Global sea level is rising. There will be a wide range of impacts that affect coastal communities, habitats, and the physical characteristics of the coast.

WHY IS SEA LEVEL RISING? HOW MUCH WILL IT RISE?

Most of the observed increase in global average temperatures over the past 50 years is very likely due primarily to human-induced emissions of heat-trapping gases. Increasing temperatures in the atmosphere cause sea level to rise by:

- Warming ocean water, which causes it to expand.
- Melting glaciers and ice caps.
- Possibly increasing the rate at which ice sheets discharge ice and water into the oceans.

Sea level was essentially stable for the last 2,000 to 3,000 years, until an acceleration occurred in the late nineteenth century. During the last century, global sea level rose at an average rate of 0.07 inches (0.17 centimeters) per year, or about seven inches total.

In many coastal regions, the land is also rising or sinking, so the rate of sea-level rise for a particular area is different from the global average. Along the U.S. mid-Atlantic coast, tide gauge measurements indicate that local sea level rose between 10 and 18 inches during the last century, depending on the location.

Global warming over this century is projected to be greater than last century. Studies using climate models suggest that the global rate of sea-level rise this century will also be greater than the last century. In 2007, the Intergovernmental Panel on Climate Change (IPCC) projected that global sea level will rise between 7 and 23 inches over the next century, excluding any rapid changes in ice flow from Greenland and Antarctica. More recent studies suggest that a rise in sea level of three feet or more by the end of this century is plausible.

Observed and Projected Sea-Level Rise

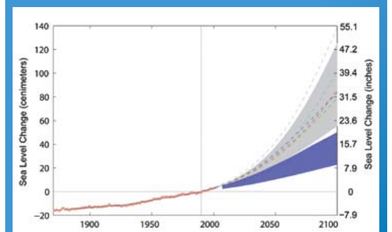

Figure 1. Observations and several different projections of future sea-level rise to the end of this century. The blue shaded area represents projections based on the 2007 IPCC scenario that assumes a world of rapid economic growth, global population growth that peaks in the middle of this century and then declines, and a balance of fossil fuel use with new, more efficient technologies. The gray shaded area and dashed lines represent projections based on relationships between global temperature and sea-level rise. (Blue shaded area from IPCC, 2007, FAQ 5.1, Figure 1. Other data from Rahmstorf, S., 2007: A semi-empirical approach to projecting future sea-level rise. Science, 315(5810), 368-370. Reprinted with permission from AAAS.)

WHAT ARE THE EFFECTS OF SEA-LEVEL RISE?

Today, rising sea levels affect coastal regions in many ways:

- Submerging low-lying lands
- Eroding beaches
- Converting wetlands to open water
- Causing more severe coastal flooding
- Increasing the salinity of estuaries and aquifers

These effects would become more severe if sea-level rise accelerates.

Some of the major findings of this Product indicate that:

- Coastal changes are caused by complex and interconnected processes. While some coastal areas will become covered by water when sea level rises, there will also be many other effects. Today, most of the available coastal elevation data are not precise enough to fully assess the effects of sea-level rise for local planning and decision-making purposes.
- It is *virtually certain* (more than 99 percent likelihood) that areas with sandy shores on the mid-Atlantic coast, such as beaches and barrier islands, will erode faster as sea level rises.
- If the rate of sea-level rise increases by 0.08 inches (0.2 centimeters) per year or more over the current rate, it is *likely* (more than 66 percent likelihood) that some barriers islands in the Mid-Atlantic will reach a tipping point and undergo substantial changes that cannot be reversed. These islands may move more rapidly toward the mainland or separate into smaller islands.

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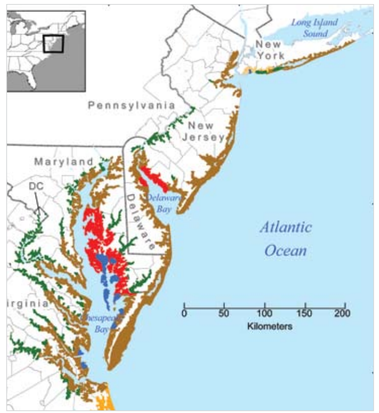
- Tidal wetlands in the United States, such as the Blackwater River marshes in Maryland, are already being covered with water due to sea-level rise and high rates of wetland loss, and also, in many regions, due to sinking land. Wetland ecosystems provide flood controls, storm surge buffers, water quality buffers, and fish nursery areas. These losses can have important consequences for society.
- Many plants and animals rely on wetlands, beaches, and other coastal habitat threatened by sea-level rise. Habitat losses could lead fish and birds to move or produce fewer offspring.

Potential Mid-Atlantic Wetland Survival



Will Wetlands Be Converted to Open Water?

Rate of Sea Level Rise								
Current Rate	Yes	?	?	No	No	No	No	No
Current rate + 0.08 inches per year	Yes	Yes	Yes?	?	No	No	No	No
Current rate + 0.28 inches per year	Yes	Yes	Yes	Yes	Yes	Yes?	?	No

? = Wetlands would be marginal Yes? = Wetland would be marginal or lost

Figure 2. Estimate of wetland survival over the next century in response to three sea-level rise scenarios as determined by a panel of wetland experts. Except for areas shown in red and blue, most wetlands are likely to survive if the rate of sea-level rise does not increase. Wetlands are likely to survive an acceleration of 0.08 inches (0.2 centimeters) per year only under optimal conditions of plant growth and sediment accumulation. Almost no wetlands are likely to survive if the rate of sea-level rise increases by 0.28 inches (0.7 centimeters) per year.

WHAT ARE THE IMPLICATIONS OF SEA-LEVEL RISE FOR HUMAN ACTIVITIES?

As sea level rises, it becomes more difficult to manage different interests effectively. Increasing population and development in coastal areas often competes with the desire to maintain coastal ecosystems, such as beaches, barrier islands, and wetlands, and the valuable services they provide to society. Movement to the coast and development continues in the Mid-Atlantic, despite the growing vulnerability to coastal hazards.

How sea-level rise affects human activities depends in part on how society responds to this change. Rising sea level increases the vulnerability of development on coastal floodplains. Higher sea level provides a higher base for storm surges to build upon and decreases the rate at which low-lying areas drain. This increases the risk of flooding from heavy rains. More shore erosion also leads to greater flood damages by removing protective dunes, beaches, and wetlands and by leaving some properties closer to the water. In cases where the shore has structures to protect it, public access along the shore could be lost unless measures are taken to preserve that access.

The coupling of sea-level rise with storm surge is one of the most important considerations for assessing impacts of sea-level rise on infrastructure. Sea-level rise poses a risk to the ability to provide reliable and sustained transportation services in coastal regions. Disrupted transportation in these areas can lead to transportation problems across the United States.

WHAT ARE SOME FUNDAMENTAL PATHWAYS FOR RESPONDING TO SEA-LEVEL RISE?

As rising sea level threatens coastal lands, people must decide whether to attempt to hold back the sea or to allow a rising sea to naturally take its course. People have been responding to sea-level rise through one of three pathways:

- ***Retreat***. Allow wetlands and beaches to migrate inland. This approach avoids building in the most vulnerable areas or removes structures that are already there.
- ***Shoreline armoring***. Protect development with structures such as dikes, seawalls, and bulkheads. This approach maintains existing land use, but can increase the loss of wetlands and beaches. It can also affect whether there is public access to the shoreline.
- ***Elevate***. Raise structures and land surfaces, including beaches and possibly wetlands.

Retreat

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Combinations of these three approaches are also possible. Each approach will be more appropriate in some locations than in others. Shore protection costs, property values, the environmental values of habitat, and the feasibility of protecting shores without harming the habitat all differ, depending on the location.

Shoreline armoring

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Elevate

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For several types of sea-level rise impacts, the cost of preparing now is small compared to the cost of reacting later. Some opportunities to prepare can be lost if action is delayed.

HOW CAN SOCIETY PREPARE FOR A RISING SEA?

The expectation that the rate of sea-level rise will increase emphasizes the need to thoroughly assess vulnerability and examine the costs and benefits of taking actions to adapt. Determining whether, what, and when specific actions are justified is not simple. The timing and size of potential impacts, and the costs and benefits of taking action, are all uncertain.

The majority of people and institutions have not planned for sea-level rise. Most coastal institutions assume that sea level and shorelines do not change. Actions to prepare for the impacts can be hindered by various issues, such as policies that encourage coastal development; floodplain maps that do not account for sea-level rise; flood insurance rates that are not adjusted as sea level rises; policies that prefer building hard structures over using plants and sediments to protect the shore; and lack of plans to show which areas would or would not be protected as sea level rises.

Opportunities to prepare for sea-level rise include:

- Developing land-use plans for the preservation of wetlands, beaches, and other coastal ecosystems.
- Specifying the location and design of new homes and infrastructure.
- Making provisions for preserving public access along the shore.
- Examining whether and how changing risk due to sea-level rise is reflected in flood insurance rates and floodplain policies.

The time, and often cultural shift, required to change federal, state, and local policies sometimes makes

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change difficult. In the mid-Atlantic coastal zone, only a limited number of analyses and resulting statewide policy revisions to address rising sea level have been undertaken.

Many coastal management decisions made today may affect the ultimate success of efforts to prepare for sea-level rise. Existing state policies that restrict development along the shore to reduce hazards or to protect water quality could preserve open space that may also help coastal ecosystems adapt to rising sea level. On the other hand, efforts to protect developed areas can make it less likely that those locations would be abandoned as sea level rises.

WHAT CAN BE DONE TO BETTER ASSESS EFFECTS OF AND RESPONSES TO SEA-LEVEL RISE?

Projecting coastal change over the next century is difficult because many factors contribute to that change. Both natural and social science research is needed to help understand, predict, and respond to the effects of sea-level rise on the environment, the economy, and society. Addressing the challenge of sea-level rise could be achieved by activities that:

- Develop research programs that include both natural and social scientists.
- Expand the network of basic observations and observing systems, develop data collected over time on environmental and landscape changes, and assemble data for the coastal zone that can be used as a baseline to compare with future data.
- Use the historic and geologic record of coastal change to increase knowledge of past change, improve predictive models, identify tipping points in coastal systems, and relate past changes in climate to coastal change.
- Improve assessment methods and combine studies of the past and present into predictive models.
- Support decision making by providing easy access to data and resources, effectively transferring knowledge of vulnerability and risk that affect decision making, and educating the public about consequences and alternatives.

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

Cover photo source: ©iStock.com/Chris Parypa

The potential impacts of sea-level rise on society, the economy, and the environment are large. Research that improves understanding of the various potential impacts would help to improve adaptation, mitigation, and avoidance-of-risk measures, and would benefit both the United States and coastal nations around the world.

To order *Coastal Sensitivity to Sea-Level Rise*, please visit: http://gcrio.org/orders/sap4-1

Findings of the U.S. Climate Change Science Program
Synthesis and Assessment Product 4.1