (*e.g.*, dredging, dams, coastal engineering), and 3) the geological character of the coast and nearshore. Spatial and temporal variations in these physical processes and the geology along the coast are responsible for the variety of coastal landforms. As a result, the majority of the U.S. coast is undergoing long-term net erosion at highly varying rates as shown in Figure C.7.

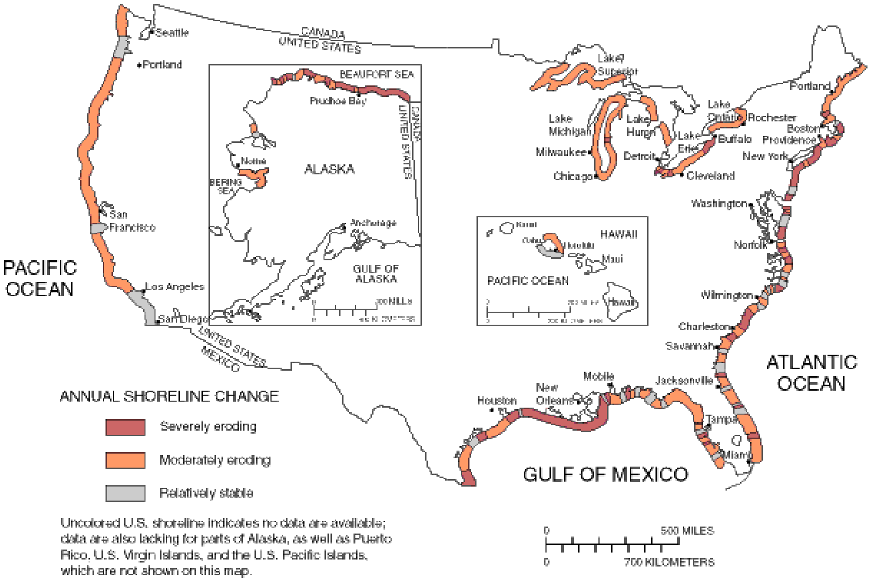

Figure C.7. Coastal Erosion Rates Around the U.S. All 30 coastal states are experiencing erosion at highly variable rates due to natural processes and human activity. From USGS National Atlas 1985.

The complex interactions among these factors make it difficult to identify a precise relationship between sea-level rise and shoreline change and to reach consensus among coastal scientists on quantitative approaches that can be used to predict how shorelines will change in response to sea-level rise. The difficulty in linking sea-level rise to coastal change stems from the fact that shoreline change does not occur directly as the result of sea-level rise. Instead, coasts are in an almost continual state of change in response to many driving forces and subject to the underlying geological character and the availability of sediment to the coastal system. Consequently, while there is strong scientific consensus that climate is changing and affecting coastal regions, there are still uncertainties associated with quantitative predictions of how the coast will respond to likely changes in future sea level.

With current planning and decision making, we often assume that these systems operate in a steady-state. While the factors that influence coastal change in response to sea level rise are well known, our ability to incorporate this understanding into computer models that can be used to predict shoreline change over long time periods is limited and models are in their infancy. Part of the reason for this is the complexity of quantifying the effect of these factors on shoreline change. The models incorporate relatively few factors that influence shoreline change and rely on assumptions that do not always apply to real-world settings. In addition, these assumptions apply best to present conditions, not necessarily those that may exist in the future. The models that do incorporate many of the key factors (*e.g.*, the geological framework and sediment budget) require detailed data (*i.e.*, sediment transport rates, landform evolution feedbacks) on a local scale. To apply over larger coastal regions, the necessary baseline information for most areas is not available. The unfortunate consequence is that our current capability to make long-term reliable predictions is limited. In addition, there is some indication that coastal landforms, such as barrier islands, might have “tipping points” or “thresholds” when limits are exceeded and the landforms become unstable and disintegrate. It is possible that this is already happening to barrier islands along the Louisiana coast and may occur in the near future along the North Carolina and the Maryland-Virginia coast with increased sea-level rise and storm activity (Culver et al., 2007; Sallenger et al., 2007; Riggs and Ames, 2003).

This report reviews the knowledge of how sea-level rise can impact coastal regions and the challenges that we face in planning and coping with these impacts. A large part of this discussion is based on information from new assessments that address the potential impacts of sea level rise on the tidal inundation of low-lying lands, ocean shoreline processes, and the vertical accretion of tidal wetlands in the mid-Atlantic region. Following the terms of our charge from CCSP (2007), we do not evaluate the impacts of sea level rise on coastal flooding; nor do we evaluate the impacts of possible changes in the frequency and severity of coastal storms. That does not mean that the report ignores storm effects or assumes that the seas are always calm. Existing landforms, ecosystems, and human activities are already adapted to a certain level of storminess. Unless otherwise stated, the chapters that follow all assume that storms will continue in the future, and that many of the impacts of sea-level rise—on both people and the environment-- will only be realized after a severe storm.

C.3.3 Managing the Coastal Zone as Sea Level Rises

Coasts are dynamic junctions of water, air, and land. The interactions vary greatly over time and space. Winds and waves, tides and currents, migrating sand dunes, and river deltas combine to form ever-changing coasts, yet development continues in high risk coastal areas. If sea level rise accelerates, all of these landforms will become more dynamic. Some researchers believe that the combination of stable sea level and moderate climate during the current interglacial period has been a major factor contributing to the growth in human development and our modern civilization (Stanley and Warne, 1993; Day *et al.*, 2007). The notion that sea level is constant and that coasts are stable is deeply embedded in many institutions, and in the assumptions of most coastal residents.

Adapting to an accelerated sea-level rise would require changes in both our institutions and our mindset about natural processes.

A key question for coastal zone management is how and where to “mitigate” or adapt to these new coastal conditions. Shoreline erosion problems affecting property and development or coastal wetland habitat losses tend to dominate shore-protection policy rather than sea-level rise explicitly. Today, many property owners and government programs are already engaged in coastal engineering activities designed to protect property and beaches in developed areas by thwarting natural dynamic processes—but in undeveloped areas, the natural processes usually govern. At first, an acceleration of sea-level rise may simply increase the cost of current practices. Eventually, however, policy makers may have to evaluate whether the approach to coastal development and protection assuming a relatively stable sea level should be modified to best respond to the higher sea levels.

To facilitate these decisions, policy makers need credible information. Predicting these changes with the precision that a decision maker would prefer to have is not always possible. Yet there is little doubt that physical changes to the coastal system will also modify coastal ecosystems and the fish and wildlife. Further complicating the picture, are other related effects of climate change: storms, precipitation, run-off, drought, management practices, economic setting, and sediment supply. At present, our scientific understanding of the physical response of the coast to sea-level rise is lacking and in combination with the wide variety of human engineering activities along the shoreline, prediction of future effects with high confidence is challenging.

In most cases, we manage our coasts as if sea level were stable, the shoreline fixed in location, and storms were regular and predictable. In this report, several chapters examine how sea-level rise and increased storminess might require managers to consider longer term perspectives. We also examine some possible tactics for coastal planning and management that might be more effective as sea-level rise accelerates.

We have outlined the three sea-level rise scenarios used in this report, but in addition, we begin to consider how the impacts of sea-level rise may depend on the portion of the shoreline stabilized, as well as on the rate of sea-level rise. Unlike the future rate of sea-level rise, coastal managers collectively have some control over how much of the shore is ultimately protected, at least for the short term. Follow-on efforts will examine scenarios assuming continuation of existing policies, and will consider whether the cumulative environmental impacts might lead to a different set of choices for dealing with sea-level rise.

In summary, continued sea-level rise, at current or accelerated rates, coupled with increasing storm intensity, will result directly in increasing vulnerability for people, property, and ecosystems and indirectly have national implications. Coasts are likely to erode and retreat more than we would expect from inundation by sea-level rise alone, especially for fragile barrier islands and low-lying delta regions. We need continued improvement in the science of coastal change, more comprehensive systems of data collection and analysis, observation, monitoring, modeling, and communication of results to the public and policy makers. Planning and decision making for the coastal zone across all levels of government needs to reflect the new scientific understanding of climate change and effects of sea-level rise and increased storms. Improvements in communication are needed to ensure that science is more relevant to inform policy. We hope that this report sets the stage for coastal decision makers to fully incorporate the ramifications of climate change and its effects on sea-level rise into long-term management and planning.

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