Part II Overview: Societal Impacts and Implications

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The first set of chapters examined some of the physical and environmental impacts of sea-level rise on the Mid-Atlantic, with a focus on the natural environment. Part I closed by looking at the species that depend on the wetlands and beaches potentially threatened by rising sea level.

This part of the report examines the implications of sea-level rise for the built environment. Although the direct effects of sea-level rise would be similar to those on the natural environment, people are part of the built environment, and people will want to respond to changes as they emerge, especially if important assets are threatened. The choices that people make could be influenced by the physical setting, the properties of the built environment, human aspirations, and the constraints of laws and economics.

The following chapters examine the impacts on four human activities: shore protection/retreat and habitation, public access, and flood hazard mitigation. This assessment does not predict the choices that people *will* make; instead it examines some of the available options and assesses actions that federal and state governments and coastal communities can take in response to sea-level rise.

II.1 THE CONNECTION BETWEEN THE PART II CHAPTERS

As rising sea level threatens coastal lands, the most fundamental choice that people face is whether to attempt to hold back the sea or allow nature to takes its course. Both choices have important costs and uncertainties. "Shore protection" or preservation of the status quo allows homes and businesses to remain in their current locations, but often damages coastal habitat and requires substantial expenditure. "Retreat" can avoid the costs and environmental impacts of shore protection, but often at the expense of lost land and—in the case of developed areas—the loss of homes and possibly entire communities. In nature reserves and major cities, the preferred option may be obvious. But because both choices have some unwelcome consequences, in many areas it may be very difficult to decide whether to protect or retreat. Until this choice is made, however, preparing for long-term sea-level rise in a particular location may be impossible.

Chapter 5 begins a dialogue in examining issues related to shores that may be protected and which are likely to retreat. These efforts are not meant to be a prediction of what will occur (that is not yet possible), but recognize that assessing current policies and trends is a starting point. Most areas lack a plan that specifically addresses whether the shore will be protected or retreat. Even in those areas where a state plans to hold the line or a park plans to allow the shore to retreat, the plan is based on existing conditions. Current plans consider the costs or environmental consequences of sustaining shore protection for the next century and beyond. Future examination of these issues has two motivations:

- investigate whether existing land use trends pose a risk to the landward migration of tidal wetlands necessary to sustain those ecosystems as sea level rises; and

- motivate dialogues within communities about which shores should be protected and which should retreat.

One of the most important decisions that people make related to sea-level rise is the decision to live or build in a low-lying area. Chapter 6 quantifies the population and number of households within the land potentially inundated by rising sea level. The results are based on Census data for the year 2000, and thus are not estimates the number of people or value of structures that *will* be affected, but rather estimate the number of people who have a stake *today* in the possible future consequences of rising sea level. The calculations in this chapter build quantitatively on the elevation results from Chapter 1 and existing shore protection measures (*e.g.*, coastal armoring). As one would expect, most of the people and investments are in the areas where shore armoring has occurred. Chapter 6 also summarizes a study sponsored by the U.S Department of Transportation on the potential impacts of global sea-level rise on the transportation infrastructure.

Chapter 7 looks at the implications of sea-level rise for public access to the shore. The assessment concludes that only impacts examined in the literature are the impacts of responses taken to armor the shore, or to address sea-level rise.. One class of shore “protection” approaches (shoreline armoring) tends to decrease public access *along* the shore; while another method of shore “protection” (beach nourishment) sometimes increases public access.

Lastly, Chapter 8 examines the implications of rising sea level for flood hazard mitigation, with a particular focus on the implications for the Federal Emergency Management Agency (FEMA) and other coastal floodplain managers. Rising sea level increases the vulnerability of coastal areas to flooding because higher sea level increases the frequency of floods by providing a higher base for flooding to build upon. Erosion of the shoreline could also make flooding more likely because there is less protection against storm forces or the incursion of high tides, waves, or storm surge. Higher sea level also raises groundwater levels, increasing runoff and thereby increasing flooding from rainstorms.

Chapter 8 opens with results of studies on the relationship of coastal storm tide elevations and sea-level rise in the Mid-Atlantic. It then provides background on government agency floodplain management and on state activities related to flooding and sea-level rise under the Coastal Zone Management Act. Federal agencies, such as FEMA, are beginning to specifically plan for future climate change in their strategic planning. Some coastal sates, such as Maryland, have conducted state-wide assessments and studies of the impacts of sea-level rise and have taken steps to integrate this knowledge with local policy decisions.

The four chapters in Part II incorporate the underlying sea-level rise scenarios of this report differently, because of the differences in the underlying analytical approaches. The Census data analyses in Chapter 6 evaluated population and property in 50-cm elevation increments from 50 to 300 cm above spring high water. Chapters 7 and 8 both provide qualitative analyses that are not especially sensitive to the rate of sea-level rise. Both chapters assess various scenarios with rates of sea-level rise that are higher than the 20th century trend.

Chapter 5. Shore Protection and Retreat, Land Use and Wetland Migration: Adapting to Sea-Level Rise

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5.1 BACKGROUND

As discussed in previous chapters, many types of shoreline will become increasingly vulnerable as sea level continues to rise. Decisions about how to moderate or adapt to the impacts of sea-level rise will be different for different land uses and will rely not just on a variety of physical and geological considerations, but will also have to consider the value of land (monetary, resource-value, and perceived value), public opinion, public safety and risk assessments, ecosystem survival, legacy policy, as well as multiple other factors.

In the mid-Atlantic region, the land along the ocean coast that is not part of a park or conservation area is almost entirely developed. There is increasing pressure to develop land along tidal creeks, rivers, and bays—and barrier islands are in a continual state of redevelopment in which seasonal cottages are replace with larger homes and high-rises. Coastal development generally does not consider the need for future adaptation to sea-level rise. For example, a local planning decision to allow a housing subdivision near the shore may not explicitly consider the potential cost of taking measures to prevent that land from being inundated by the sea in several decades, the potential risk to ecosystems associated with those measures, or other options such as the possibility of allowing the land to be gradually submerged by rising water.

EPA has undertaken studies assessing the likelihood of different adaptation options (Nicholls *et al.*, 2007, p. 343). Although the methods and output of those studies have been peer-reviewed and presented at several conferences (*e.g.* Clark, 2001; Nuckhols, 2001; Coyman, 2003; Kean, 2003), the results are only available in books (Titus, 2005) and conference proceedings (Hudgens and Neumann, 2000; Titus, 2004). Since these studies have yet to appear in the peer-reviewed scientific literature, this synthesis report makes limited use of their results, and for that reason this chapter gives only a brief overview of adaptation options. For example, shoreline armoring or elevating land, through actions such as beach nourishment, are part of a suite of options to adapt to sea-level rise. Such options are commonly referred to as “shore protection”, although the term *protection* usually implies stabilizing the existing shoreline to protect real estate, buildings, and infrastructure. However, one of the consequences of shore protection can be to alter the normal shoreline processes that act to sustain wetlands and the ecosystems that depend on them. Although these methods may adequately protect existing land use, they may not account for the ability of ecosystems to adapt to sea-level rise.

Many of the options for responding to sea-level rise have both advantages and disadvantages; it is not the role of this assessment to advocate one option over another in different regions for different land uses, nor to predict what coastal managers might do.

Table 5-1 provides a summary of various "protection and "retreat" mechanisms, purposes, and environmental effects.

Lastly, this chapter synthesizes information on areas where wetlands may be able to accommodate sea-level rise by migrating, and areas where that cannot currently occur because of the limits of land use. In chapter 9, there is further discussion on implications for decision-making along the coast.

5.2 SHORE PROTECTION AND RETREAT

Most of the chapters in this report examine measures or impacts related to shore protection and retreat. This section provides an overview of the key concepts and common measures for holding back the sea or facilitating a landward migration.

5.2.1 Shore Protection

The term "shore protection" generally refers to a class of activities that prevent flooding, erosion, or inundation of land and structures. The term is somewhat of a misnomer because shore-protection measures protect land and structures immediately inland of the shore, rather than the shore itself. Shore protection is often the antithesis of shoreline preservation. In common use, "shore protection" often includes measures that prevent wetlands from eroding. However, this report uses the term more narrowly, to refer to activities that prevent dry land from being flooded or converting to wetland or open water.

Shore protection measures can be broadly divided into two categories: shoreline armoring, and elevating land surfaces. Shoreline armoring replaces the natural shoreline with an artificial shore, but areas inland of the shore are generally untouched. Elevating land surfaces, by contrast, can maintain the natural character of the shore, but requires rebuilding all the vulnerable land. Some methods are hybrids of both approaches. The *Coastal Engineering Manual* (U.S. Army Corps of Engineers, 2002) provides a comprehensive discussion, however brief descriptions are provided below for context in this report.

5.2.1.1 Shoreline Armoring

Shoreline armoring involves the use of structures to keep the shoreline in a fixed position or to prevent flooding when water levels are higher than the land.

Keeping the shoreline in a fixed position

Sea walls are impermeable barriers designed to withstand the strongest storm waves, and to prevent overtopping during a storm. During calm periods, they may either be landward of a beach, or their seaward side may be in the water. During storms, they often reflect the wave energy downward, causing additional beach erosion. Sea walls are often used along important transportation routes such as highways or railroads (Figure 5.1a).

Figure 5.1 a). Galveston Seawall, and b) Bulkhead between marsh and shorefront home. *Monmouth County, New Jersey.*

Bulkheads are vertical walls designed to prevent the land from slumping toward the beach. They must resist waves and currents to accomplish their design intent, but they are not designed to be sea walls that can withstand punishing storm conditions. They are usually found on lower energy estuarine shorelines, particularly in marinas, harbors, and places where boats are docked, and many residential areas where homeowners prefer a tidy shoreline. Like seawalls, they may either be landward of a beach or their seaward may be in the water. In the latter case, they reflect wave energy both downward and back into the estuary. Bulkheads hold soils in place, but they do not normally extend high enough to keep out foreseeable floods. (Figure 5.1b).

Retaining structures include several types of structures that serve as a compromise between a sea walls and a bulkhead. They are often placed at the rear of beaches, and are often intended to be unseen. Sometimes they are sheet piles that are driven into the sand, sometimes they are long, cylindrical, sand-filled “geo-tubes” (Figure 5.2 a and b). Often they are concealed as the buried core of an artificial sand dune. Like seawalls, they are intended to be a final line of defense against waves; but they can not survive continuous wave attack for long.

Figure 5.2. Geotube before (a) and after (b) being buried by beach sand. *Bolivar Peninsula, Texas.*

Revetments are walls whose sea side follows the slope of the beach. Like the beach they replace, they are more effective at absorbing the energy of storm waves than bulkheads and seawalls. As a result, they are less likely to fail during a storm, and reflect less energy. Some revetments are smooth walls, while others have a very rough appearance. (Figure 5.3 a and b).

Figure 5.3 Two types of stone revetments a) *Near Surfside Texas and b) Jamestown, Virginia.*

Protecting Against Flooding or Permanent Inundation

Dikes are high, impermeable earthen walls designed to keep the area behind them dry. They can be set back from the shoreline if the area to be protected is a distance inland. To be effective, they require a drainage system compatible with their objective. Land below mean low water requires a pumping system to remove rainwater and any water that seeps through the dike. Land whose elevation is within the range of the tides, can be drained with tide gates except during storms (Figure 5.4a).

Dunes are accumulations of windblown sand, but they often function as a temporary barrier against wave runup and overwash (Figure 5.4b).

Figure 5.4 a) A Dike bin Miami-Dade County, Florida, and b) a newly–created dune in Surf City, New Jersey

Tide gates are barriers across small creeks or drainage ditches. By opening during low tides and closing during high tides, they enable a low-lying area above mean low water to drain without the use of pumps. (Figure 5.5).

Figure 5.5: The tide gate at the mouth of Army Creek on the Delaware side of the river. The tide gate drains flood and rain water out of the creek to prevent flooding. The five circular mechanisms on the gate open and close to control water flow (courtesy NOAA Photo Library).

Storm surge barriers operate on the same principal as tide gates, except on a much larger scale and only during storms. They close a river mouth or inlet to prevent storm surges or high wave energy from entering an estuary. The rest of the time they are open. These barriers must be strong enough to hold back water flowing from the river and also the storm waves and surge on their seaward side. People make management decisions about when to close the gates or raise the submerged barriers (Figure 5.6).

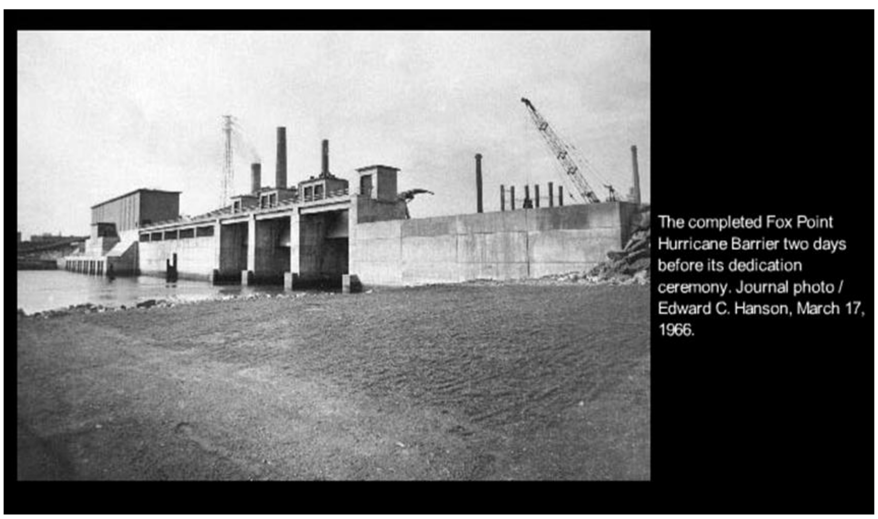

Figure 5.6. The storm surge barrier/gate for Providence, RI.

5.2.1.2 Elevating Land Surfaces

Beachfill, also known as *Beach Nourishment* and *Sand Replenishment* involves the purposeful addition of sand to a beach. Sand from offshore or an inland source is dumped onto a shoreline, often in tremendous quantities, to provide a buffer against wave action and flooding (National Ocean Service, 2000b). Placing sand onto an eroding beach can reverse erosion for a time; but unless radically new conditions are established, erosion generally resumes, necessitating periodic re-nourishment.

Dunes are shore parallel features that when designed and constructed by people are intended to intercept wind-transported sand and keep it from being blown inland and off the beach. The effectiveness of dunes is often increased by planting dune grass or installing sand fencing.

Elevating land and structures is the equivalent of a beachfill operation in the area landward of the beach. After a severe hurricane in 1900, most of Galveston was elevated by more than one meter. Unlike beach nourishment, this form of shore protection can be implemented by individual property owners. Several federal and state programs exist for elevating homes, which has become commonplace in some coastal areas, especially after a severe flood.

Dredge and fill is rarely used today because of the resulting loss of tidal wetlands, but the legacy remains with a large number of very low-lying communities along estuaries. It involved converting tidal wetlands to a combination of dry land suitable for home construction and navigable waterways to provide boat access to the new homes. Channels were dredged through the marsh, and the dredge material was used to elevation the remaining marsh to create dry land.

5.2.1.3 Hybrid Approaches to Shore Protection

A number of hybrid approaches are also available. Generally the goal of these approaches is to retain some of the storm-resistance of a hard structure, while also maintaining some of the features of natural shorelines. Some of the traditional approaches include breakwaters and groins, hard structures that reduce the extent to which waves and current can cause erosion, without replacing the beach with a structure. Recently, several state agencies, scientists, and others have become interested in measures that reduce erosion along estuarine shores, while preserving more habitat than bulkheads and revetments. Those measures are commonly known as *living shorelines*, and are extensively discussed in a recent assessment by the National Research Council (2006).

5.3.2 Retreat

The alternative to shore “protection” is commonly known as “retreat”. A retreat can either occur as an unplanned response in the aftermath of a severe storm, or as a planned response to avoid the adverse effects of shore protection. Some studies have concluded that a retreat requires a longer lead time than shore protection (*e.g.*, Titus, 1998; IPCC CZMS, 1992; O’Callahan, 1992).

Measures for shore protection generally involve civil engineering activities to control the forces of nature, along with some level of environmental engineering to avoid adverse impacts. Some measures that facilitate retreat involve engineering, but institutional and planning measures are also part of the mix.

Relocating Structures is possibly the most important engineering activity involved in a retreat. Perhaps the most ambitious relocation in the Mid Atlantic has been the landward relocation of the Cape Hatteras Lighthouse (Figure 5.7a) More commonplace is the routine structural moving activity involved in moving a house back several tens of meters within a given shorefront lot, as well as the removal of structures threatened by shore erosion (Figure 5.7b).

Figure 5.7 a) Cape Hatteras Lighthouse after Relocation. The original location is in the foreground, and b) a home threatened by shore erosion. The geotextile sand bags are protecting the septic system. *Kitty Hawk, North Carolina*.

Erosion-based setbacks are a common planning tool to facilitate a retreat. North Carolina prohibits new structures based on the current erosion rate times 30 years (in the case of easily moveable homes) or 60 years (in the case of large immoveable structures). Maine's setback considers accelerated sea-level rise over the next century.

Buyout programs provide funding to compensate landowners for losses due to coastal hazards, by purchasing vulnerable property. In effect, these programs transfer some of the risk of sea-level rise from the property owner to the public, which pays the cost.

Rolling easements are regulatory mechanisms or interests in land that prohibit shore protection and instead allow wetlands and beaches to potentially migrate inland as sea level rises. In effect, rolling easements transfer some of the risk of sea-level rise from the environment or the public, to the property owner.

Purchase programs involve the anticipatory purchase of undeveloped lands vulnerable to sea-level rise before the can become developed.

Density restrictions allow some development but limit densities near the shore. Although the original motivation may be to reduce pollution runoff into estuaries, they also facilitate retreat by limiting development.

Table 5.1 is a summary of the purposes for various methods for shore "protection", shore "retreat' and their environmental effects.

Table 5.1 Potential Environmental Effects of Responses to Sea-Level Rise

Method	**Purpose**	**Environmental effects**
Using structures to interfere with waves and currents		
Breakwater	Reduce erosion	May attract marine life; downdrift erosion
Groin	Reduce erosion	May attract marine life; downdrift erosion
Using structures to define a shoreline		
Sea wall	Reduce erosion, protect against flood and wave overtopping	Elimination of beach; scour and deepening in front of wall; erosion exacerbated at terminus
Bulkhead	Reduce erosion, protect new land fill	Prevents inland migration of wetlands and beaches. Wave reflection erodes bay bottom, preventing SAV. Prevents amphibian movement from water to land.
Revetment	Reduce erosion, protect land from storm waves, protect new land fill	Prevents inland migration of wetlands and beaches. May create some habitat for oysters and refuge for some species.
Retaining structure	Reduce storm-based erosion	Separates habitats if exposed; otherwise little effect
Using structures to protect against floods and/ or permanent inundation		

Dikes	Prevents flooding and permanent inundation (when combined with a drainage system).	Prevents wetlands from migrating inland. Thwarts ecological benefits of floods (*e.g.*, annual sedimentation, higher water tables, habitat during migrations, productivity transfers)
Tide gates	Reduces tidal range by draining water at low tide and closing at high tide.	Reduced tidal range reduces intertidal habitat. May convert saline habitat to freshwater habitat.
Storm surge barriers	Eliminates storm surge flooding; could protect against all floods if operated on a tidal schedule	Necessary storm surge flooding in salt marshes is eliminated.
Elevating land as the sea rises		
Dunes	Protect inland areas from storm waves, provide a source of sand during storms to offset erosion.	Can provide habitat; can set up habitat for secondary dune colonization behind it
Beachfill	Reverses shore erosion, and provide some protection from storm waves.	Short-term loss of shallow marine habitat; could provide shore habitat for endangered species; would provide sediment to augment dune growth
Elevate land and structures	Avoid flooding and inundation from sea-level rise by elevating everything as much as sea rises.	Deepening of estuary unless bay bottoms are elevated as well.
Retreat		
Setback	Avoid the need for shore protection by keeping development out of threatened lands	Impacts avoided until shore erodes up to the setback line. Environmental impacts of development also reduced.
Density Restriction	Reduce the benefits of shore protection and thereby make it less likely.	Depends on whether owners of large lots decide to protect shore. Environmental impacts of development also reduced.

5.3 OVERVIEW OF LAND USE ALONG THE MID-ATLANTIC

The land uses along the mid-Atlantic coast include residential, commercial, industrial, government, military, agriculture, forest, and wetland. If threatened by rising sea level, many land uses (*e.g.*, urban, residential, commercial, industrial, transportation) would require shore protection for current land uses to continue. This is not to suggest that all of these lands *should* be protected, but researchers have generally concluded that most land owners will at least attempt to protect their investments or seek assistance from government agencies for such protection. The costs of armoring, elevating or nourishing shorelines are generally less — often far less — than the value of the land to the landowner. But there are also some land uses for which the cost and effort of shore protection may be less attractive than allowing the land to convert to wetland, beach or shallow water. Those land uses might include marginal farmland, conservations lands, portions of some recreational parks, and perhaps even portions of back yards where lot sizes are large.

Different categories of land use dominate different portions of the mid-Atlantic Coast. The greatest concentrations of low-lying undeveloped lands along estuaries are in North Carolina, along the Eastern Shore of Chesapeake Bay and along portions of Delaware Bay. Development has come more slowly to the lands along the Albemarle and Pamlico Sounds than other parts of the mid-Atlantic Coast. Maryland law prevents development along much of the Chesapeake Bay shore, and a combination of floodplain regulations and aggressive agricultural preservation programs limit development along the Delaware Bay shore in Delaware.

The Mid Atlantic has approximately 1,100 km of shoreline along the Atlantic Ocean. Along approximately two fifths of this coastline are ocean beach resorts with dense development and high property values. Federal shore protection has been authorized along almost all of these shores. These lands are fairly evenly spread throughout the Mid-Atlantic states, except for Virginia. Along approximately one third of the ocean coast, by contrast, landowners such as The Nature Conservancy and the U.S. Department of Interior are committed to allowing natural shoreline processes to operate. These shores include all of Virginia’s Atlantic Coast except for part of Virginia Beach, and a large part of North Carolina’s Outer Banks. The remaining quarter of the coast is lightly developed, yet shore protection is possible for these coasts as well due to the presence of important coastal highways and recreational areas, such as the Outer Banks (NC) and Fire Island (NY).

Despite momentum toward coastal development (and excluding land that is already given over to conservation uses), options still appear to be open for more than half of the dry land in the Mid-Atlantic within 1 m above the tides, and it may be possible to design land use plans that could accommodate both development and wetland migration in these areas.

Decisions to moderate the encroachment of the sea are based on physical, ecological, social, historic, and political reasons, and not just on the basis of land-use categories. Nonetheless, good data sets regarding land use and planned future land use must be an essential component in making decisions about the sort of adaptation measures to implement, if any. It is clearly of great value to make decisions about land use and development by including consideration of the impact of sea-level rise, with and without adaptation measures.

State-by-state differences in development plans and management practices lead to significant regional variations in the land available for wetland migration, and in appendices A-G more detail is provided at this scale. In the next section, we provide a broad overview of the potential for wetlands to migrate inland or otherwise form on lands that are dry today along the mid-Atlantic coast.

5.4 LAND AVAILABLE FOR LANDWARD MIGRATION AND FORMATION OF TIDAL WETLANDS

Wetlands and beaches provide important natural resources, wildlife habitat, and buffering of the coast (Chapter 4). As sea level rises, wetlands and beaches can potentially migrate inland as new areas become subjected to waves and tidal inundation—but not if human activities prevent such a migration.

Tidal wetlands have two important mechanisms for surviving as sea level rises: Vertical accretion (discussed in Chapter 3) and wetland migration. In this context, “survive” means maintaining the area of wetlands, not the survival of a particular plant community; and “wetland migration” means the natural process by which tidal wetlands, including marshes and beaches, move inland as sea level rises or beaches erode. For the last several thousand years, the relatively slow rate of sea-level rise allowed the area of tidal wetlands to increase in many areas: wetland accretion allowed the existing wetlands to keep pace with rising sea level, while wetland migration enabled a landward expansion of wetlands as dry land became submerged.

The two key relationships determining future wetland area are the relationship between wetland vertical development and sea-level rise, and between the rates of seaward erosion and inland migration. If wetland vertical development keeps pace with sea-level rise, wetland area will expand if inland migration is greater than seaward erosion, remain unchanged if inland migration and seaward erosion are equal, and decline if seaward erosion is greater than inland migration. If wetland vertical development lags behind sea-level rise (*i.e.*, wetlands do not keep pace), the wetlands will eventually become submerged and deteriorate even as they migrate inland, resulting in a loss of wetland area.

The prospect of accelerated sea-level rise along with coastal development, however, could potentially disrupt both of the processes by which tidal wetlands have been sustained in the past. Chapter 3 addresses the accretion issue in detail, concluding that in the high scenario in which sea-level rise accelerates by 7mm/yr, most existing tidal wetlands could not keep pace. Although the creation of wetlands due to wetland migration can occur whether or not wetlands are lost at their lower seaward boundary, existing policy and planning studies have assumed that wetland creation would be more important if existing wetlands are lost, than if they are maintained (IPCC CZMS, 1990; Titus 1991, 1998). For example, early estimates (*e.g.*, EPA, 1989) suggested that a 70 cm rise in sea level over the course of a century would convert 65% of the existing mid-Atlantic wetlands to open water, and that this region would experience a 65% net loss if all shores were protected so that no new wetlands could form inland. That loss would only be 27%, however, if new wetlands were able to form on undeveloped lands and 16% of developed areas converted to marsh as well.

The fact that intertidal zones migrate inland does not necessarily mean that they will be of high environmental quality, or even that they will be able to sustain themselves as sea level continues to rise. For example, as upland forest or nontidal wetlands become exposed to saline water for a sufficient amount of time, freshwater plants may become stressed (water logging, salt stress, or sulfide toxicity) and eventually die. Forests may give way to shrub species that can tolerate some salt, and eventually a community of salt tolerant high marsh plants may be established (Brinson *et al.*, 1995). While the transition from freshwater to tidal salt environment is slowly occurring, the existing marsh may also be accreting if there is enough sediment available. In order for wetlands to have a greater chance of survival under conditions of sea-level rise (and especially accelerated sea-level rise), migration inland will be necessary in some cases.

Very little land has been set aside for the express purpose of ensuring that wetlands can migrate inland as sea level rises. But those who own and manage estuarine conservation lands do allow wetlands to migrate onto adjacent dry land. With a few notable exceptions[18], the managers of most conservation lands along the ocean and large bays allow beaches to erode as well. Numerous studies have pointed out that the potential for landward migration of coastal wetlands is limited by the likelihood that many shorelines will be preserved for existing land uses (EPA, 1989; IPCC CZMS, 1990). Chapter 1 showed that without shore protection, the amount of dry land close to sea level which might potentially convert to tidal wetlands as sea level rises is approximately 20% of the area of existing wetland.

[18] Exceptions include Cape May Meadows in New Jersey, beaches along Delaware Bay nourished for horseshoe crab habitat, and northern portions of Assateague Island being nourished to prevent that part of the island from disintegrating.

Some preliminary studies (*e.g.* Titus, 2004) indicate that the land potentially available for new wetland formation would be almost twice as great if future shore protection is limited to lands that are already developed, than if developed and legally developable lands are protected. If erosion of the seaward marsh boundary increases, the wetlands that formed on these formerly dry lands through wetland migration will account for an increasing fraction of all wetlands. This has significant implications for decision-making in the future, and efforts to better quantify the effect of shore protection and other adaptation measures in the face of rising sea level must be a priority if coastal managers, planners and policy-makers are to be able to incorporate appropriate information.

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Chapter 6. Population, Land Use, and Infrastructure

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The coastal zone has competing interests of increasing population accompanied by 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 and in a sustained manner.

This chapter quantifies the current population, infrastructure, and socioeconomic activity that may potentially affected by sea-level rise. The first study draws upon a methodology and approach prepared for this particular report. For population and land use, the assessment combines a GIS analysis of information on elevation and preliminary information on shore protection along with census statistics and land use statistics that are presented in geospatial distributions. This approach also provides specific numerical estimated information down to the county level which is of most benefit to local coastal managers. It is not without uncertainty and the statistical results are presented in terms of high and low estimates.

For understanding the impacts if sea-level rise of the nation's transportation infrastructure, a recent study (DOT, 2007) performed for the U.S Department of

Transportation Center for Climate Change and Environmental Forecasting using a similar GIS analysis is summarized.

At the end if this discussion Table 6.9 provides a summary of the data sources, approaches, and limitations of the analysis.

KEY FINDINGS

- The available data prevents a precise estimate of the number of people whose homes would be inundated by a rise in sea level. Based on a set of optimistic assumptions, at least 25,000 people live on land within one meter above spring high water. But the actual figure is likely to be much greater.
- The available data is sufficient to estimate the number of people who live in the immediate vicinity of land potentially inundate 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 percent of this population is along the Atlantic Ocean or adjacent coastal bays.
- 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

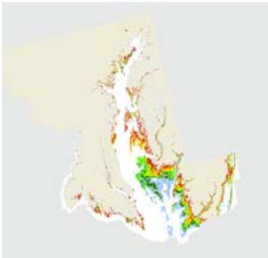
Carolina, plus Washington, DC, approximately 3,500 km of our National Highway System, Interstates and other major arterials could be at risk for regular inundation given a sea-level rise of 50 cm. Approximately 1,390 km of railway for these same states could be affected for the same scenario.

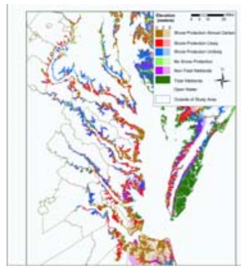
- The lower lying, less developed watershed regions like Pamlico and Albemarle Sounds, which are less developed and have more wetland acreage than watersheds to their north, may have a higher percentages of their populations in regions that are unlikely to take shoreline armoring or elevation measures.
- The top four land use categories in the lower elevation areas that are likely to be impacted by a 50cm sea-level rise for the Mid-Atlantic are, in order: Agriculture, Wetland, Forest, and Developed lands.

6.1 INTRODUCTION

The methodology for addressing population and land use uses a GIS analysis approach, creating overlays and joining GIS tables to provide useful summary information.

Figure 6.1 illustrates the four layers used in the analysis: the elevation layer (Chapter 1), the response layer reflecting preliminary information on existing approaches to shore protection, a census block layer NOAA Spatial Trends in Coastal Socioeconomics (STICS) Tool (NOAA, 2006) Census 2000 data base (U.S. Census Bureau, 2000), and a land use database.





Elevation **Existing Actions on Shore Protection**

Census **Land Use**

Figure 6.1 Input layers to Question 6 GIS analysis.

To illustrate the layers, Figures 6.2 thru 6.4 provide a look at the fundamental underlying layers being use in this study, using Delaware Bay as an example. These will be used in conjunction with the elevation and protection overlays for Delaware found in Part IV of this report. Figure 6.2 provides is an example of the census block overlay, Figure 6.3 is an example of the county overlay, and Figure 6.4 is the example of the census tract overlay.

Figure 6.2 The block overlay example for Delaware Bay.

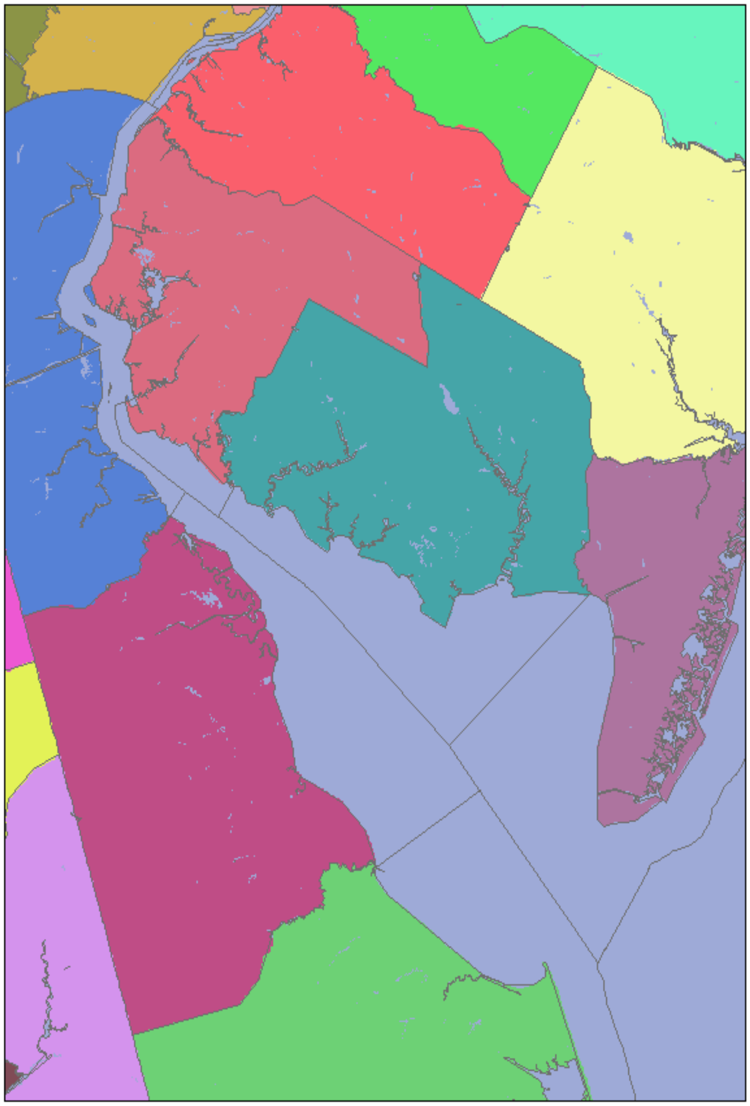


Figure 6.3 The county overlay example for Delaware Bay.

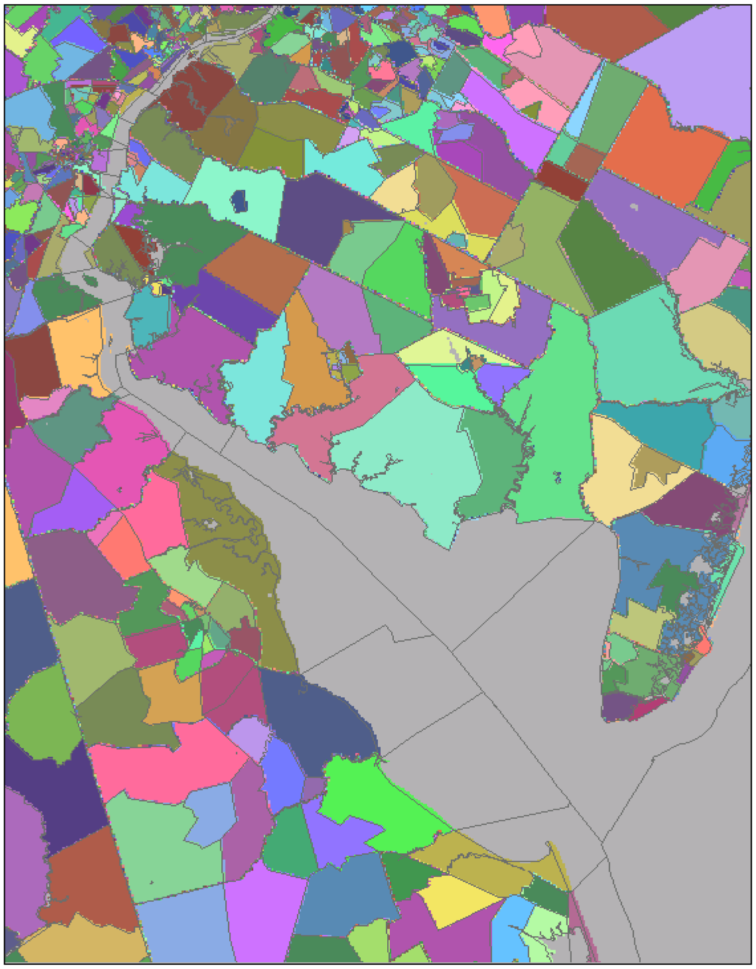


Figure 6.4 The tract overlay example for Delaware Bay.

A Census Block is a subdivision of a census tract (or, prior to 2000, a block numbering area). A block is the smallest geographic unit for which the Census Bureau tabulates 100-percent data. Many blocks correspond to individual city blocks bounded by streets, but blocks – especially in rural areas — may include many square miles and may have some boundaries that are not streets. The Census Bureau established blocks covering the entire nation for the first time in 1990. Previous censuses back to 1940 had blocks established only for part of the nation. Over 8 million blocks are identified for Census 2000 (U.S. Census Bureau, 2007).

A Census Tract is a small, relatively permanent statistical subdivision of a county delineated by a local committee of census data users for the purpose of presenting data. Census tract boundaries normally follow visible features, but may follow governmental unit boundaries and other non-visible features in some instances; they always nest within counties. Census tracts are designed to be relatively homogeneous units with respect to population characteristics, economic status, and living conditions at the time of establishment, census tracts average about 4,000 inhabitants. They may be split by any sub-county geographic entity.

The methodology and process used in the construction of the regional and state summary tables is completed using an area-adjusted system that includes as a lowest common denominator areas that 1) are greater than the zero contour of a Spring High Water vertical datum adjusted elevation model, and 2) not considered a wetland or open water according to the best possible compiled state and National Wetlands Inventory (NWI) wetlands data (FWS, 2007). Uncertainties are expressed and presented in the tables in terms of low and high estimates. The four layers are as follows:

- Elevation data: The elevation data is the driving parameter in the population analysis. The elevation data is gridded into 30 meter pixels throughout the region. All other input datasets described below are gridded to this system from their source format. Compiled for CCSP, this dataset is created individually for each state using the best data sources available. The elevations are adjusted such that the zero-contour line is set relative to the Spring High Water vertical datum.

- Census data: Census 2000 dataset contained in the NOAA Spatial Trends in Coastal Socioeconomics Program (STICS) is used in the analysis. Block boundaries are the finest scale data available, and are the building blocks of the Census analysis. Tracts, counties and states boundaries are derived from appropriate aggregations from their defining blocks. Tract and county boundaries also extend fully into water bodies, so for this analysis, they are cropped back to the sea-level boundary, but source Census data remain intact.
- Land use data: Land use/land cover is a difficult dataset to find in high resolution throughout large regions. The National Land Cover Data (USGS, 2001) product is used in this analysis. This is a 30 meter pixel classification from circa 2001 satellite imagery and is consistently derived across the region.
- Protection Zones: Compiled for CCSP, this dataset combines a number of protection and urban layers to describe the likelihood of the shoreline being protected in the event of sea-level rise.

The analysis evaluates several different datasets (Census blocks/tracts, land use) within sea-level rise zones of 25-cm intervals, up to a 3-meter rise (0-25, 0-50, 0-300cm). Census block statistics include area and percent of block affected, number of people and households affected based two methods: uniform distribution throughout the block, and a best-estimate based on assumptions concerning elevation and population density. These numbers are aggregated to the county and state level for reporting. Statistics are provided at the county level for different sea-level rise scenarios and percent inundation of blocks.

The Census tract boundaries are the smallest census unit that contains property and tax values. The same analysis is completed for tracts, and aggregated to show values affected at the tract, county and state level for 25-cm increments of sea-level rise.

This chapter examines the broad mid-Atlantic region and makes some inferences on the population that may be affected and this assessment divides the mid-Atlantic Region into sub-regions defined by watershed, as shown in Figure 6.5. The general populations within the various watersheds, although crossing over states, have to address common problems in response to sea-level rise driven by common topographies, physical and meteorological regimes. The impacts of sea-level rise will also tend to be common within the low-lying areas of each watershed. Most of the watershed boundaries are straightforward, for instance the Potomac River and Chesapeake Bay. The watershed boundaries do not include the upland portions of the watershed, however those portions are not required for the analyses of the low lying areas. The Atlantic Ocean watershed is the most complex as it is not defined by a discrete estuarine river watershed boundary, but by exposure to the outer coastline, and it has components in several states. The more localized effects at the county are discussed in the various appendices found in Part IV of this report.

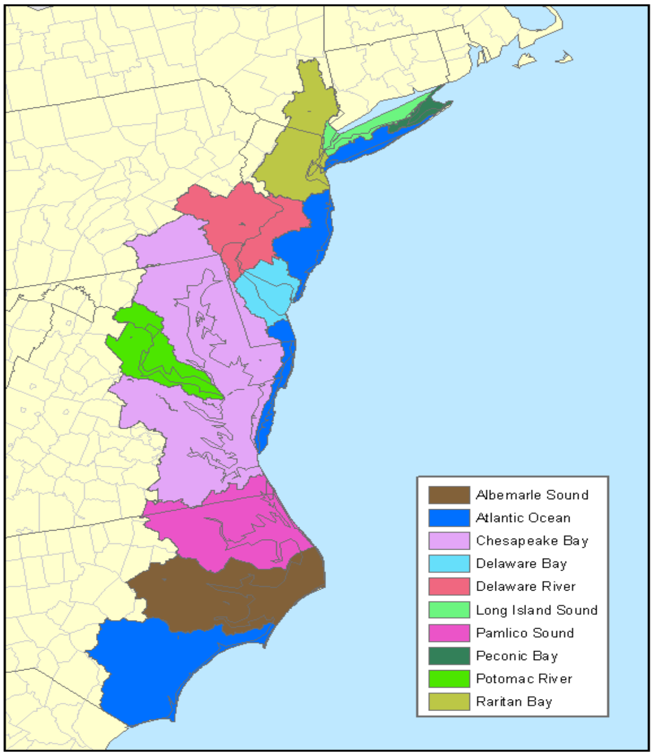


Figure 6.5 The mid-Atlantic region generalized watersheds.

6.2 POPULATION

Table II.1 in the overview provides total statistics for each of the watersheds. Not everyone in those watersheds lives in a low-lying area at risk to be inundated by sea-level rise. Table 6.1 is a summary analysis of those populations in each watershed at potential risk for various rates of sea-level rise (50cm, 1m, 2m, and 3m). These statistics represent the overall totals from which following tables and maps will show subsets in various levels of potential risk, inundation and shore protection. The low and high estimates in Table 6.1 provide the range of uncertainty by using the low and high Digital Elevation Models (DEM) for each of the scenarios of sea-level rise (50cm, 1m, 2m, and 3m). The high and low DEMs are required because of the varying scales and resolutions of the data on the various overlays (for instance the overlay of the census block on the elevation layer). The uncertainty in how much of a particular census tract or block may be inundated must also be addressed by listing high and low estimates. Table 6.1 is the high estimate of the potential populations because it is for census blocks that could have any inundation at all and thus includes a maximum count.

Of note in Table 6.1a are the relatively high population statistics for the Chesapeake Bay and the Atlantic Ocean, the Atlantic Ocean population counts increasing faster than those for the Chesapeake as the inundation scenario worsens.

Table 6.1a Subset of the population from census blocks within watershed tracks using any inundated blocks for various sea-level rise scenarios.

Population	50cm		1m		2m		3m	
Watershed	Low	High	Low	High	Low	High	Low	High
Long Island Sound	1,641	173,786	1,641	191,218	93,752	234,593	138,016	298,162
Peconic Bay	7,871	20,415	7,871	29,147	15,484	37,091	26,789	41,696
NHY-Raritan Bay	24,298	577,285	35,960	678,676	132,176	931,241	351,176	1,211,728
Delaware Bay	18,762	56,688	22,665	62,778	41,203	84,551	58,551	100,835
Delaware River	14,553	200,962	19,381	239,481	79,750	361,014	118,273	442,054
Chesapeake Bay	291,571	698,778	326,833	807,728	617,314	1,156,241	884,889	1,390,546
Potomac River	0	95,043	0	124,516	32,248	145,610	92,873	171,611
Albemarle Sound	39,628	64,687	61,146	75,830	82,804	96,638	101,772	111,048
Pamlico Sound	50,876	116,638	69,724	147,290	134,906	249,726	190,889	292,949
Atlantic Ocean	225,367	860,120	362,801	1,109,285	925,171	1,434,265	1,346,607	1,727,375
All Watersheds	674,567	2,864,402	908,022	3,465,949	2,154,808	4,730,970	3,309,835	5,788,004

There is also uncertainty regarding where in the block the population resides and thus the relationship between the portion of a block’s area that is lost and the portion of the population residing in the vulnerable area. This analysis estimates vulnerable population based on the percentage of a census block that is inundated. For instance, the total population low and high estimated counts for a 1 m sea-level rise or all watersheds are 908,022 and 3,465,949 for “any inundation” of census block (see columns 4 and 5 above in Table 6.1). But homes are not necessarily distributed uniformly throughout a census block. If 10% of a block is very low, for example, that land may be part of a ravine, or below a bluff, or simply the low part of a large parcel of land. Therefore, the assumption of uniform density would often overstate the vulnerable population. Table 6.1b provides estimates for alternate assumptions regarding the percentage of a block that must be vulnerable before one assumes that homes are at risk. (This table presents the results by state rather than by subregion.) If we assume that 90% of a block must be lost before home are at risk, and that the population is uniformly distributed across the highest 10% of the block, then 26,059-883, 981 people live within one meter above spring high water, allowing for our low and high elevation estimates. Combining the low elevation estimate with the 90% assumption is a combination of very optimistic assumptions; therefore, we can be extremely confident that the number of people vulnerable to a one meter rise in sea level is greater than 26,000.

Table 6.1b Population living on land within one meter above spring high water
(Alternate assumptions about how much of the land must be lost before homes are lost)

	Percentage of block within one meter above spring high water									
	99[1]		90[2]		50[2]		0[3]		Best	
	Low	High	Low	High	Low	High	Low	High	Low	High
NY	784	421,900	784	470,906	2,617	685501	42326	1126292	21286	941938
NJ	12,547	302,804	15,775	352,517	41,268	498655	177509	834446	65182	596519
DE	483	7,205	816	9,237	2,048	16653	44295	85480	4990	22327
PA	646	7,835	646	8,949	1,539	15092	10365	43456	2894	26977
DE	483	7,205	816	9,237	2,048	16653	44295	85480	4990	22327
MD	610	4,847	1,895	8,044	4,386	17719	46890	137494	4224	17669
DC	0	0	0	0	0	46	0	9596	0	168
NC	1,924	14,144	5,327	25,091	17,453	60096	283592	345534	12982	39704
Total	17,477	765,940	26,059	883,981	71,359	1310415	649272	2667778	116548	1667629

(1) Population estimates in this column assume that no homes are vulnerable unless 99% of the dry land in census block is within one meter above spring high water.
(2) Same as 1 but for 90 and 50 percent.
(3) Assumes uniform population distribution.

The census information also allows further breakout analysis of the population by owner and renter occupied residences. This Census information gives a sense of the characterization of permanent home owners versus the more transient rental properties that could translate to infrastructure and local economy at risk as well. The number of owner occupied and renter occupied housing units in each watershed by various sea-level rise scenarios are shown in Tables 6.2 and 6.3. Similar to the estimates in Table 6.1., these are high estimates for which any portion of a particular census block is inundated. The actual coastal population potentially affected by sea-level rise also includes people staying in hotels for a few days and population census data on coastal areas rarely are able to fully reflect all of the population and resultant economic activity. It is noted that this present analysis does not include that subset of vacant properties used for seasonal, recreational, or occasional use as a way to characterize the "transient" population that the outer coasts typically have. This follow-on will be important because in many areas, the permanent populations are expected to increase as retirees occupy their seasonal homes for longer portions of the year.

Table 6.2 Number of Owner occupied residences in each watershed region for various sea-level rise scenarios – low and high estimates.

Owner occupied residences								
Watershed	50cm		1m		2m		3m	
	Low	High	Low	High	Low	High	Low	High
Long Island Sound	0	0	0	0	0	0	0	0
Peconic Bay	3,407	8,633	3,407	11,655	6,661	14,940	11,207	16,802
NYH-Raritan Bay	9,112	229,550	13,446	269,421	50,379	369,924	137,679	480,239
Delaware Bay	7,202	21,274	8,723	23,615	15,076	31,422	21,139	37,595
Delaware River	4,100	75,358	6,014	89,713	30,382	133,454	45,483	162,355
Chesapeake Bay	106,863	258,163	120,793	299,554	225,985	435,312	330,319	524,999
Potomac River	0	35,176	0	46,078	11,272	54,803	35,128	66,404
Albemarle Sound	14,365	24,278	22,760	28,729	31,466	37,089	39,192	42,985
Pamlico Sound	19,191	41,910	26,731	52,459	48,932	87,136	68,665	101,805
Atlantic Ocean	81,677	328,053	140,676	423,546	360,496	550,293	520,329	656,902
All Watersheds	245,917	1,022,395	342,550	1,244,770	780,649	1,714,373	1,209,141	2,090,086

Table 6.3 Number of renter occupied housing units by watershed for various sea-level rise scenarios.

Renter occupied residences								
	50cm		1m		2m		3m	
Watershed	Low	High	Low	High	Low	High	Low	High
Long Island Sound	78	27,540	78	31,018	15,524	39,200	23,132	53,216
Peconic Bay	528	1,696	528	2,465	1,197	3,260	2,190	3,746
NYH-Raritan Bay	2,634	153,190	4,279	178,793	24,219	245,645	85,914	324,632
Delaware Bay	2,396	5,499	2,639	5,887	4,182	8,536	5,757	10,221
Delaware River	1,370	27,509	2,112	32,767	10,833	48,533	15,651	56,514
Chesapeake Bay	32,531	72,366	35,881	84,632	66,616	142,433	100,221	179,513
Potomac River	0	12,900	0	17,478	3,722	22,160	14,480	27,627
Albemarle Sound	3,052	5,688	5,269	6,834	7,994	9,837	10,458	11,794
Pamlico Sound	3,977	8,073	6,009	10,663	10,435	20,143	15,115	23,267
Atlantic Ocean	23,226	111,853	40,222	154,509	122,097	204,643	193,791	244,601

6.3 LAND USE

The NLCD 2001 (USGS, 2001) is used to overlay land use onto the DEMs for various scenarios of sea-level rise. Land use categories include Agriculture, Barren land, Developed Land, Forest, Grassland, Shrub-scrub, Water, and Wetland. An estimate of the area of land categorized by land use for all watersheds for the mid-Atlantic is found in Table 6.4 below. In the land use tables, ranges of uncertainty are provided by showing the area statistics (in hectares) for the sea-level rise scenarios using a high DEM (for a low estimate) and a low DEM for a high estimate. At the 25 cm sea-level rise scenario shown in Table 6.4, the Wetlands land use category dominates the acreage, along with Agriculture and Forests. However with increasing sea-level rise, Agriculture, Developed lands, and Forests become much more affected than Wetlands. The high and low estimates show a significant spread around the standard estimate.

Table 6.4 Mid-Atlantic All Watersheds Summary for Land Use.

Hectares	Sea Level Rise (cm) Standard Estimate (regular DEM)				
Land Use	**25**	**50**	**100**	**200**	**300**
Agriculture	15,443.10	34,839.40	83,336.40	196,095.80	329,297.30
Barren Land	3,756.20	5,781.60	9,587.40	16,903.40	25,300.80
Developed	9,399.80	19,202.40	43,833.30	101,468.20	162,609.50
Forest	14,694.20	26,921.70	55,454.50	108,129.30	179,750.80
Grassland	1,915.70	4,893.60	10,211.00	18,537.80	26,163.40
Shrub-scrub	1,193.00	2,666.30	5,601.60	9,528.10	13,002.50
Water	1,362.60	1,905.40	2,644.30	3,539.40	4,329.60
Wetland	19,320.80	31,843.70	46,446.40	64,800.30	84,500.00

Hectares	Sea Level Rise (cm) Low Estimate (high DEM)				
Land Use	**25**	**50**	**100**	**200**	**300**
Agriculture	2,585.60	8,643.00	43,179.90	142,684.60	258,845.00
Barren Land	799.6	1,537.70	5,044.50	12,385.40	19,909.30
Developed	438.9	1,687.70	11,978.20	55,459.40	101,914.20
Forest	1,221.60	5,373.90	27,054.10	76,845.20	129,126.90
Grassland	765.7	2,041.20	7,640.60	16,477.70	24,208.50
Shrub-scrub	292.7	1,065.20	3,791.90	8,388.30	11,904.80
Water	690.4	1,045.50	1,967.90	2,960.10	3,693.70
Wetland	4,691.10	13,987.20	34,724.90	56,227.30	72,970.80

Hectares	Sea Level Rise (cm) High Estimate (low DEM)				
Land Use	**25**	**50**	**100**	**200**	**300**
Agriculture	58,529.10	87,441.80	141,805.50	280,661.10	402,413.40
Barren Land	8,859.20	10,889.70	14,759.50	23,159.30	29,343.00
Developed	49,457.30	66,660.90	92,951.60	157,392.00	205,031.40
Forest	42,557.20	58,642.90	94,281.80	163,058.50	219,751.60
Grassland	7,130.00	9,804.60	14,206.50	22,293.30	29,844.50
Shrub-scrub	3,906.40	5,422.10	7,726.00	11,239.60	15,025.40
Water	3,257.60	3,619.60	4,118.20	4,987.30	5,648.10
Wetland	46,962.90	54,931.20	66,597.70	84,084.60	101,410.30

Table 6.5 below shows the same information in Table 6.4, except broken out at a higher resolution by watershed. The Developed category acreage dominates northeast water sheds like Long Island Sound and New York harbor (HYH)-Raritan Bay. Agriculture and Forest dominate the Chesapeake Bay. Not surprisingly, the Developed land category dominates the Atlantic Ocean watershed. Table 6.6 provides the low and high estimates for the values of the standard estimate in Table 6.5.

Table 6.5 Area by land use category for the mid-Atlantic for standard estimate for various sea-level rise scenarios.

	(in hectares)	Sea Level Rise (cm) Standard Estimate (regular DEM)				
Watershed	**Land Use**	**25**	**50**	**100**	**200**	**300**
Long Island Sound	**Agriculture**	4.8	7.7	15.1	23.4	29.7
Long Island Sound	**Barren Land**	83.7	108.2	123.2	177.2	184.3
Long Island Sound	**Developed**	556	785.1	1,190.60	2,729.40	3,788.80
Long Island Sound	**Forest**	33.1	49.1	72.9	158.9	238.8
Long Island Sound	**Grassland**	26.1	35.3	46.8	82.4	104
Long Island Sound	**Shrub-scrub**	14.9	19.4	25.7	56.3	65.9
Long Island Sound	**Water**	26.3	45.2	57.6	80.6	95.9
Long Island Sound	**Wetland**	126.5	197.8	275	447.8	562.1
Peconic Bay	**Agriculture**	37.1	61.1	207.9	391.6	870.9
Peconic Bay	**Barren Land**	103.7	154.1	244.4	314.6	396.4
Peconic Bay	**Developed**	204.3	366.8	912.2	1,499.70	2,929.20
Peconic Bay	**Forest**	111.4	164.3	389.3	708.4	1,481.80
Peconic Bay	**Grassland**	36	47.2	83.7	137	269.7
Peconic Bay	**Shrub-scrub**	14.9	21.6	44.5	64.6	101.7
Peconic Bay	**Water**	32.5	65.8	112.8	157.1	218.9
Peconic Bay	**Wetland**	193.8	286.3	512.7	711	1,076.00
NYH-Raritan Bay	**Agriculture**	112.4	207.4	393.1	780.2	920.9
NYH-Raritan Bay	**Barren Land**	24.5	53	177.8	384.2	456.9
NYH-Raritan Bay	**Developed**	1,152.50	2,963.30	6,119.80	18,570.40	23,238.20
NYH-Raritan Bay	**Forest**	41.4	97.7	230	642.7	929.2
NYH-Raritan Bay	**Grassland**	0	1.4	4	10.2	21.6
NYH-Raritan Bay	**Shrub-scrub**	1.6	3.1	6.6	14.1	14.8
NYH-Raritan Bay	**Water**	21.2	41.3	91.4	194.2	234.9
NYH-Raritan Bay	**Wetland**	422.5	757.7	1,282.60	2,199.80	2,468.70
Delaware Bay	**Agriculture**	1,203.20	3,048.70	4,887.80	10,789.60	16,886.70
Delaware Bay	**Barren Land**	320.2	476.4	634.1	1,007.30	1,414.00
Delaware Bay	**Developed**	200.6	372.1	610.5	1,723.10	2,962.00
Delaware Bay	**Forest**	705.7	1,407.70	2,075.00	4,321.30	6,484.10
Delaware Bay	**Water**	89	107.2	119.6	143.6	160.7
Delaware Bay	**Wetland**	976.6	1,379.60	1,647.00	2,208.10	2,500.10
Delaware River	**Agriculture**	574.2	1,628.50	2,562.50	7,364.50	10,123.60
Delaware River	**Barren Land**	56.2	147.4	216.3	502.9	670.9
Delaware River	**Developed**	631.9	1,655.70	3,114.50	9,231.20	12,790.40
Delaware River	**Forest**	154.4	448.8	676.4	1,800.50	2,360.00
Delaware River	**Water**	30.2	84.1	113.5	155.6	172.4
Delaware River	**Wetland**	466.4	949.4	1,277.90	2,362.70	2,805.80
Chesapeake Bay	**Agriculture**	4,748.90	8,864.90	24,250.50	52,599.30	89,988.70
Chesapeake Bay	**Barren Land**	1,533.40	2,423.50	3,688.00	5,098.10	6,711.50
Chesapeake Bay	**Developed**	2,075.00	2,974.20	7,462.50	15,191.40	36,832.40
Chesapeake Bay	**Forest**	6,951.30	10,951.70	22,694.30	40,836.50	71,245.40
Chesapeake Bay	**Water**	374.8	436.5	565.7	703.4	848.2
Chesapeake Bay	**Wetland**	4,987.60	7,324.20	10,634.80	14,193.30	19,190.20
Potomac River	**Agriculture**	790.6	987.8	1,407.30	2,077.80	10,226.10
Potomac River	**Barren Land**	148.1	165.4	198.4	248.7	762.1
Potomac River	**Developed**	331.1	381.8	623.5	1,067.30	2,819.10
Potomac River	**Forest**	855.2	1,015.00	1,381.00	2,123.60	8,373.50
Potomac River	**Water**	60.1	64.6	85.4	109.8	165.7
Potomac River	**Wetland**	488	533.3	624.7	781.1	1,534.10

Table 6.5 - continued. Area by land use category for the mid-Atlantic for standard estimate for various sea level rise scenarios.

	(in hectares)	Sea Level Rise (cm) Standard Estimate (regular DEM)				
Watershed	**Land Use**	**25**	**50**	**100**	**200**	**300**
Albemarle Sound	**Agriculture**	3,758.00	9,968.00	20,535.80	46,916.40	
Albemarle Sound	**Barren Land**	39.8	69.8	145.6	368	
Albemarle Sound	**Developed**	503.3	1,546.40	3,877.80	7,993.30	
Albemarle Sound	**Forest**	2,253.20	5,708.70	12,806.70	25,124.90	
Albemarle Sound	**Grassland**	1,111.70	3,071.00	6,145.60	11,379.30	
Albemarle Sound	**Shrub-scrub**	753	1,736.90	3,599.80	5,795.80	
Albemarle Sound	**Water**	168.8	301.7	480.8	674.3	
Albemarle Sound	**Wetland**	5,095.80	9,609.80	14,147.40	19,260.00	
Pamlico Sound	**Agriculture**	3,361.70	8,698.40	24,578.80	64,187.50	110,577.90
Pamlico Sound	**Barren Land**	150	321.5	775.4	2,168.30	4,311.80
Pamlico Sound	**Developed**	362.4	1,049.10	2,964.70	6,469.70	12,064.10
Pamlico Sound	**Forest**	2,036.00	4,239.90	8,635.80	18,454.20	30,514.00
Pamlico Sound	**Grassland**	520	1,225.60	2,684.20	3,995.00	5,085.50
Pamlico Sound	**Shrub-scrub**	176.1	424.7	1,062.10	1,893.40	2,553.20
Pamlico Sound	**Water**	68.5	118.6	179.6	264.3	356
Pamlico Sound	**Wetland**	3,701.30	6,136.70	8,872.90	12,163.80	17,184.20
Atlantic Ocean	**Agriculture**	852.2	1,367.00	4,497.60	10,965.50	20,725.20
Atlantic Ocean	**Barren Land**	1,296.60	1,862.30	3,384.30	6,634.00	9,612.50
Atlantic Ocean	**Developed**	3,382.70	7,107.80	16,957.10	36,992.70	53,481.50
Atlantic Ocean	**Forest**	1,552.40	2,839.00	6,493.10	13,958.50	25,044.90
Atlantic Ocean	**Grassland**	221.9	513.2	1,246.80	2,931.80	4,883.80
Atlantic Ocean	**Shrub-scrub**	232.5	460.6	862.9	1,703.90	2,635.70
Atlantic Ocean	**Water**	481.3	627	821.4	1,012.00	1,134.90
Atlantic Ocean	**Wetland**	2,862.50	4,669.00	7,171.40	10,472.80	13,196.30

Table 6.6 Area by land use category for mid-Atlantic for low and high estimates for various sea level rise scenarios

	Low Estimate (high DEM)					High Estimate (low DEM)				
Land Use	**25**	**50**	**100**	**200**	**300**	**25**	**50**	**100**	**200**	**300**
Long Island Sd										
Agriculture	0	0	1.4	5.9	16.7	20.5	22	24.8	38.1	46.9
Barren Land	0	0	0.3	40.9	65.5	179	180.6	183.4	194.3	201.8
Developed	0	0	98.9	467.6	1,432.40	2,519.70	2,763.40	3,286.40	4,585.30	5,964.50
Forest	0	0	4.5	31.1	95.9	158.9	174	211	418.4	561.4
Grassland	0	0	0.5	7.1	23.1	82.6	89.8	100.4	136.5	159.4
Shrub-scrub	0	0	3.3	8.2	21.9	52.6	55.9	61.5	71.9	75
Water	0	0	5.7	10.6	17.7	83.6	87.4	92.7	109.6	120.7
Wetland	0	0	5.9	71.5	156.6	459.4	485.6	534.9	706.2	820.6
Peconic Bay										
Agriculture	0	0	22.4	186.2	399.4	220.2	262.5	361.2	814.6	1,108.90
Barren Land	0	0	22.5	102.8	216.5	274.8	290.3	343.3	391.8	422.8
Developed	0	0	101.7	741.2	1,417.70	998.6	1,128.40	1,589.20	2,849.30	3,655.60
Forest	0	0	56.7	337.6	796.4	438.1	505.2	766.5	1,444.90	1,855.50
Grassland	0	0	7.3	42.9	124.2	98.7	112.2	178.4	271.8	322.5
Shrub-scrub	0	0	5.5	26.9	51.9	54	58	76.1	100.8	113.2
Water	0	0	11	53.8	88.3	120.4	129.2	157.5	214.7	241.4
Wetland	0	0	73.8	262.2	494.4	562.1	610	770.4	1,073.50	1,239.80
NYH-Raritan Bay										
Agriculture	0	13.2	32.3	269.9	547.3	665.9	794.1	878.4	1,054.60	1,170.40
Barren Land	0	12.3	43	179.3	358.9	226.6	279.5	347.6	469.3	515.2
Developed	0.3	96.8	335.9	4,000.80	10,626.40	14,407.90	18,580.40	21,093.60	26,278.70	30,108.00
Forest	0.1	5.9	40.9	246.2	496.3	428	545.9	719.6	1,048.10	1,363.90
Grassland	0	0	0.1	2.9	7.7	8.8	10.8	16.8	21.3	28.1
Shrub-scrub	0	0	0	4.4	11.2	12.7	15.6	15.7	16.2	16.4
Water	0	4.2	9.4	44.5	104.6	189.5	210.7	232.5	258.1	275.7
Wetland	0.3	72.3	142.7	926.1	1,695.70	2,227.10	2,438.20	2,608.90	2,841.60	3,029.80
Delaware Bay										
Agriculture	0	5	953.4	5,633.60	11,505.20	5,849.60	7,297.30	9,598.90	16,499.30	24,764.60
Barren Land	0	2	280.3	701.7	1,090.30	737	855	1,043.20	1,496.50	1,732.50
Developed	0	18.5	218.3	841.4	1,662.40	825.2	1,255.10	1,759.80	3,005.40	4,104.00
Forest	0	12.4	591.8	2,302.70	4,167.80	2,501.10	3,315.20	4,287.20	6,576.00	8,969.80
Water	0	0.5	84.7	120.6	143.6	118.2	124.4	134.6	158.7	176.4
Wetland	0	23.3	901.5	1,812.00	2,245.30	2,036.60	2,204.90	2,422.40	2,777.40	3,036.10
Delaware River										
Agriculture	4.1	8.4	312.1	2,417.40	5,254.00	4,558.10	6,675.80	8,192.00	11,682.80	14,253.80
Barren Land	0.4	0.8	27.6	201.7	383.4	360.4	472.6	565.8	766.2	935.9
Developed	42.1	88.1	439	2,961.90	6,509.60	6,509.90	8,668.90	10,967.20	18,521.70	22,406.80
Forest	7.8	11.4	90.9	663.3	1,274.70	1,259.90	1,770.80	2,136.20	3,226.90	3,912.30
Water	2.6	4.2	23.5	77.6	112.5	167.9	188.2	200.2	299	321.1
Wetland	7.7	15.4	333	1,167.80	1,775.20	2,234.10	2,722.30	3,012.30	3,843.50	4,273.90

Table 6.6 - continued. Area by land use category for mid-Atlantic for low and high estimates for various sea level rise scenarios

	Low Estimate (high DEM)					High Estimate (low DEM)				
Land Use	**25**	**50**	**100**	**200**	**300**	**25**	**50**	**100**	**200**	**300**
Ches. Bay										
Agriculture	149	1,261.10	11,183.00	40,154.90	66,196.40	14,606.60	22,563.50	40,462.70	76,856.20	105,666.40
Barren Land	45.7	478.2	2,073.10	3,746.30	4,918.30	2,869.40	3,663.90	4,649.90	6,498.50	7,297.00
Developed	33.7	304	2,223.80	9,146.00	17,784.30	6,685.30	8,730.20	13,180.50	32,408.60	46,113.80
Forest	103.5	1,224.50	9,100.10	26,703.50	45,419.30	17,060.20	22,886.90	38,373.10	66,326.80	86,409.50
Water	15.1	62.2	165.3	356.1	467	506.9	571.6	667.3	823.7	911.7
Wetland	150.6	1,362.90	5,013.50	9,073.40	12,196.30	8,596.40	10,501.40	14,287.40	18,529.90	21,038.00
Potomac River										
Agriculture	0	0	0	693.7	1,854.80	1,746.20	1,975.40	4,904.80	12,432.70	15,752.70
Barren Land	0	0	0	103.4	205.5	223.4	238.1	462.6	890.2	1,109.80
Developed	0	0	0	408.2	1,004.70	753.3	861.8	1,836.50	3,105.00	4,073.20
Forest	0	0	0.4	550.5	1,596.30	1,822.30	2,073.20	4,632.50	10,103.90	13,325.90
Water	0	0	0	28.3	45.9	94.3	100	130	168.5	177.8
Wetland	0	0	0.2	236	482.3	713.4	752	1,124.70	1,627.80	1,838.10
Albemarle Sd.										
Agriculture	1,646.40	4,613.70	16,441.60	39,134.20	66,244.10	4,375.40	7,204.00	12,819.00	28,024.00	42,663.20
Barren Land	227.8	254.9	321.4	502.6	792.4	2,463.30	3,600.50	5,907.30	8,888.80	10,963.90
Developed	122.2	438.2	2,463.30	6,738.50	10,679.90	2,334.50	3,931.60	8,279.40	22,998.20	25,717.00
Forest	513.5	1,946.00	8,683.50	21,889.80	31,430.50	2,366.30	3,298.00	4,950.40	8,969.80	13,395.90
Grassland	386.5	1,127.80	4,792.00	10,051.90	14,831.80	31,694.80	38,649.70	44,721.10	54,623.60	61,626.10
Shrub-scrub	207.1	794.7	2,724.20	5,472.20	7,314.00	4.5	7.8	18.9	69.8	188.5
Water	349.2	513.8	749.9	983.3	1,215.80	2,465.60	3,963.40	8,440.70	18,219.20	24,805.50
Wetland	2,052.30	6,311.50	14,486.10	20,617.00	25,118.20	422	584.9	928.6	1,780.70	3,011.20
Pamlico Sd.										
Agriculture	740.9	2,616.80	13,138.40	46,894.80	92,312.40	12,448.10	22,623.80	39,676.90	84,532.10	137,202.50
Barren Land	81	149	474.7	1,623.40	3,540.00	496.2	735.8	1,326.80	2,923.30	5,163.50
Developed	62.5	260.1	1,626.80	5,033.80	8,469.40	1,499.90	2,510.60	4,582.80	9,565.20	14,457.90
Forest	237.5	1,398.80	5,497.50	14,011.50	25,119.50	5,806.10	8,877.40	13,802.80	23,805.70	35,877.30
Grassland	229.7	629.6	2,015.50	3,998.50	5,018.40	1,805.10	2,564.80	3,577.50	4,618.30	5,845.30
Shrub-scrub	26.2	150.9	677.6	1,699.50	2,362.80	581.8	906.2	1,434.60	2,136.10	2,919.80
Water	80.6	123	213.8	310	380	214.8	245.9	295.9	383.8	509.5
Wetland	974.6	3,761.50	8,507.10	12,618.50	16,680.00	8,649.00	10,191.10	12,079.20	15,376.30	21,956.40
Atlantic Ocean										
Agriculture	45.3	124.8	1,095.50	7,294.00	14,514.80	3,649.20	5,034.50	8,219.70	17,314.20	26,206.40
Barren Land	444.7	640.5	1,801.70	5,183.30	8,338.60	3,178.70	3,828.90	5,411.20	8,853.50	10,780.10
Developed	178.2	482	4,470.60	25,120.20	42,327.50	13,105.10	18,843.80	29,210.00	47,568.70	61,291.20
Forest	359.1	775	2,987.90	10,109.10	18,730.20	5,398.00	7,211.30	11,540.20	21,036.20	31,506.80
Grassland	149.6	283.8	825.3	2,374.30	4,202.40	830	1,221.00	2,017.90	3,806.10	5,742.70
Shrub-scrub	59.4	119.6	381.2	1,177.10	2,143.10	739.4	966.1	1,365.50	2,148.10	3,052.70
Water	242.9	337.5	698.7	962.1	1,096.30	994.1	1,093.10	1,209.60	1,358.70	1,454.90
Wetland	1,505.70	2,440.40	5,261.00	9,443.00	12,127.00	7,767.40	8,959.20	10,878.30	13,756.00	16,010.40

Similar analyses to those found above for the watershed regions were also completed for each county within the Mid-Atlantic States. These tables are included in the chapters in Part IV of this report, which assess impacts at local, state, and county levels. A higher order statistical analysis than the GIS analysis presented, such as a hedonic pricing method, was not attempted due to lack of time and resources.

6.4 INFRASTRUCTURE

6.4.1 Public Works and Infrastructure

One impact of sea-level rise would be that the clearance under bridges will decrease. As a result some boats will no longer fit under fixed bridges, and some drawbridges will need to increase either the number or the duration of their openings. When a drawbridge opens on a busy coastal highway on a summer weekend, the effects on traffic can be a spectacle. Hundreds of cars can be backed up for miles, and if intervening traffic lights allow cross traffic over the highway it can take some time to clear the effects of a recently closed drawbridge. Bridges connecting coastal barriers and spans that connect the mainland to islands spend their entire lives in salty water. This is a continual threat to their structural integrity, both from immersion and from the salty aerosols in the coastal atmosphere. Coastal bridges need constant maintenance. If sea-level rise pushes salinity farther upstream, raises local salinity, immerses more of a bridge's support structure, or brings the deck that much closer to the water, then maintenance problems will grow. Exposure to salt water is bad for transportation and it is bad for other infrastructure too. Pipelines, storm water outfalls, and industrial cooling water intakes all sit in water that may become increasingly saline as time goes by.

Estuarine navigation channels may need to be extended landward from where they terminate now to provide access to a retreating shoreline. Disposing of dredge spoils is a common problem in the mid-Atlantic. The corollary benefit is that not as much dredging will be required in deeper water because a rising elevation will provide extra clearance.

If decisions are made to de-couple developed areas from the effects of rising sea levels by not stabilizing shorelines, then eventually places will be abandoned. Before they can be completely left to nature they will need to be unbuilt. Structures will need to be demolished and removed. Ideally foundation slabs and paved streets will be torn up. Underground pipelines could remain, but pump stations and manholes should be filled. Underground storage tanks, particularly those that held fuels, need to be removed, and contaminated soils will have to be remediated before a site is allowed to revert back to nature.

6.4.2 Public Health and Safety

Higher sea levels may shorten evacuation windows during coastal storms. If highways and causeways flood now as storms approach, they are going to be flooded sooner if the sea is higher. Many of the coastal cities and urbanized barriers already need more hours to completely evacuate than they have now. Higher sea level that shortens the evacuation period could be a grave threat. If rising seas translate to rising water tables in developed areas, places on estuarine shorelines that don’t have sanitary sewers and instead rely on septic systems to treat human waste may have additional problems. Many of these places already have septic problems because of high coastal water tables. Any increase may force abandonment or the implementation of expensive measures to process sanitary waste.

6.4.3 Transportation Infrastructure

ICF International recently completed the first phase of a study sponsored by the U.S. Department of Transportation (US DOT, 2007) on "The Potential Impacts of Global Sea-Level Rise on Transportation Infrastructure". This recent study uses a GIS-based analytical approach that is similar to that used by EPA and NOAA in the previous sections for population and land use. The following paragraphs provide a summary of the Phase 1 report.

The study also covers the mid-Atlantic region and is being implemented in two phases: Phase 1 focuses on North Carolina, Virginia, Washington, DC and Maryland and was recently completed. Phase 2 focuses on New York, New Jersey, Pennsylvania, Delaware, South Carolina, Georgia, and the Atlantic coast of Florida and is expected to be completed in 2008. This study was designed to produce rough estimates of how future climate change, specifically sea-level rise and storm surge, could affect transportation infrastructure on a portion of the East Coast of the United States. The study's major purpose is to aid policy makers, specifically transportation officials at the Federal, State and local levels, by providing quantified estimates of these effects as they relate to roads, rails, airports and ports.

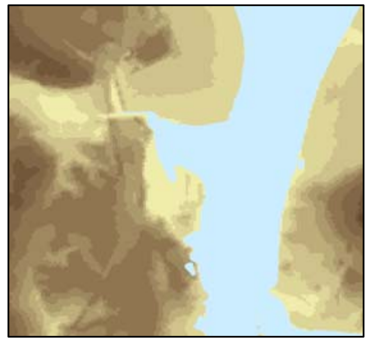
The GIS approach produces maps and statistics that demonstrate the location and quantity of transportation infrastructure that could be affected under a range of potential increases in sea level, which are based on estimates of global sea-level rise included in the United

Nations Intergovernmental Panel on Climate Change's Third Assessment Report (IPCC, 2001).

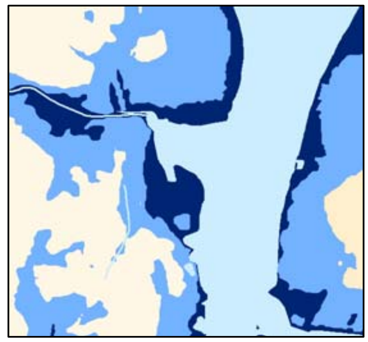
The report considers that the rising sea level, combined with the possibility of an increase in the number of hurricanes and other severe weather related incidents, could cause increased inundation and more frequent flooding of roads, railroads, and airports, and could have major consequences for port facilities and coastal shipping. Many of the low-lying railroads, tunnels, ports, runways, and roads are already vulnerable to flooding and a rising sea level will only exacerbate the situation by causing more frequent and more serious disruption of transportation services and also introduce problems to infrastructure not previously affected by these factors.

The following is an excerpt from the US DOT study approach to assess impacts of sea-level rise on transportation infrastructure, and defines the four basic steps involved in the analysis. These steps are elaborated on below:

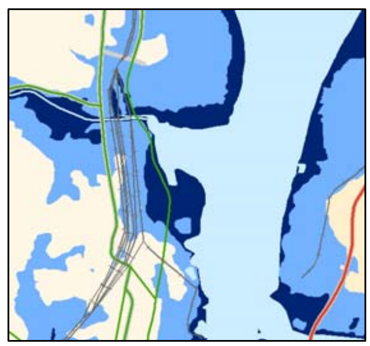
- *Using Digital Elevation Models (DEM) evaluated the elevation in the coastal areas and created tidal surfaces to describe the current and future predicted sea water levels.* This spatial information helped identify areas that are, without proper protection, expected to be ***regularly inundated*** or that are ***at-risk*** of periodic inundation due to storm surge.



- *Identified land that, without protection, will regularly be inundated by the ocean or is at-risk of periodic inundation due to storm surge at the given temporal intervals.* From this spatial information it is possible to plan for the protection of current infrastructure and to prevent the building of infrastructure in areas that are, without proper protection, expected to be ***regularly inundated*** or that are ***at-risk*** of periodic inundation due to storm surge.



- *Identified the transportation infrastructure that, without protection, will regularly be inundated by the ocean or at-risk of periodic inundation due to storm surge at the given temporal intervals.* The maps and GIS data produced by this study detail the infrastructure that is expected to be ***regularly inundated*** or that is ***at-risk*** so that measures may be taken to protect, reroute, or remove the infrastructure as the ocean encroaches upon them.



- *Provided statistics to demonstrate the potential amount of inundated and at-risk land at the given temporal intervals.* The statistics calculated describe both the total amount of inundated and at-risk land and the total length of roads, railroads and other infrastructure that may be ***regularly inundated*** or that is ***at-risk*** of periodic inundation.

Potentially Impacted Transportation Network

Type	Inundated	At-Risk
Roads (km)		
Interstate Highways	0.9	11.2
Principal Arterials	7.2	38.3
Minor Arterials	0.0	0.0
National Highway System Features	6.4	41.7
Other Transportation Types (km)		
Railroads	36.1	64.5
Seaport	0	0
Potentially Impacted Land Area (acres)		
Total Impacted Area	2261	4853
Airport Property Area	0	0
Airport Runway Area	0	0

The US DOT study compares current conditions (2000) to estimates of future conditions resulting from increases in sea level. The estimates of increases in sea level are based upon the *range of averages* of the Atmosphere-Ocean General Circulation Models (AOGCMs) for all 35 SRES (Special Report on Emission Scenarios) as reported in figure 11.12[19] from the IPCC's Third Assessment Report (IPCC 2001). The study examines the effects of a range of potential increases in sea level, from 6 cm to 48.5 cm. The sea-level rise scenarios used in this US DOT study are similar to the previous scenarios discussed in Part I of this report.

The study first established the areas that would be *regularly inundated* or *at-risk* during storm conditions, given eight potential increments of sea-level rise. It defines regularly inundated areas or base sea level as NOAA's Mean Higher High Water (MHHW) tidal datum (NOAA, 2000). (Note that MHHW is used instead of Spring High Water, however those elevations are very similar in the Mid-Atlantic.) The eight regularly inundated areas that the study examines are those sections of the coast that fall between MHHW in 2000 and the adjusted MHHW levels (MHHW in 2000 plus a sea-level rise increment of 6 cm, 6.5 cm, 13 cm, 17.5 cm, 21 cm, 30 cm, 31 cm or 48.5 cm). For at-risk areas or areas that could be affected by storm conditions, the study uses a base level of NOAA's highest observed water levels (HOWL) for 2000, and adjusts this upwards based on the eight sea-level rise increments. The *at-risk* areas examined are those areas falling between the adjusted MHHW levels and the adjusted HOWL levels.

[19] IPCC3, WG1, c.11, page 671. http://www.grida.no/climate/ipcc_tar/wg1/pdf/TAR-11.PDF

The caveats and limitations of the study are discussed in context with the objectives of the study and are in line with those expressed earlier in this overall report (Executive Summary):

> The study was not intended to create a new estimate of future sea levels, or to provide a detailed view of a particular area under a given scenario. Instead, the study explored existing predictions of global sea-level elevations from the United Nations Intergovernmental Panel on Climate Change (IPCC) Third Assessment Report (TAR) and examined large areas for study. The inherent value of this study is the broad view of the subject and the overall estimates identified.
>
> This study was meant to provide a broad first look at potential sea-level changes on the Atlantic coast, and the results should not be viewed as defining specific changes in water levels at specific points in time. Due to the overview aspect of this study, and systematic and value uncertainties in the involved models, this analysis appropriately considered sea-level rise estimates from the IPCC TAR as eustatic occurrences. The confidence stated by IPCC in the regional distribution of sea-level change is *low* due to significant variations in the included models; thus it would be inappropriate to use the IPCC model series to estimate local changes. Local variations, whether caused by erosion, subsidence or uplift, local steric factors or even coastline protection, were not considered in this study. The unpredictability of anthropogenic mitigation was also not taken into consideration. Some studies are underway that may, in the future, allow for this to be considered, but are not currently publicly available.

Statistics and maps of affected transportation infrastructure at the State and county level were created for each scenario. For each scenario the maps and statistics identify:

- Kilometers of ***Interstate Highways*** potentially impacted
- Kilometers of Non-Interstate ***Principal Arterial*** roads potentially impacted
- Kilometers of ***Minor Arterial*** roads potentially impacted
- Kilometers of ***National Highway System*** facilities potentially impacted
- Kilometers of ***Railroads*** potentially impacted

- Total acres of ***Land*** potentially impacted
- Acres of ***Airport Property*** potentially impacted
- Acres of ***Airport Runways*** potentially impacted
- Acres of ***Port Property*,** for large freight ports**,** potentially impacted

Sample outputs maps and tables for Washington, DC:

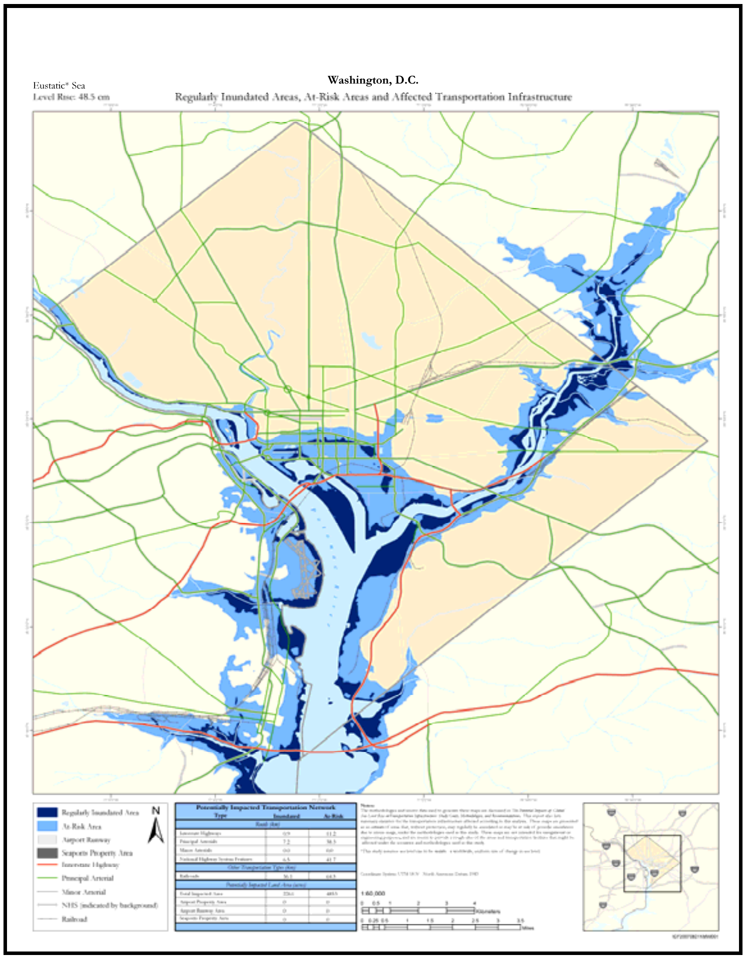


Figure 6.6 From US DOT (2007), a representative output map from this study showing regular and at-risk areas at the 48.5 cm scenario.

Table 6.7 From US DOT (2007), a representative output table from the US DOT study showing regular and at-risk areas at the 48.5 cm scenario, the highest level examined in the US DOT study.

DC State Statistics	48.5 cm					
Increase in Eustatic SLR	Regular Inundation		At-Risk		Total	
Length	Km	% Affected	Km	% Affected	Km	% Affected
Interstates	0.9	4%	11.2	49%	12.1	53%
Non-Interstate Principal Arterials	7.2	4%	38.3	22%	45.6	26%
NHS Minor Arterials	0.0	0%	0.0	0%	0.0	0%
National Highway System (NHS)	6.4	5%	41.7	32%	48.1	37%
Rails	3.8	5%	29.4	38%	33.3	43%
Area	Acres	% Affected	Acres	% Affected	Acres	% Affected
Ports	0	0%	0	0%	0	0%
Airport Property	0	0%	0	0%	0	0%
Airport Runways	0	0%	0	0%	0	0%
Total Land Area Affected	2,261	5%	4,853	11%	7,114	16%

The maps and tables above for the Washington, DC region indicate there is considerable transportation infrastructure at risk under a 48.5cm sea-level rise scenario, the highest of the eight sea-level rise scenarios. Four to five percent (0.9 km of Interstates, 7.2 km of non-interstate Principal arterials) of the Washington, DC highways examined in the US DOT study would be regularly inundated, while an additional 22% to 49% (11.2 km of Interstates, 38.3 km of non-Interstate principal arterials) could be affected by storm conditions. (It should be noted that the elevation data for the transportation facilities is of the land upon which the highway or rail line is built). Looking at the results across the range 6 to 48.5 cm range of SLR examined in the US DOT study across the four states, several trends become clear. Sea-level rise has the potential to affect many kilometers of highways and roads across the region. While in percentage terms Washington, DC appears more vulnerable, in absolute terms both Virginia and North Carolina could see disruption across still more kilometers of highways and rails under the sea-level rise scenarios analyzed in the study. It is also useful to note that for roads, this study focuses on larger roads. Generally, there are many miles of local roads and collectors that could also be affected. This report output should be obtained and looked at in tandem with the regional and state and county data contained in the appendices of this overall report (CCSP 4.1) to obtain a complete assessment of the impacts of various scenarios of sea-level rise. Overview maps were created for each state for each scenario and specific maps for each county that was affected for each scenario were also created.

The study examined effects on three large ports: Baltimore, MD, Norfolk, VA, and Wilmington, NC. All three ports could be vulnerable to even gradual sea-level rise, especially the port in Wilmington. At the 48.5 cm SLR scenario, it is estimated that 70 percent (320 acres) of the port property at risk for inundationl. For Norfolk, the estimated percentage is 48 percent (659 acres), while for Baltimore port it is 31 percent (291 acres).

For airports and rail, the picture is less stark. According to the analysis 2 percent of rail would be vulnerable to SLR of 48.5 cm (164.0 km in Virginia, 52.7 km in Maryland, and 194 km in North Carolina), except in Washington, DC, where 5 percent (3.8 km) would be vulnerable. For airports, 3 percent of airport runways/tarmacs in Maryland (22 acres) and 5 percent in Virginia (164 acres) and North Carolina (132 acres) could be vulnerable at the high end. (Washington Ronald Reagan National Airport is included in the Virginia totals.)

Table 6.8 below is a statistical summary of the US DOT (2007) Phase 1 States and Washington, DC for the totals (sum of) of the Regularly Inundated and At-Risk categories for the low (30cm) and high (48.5cm) scenarios.

Table 6.8 Summary of statistics for the total of regularly inundated and at risk infrastructure for 30cm and 48.5cm increase in SLR (US DOT (2007)).

Total Regularly Inundated and at Risk								
For a 30 cm increase in SLR	Washington DC		Maryland		Virginia		North Carolina	
Length	Km	% Affected	Km	% Affected	Km	% Affected	Km	% Affected
Interstates	11.7	52%	23.2	3%	159.2	9%	8.5	1%
Non-Interstate Principal Arterials	42.9	25%	178.1	7%	510.2	11%	393.6	6%
NHS Minor Arterials	0.0	0%	176.6	11%	55.7	1%	358.6	7%
National Highway System (NHS)	45.9	36%	160.0	7%	527.7	5%	656.5	9%
Rails	31.9	41%	338.2	13%	543.6	7%	389.3	5%
Area	Acres	% Affected	Acres	% Affected	Acres	% Affected	Acres	% Affected
Ports	0	0%	938	100%	1323	96%	412	90%
Airport Property	0	0%	1,566	12%	4,064	11%	4,147	11%
Airport Runways	0	0%	89	13%	426	14%	307	11%
Total Land Area Affected	6,898	16%	929,929	14%	1,157,959	4%	3,388,800	11%

Total Regularly Inundated and at Risk								
For a 48.5 cm increase in SLR	Washington DC		Maryland		Virginia		North Carolina	
Length	Km	% Affected	Km	% Affected	Km	% Affected	Km	% Affected
Interstates	12.1	53%	24.0	3%	167.9	9%	8.7	1%
Non-Interstate Principal Arterials	45.6	26%	204.1	8%	533.1	11%	419.9	6%
NHS Minor Arterials	0.0	0%	193.4	12%	64.4	1%	370.5	8%
National Highway System (NHS)	48.1	37%	178.9	8%	555.0	5%	682.6	10%
Rails	33.3	43%	365.6	14%	579.6	8%	411.8	5%
Area	Acres	% Affected	Acres	% Affected	Acres	% Affected	Acres	% Affected
Ports	0	0%	938	100%	1335	97%	439	95%
Airport Property	0	0%	1,865	15%	4,198	12%	4,291	12%
Airport Runways	0	0%	104	16%	434	14%	323	12%
Total Land Area Affected	7,114	16%	1,008,427	15%	1,232,183	5%	3,491,490	11%

Of note in the table are the high percentage of arterial lengths affected in Washington, DC in either of the two scenarios and the high percentage of acreage of ports affected in all the other states. Washington, DC has no freight ports sufficiently large to include in the study. The differences in the statistics for these two scenarios are a result of the uncertainty in potential SLR.

6.5 SUMMARY

Table 6.9 is a summary of the limitations of the information and how it is applied in this chapter and covers both the population and land use analysis in the center column and the DOT study analysis in the right column. The two studies both rely upon methodologies to use a baseline elevation surface, include elevation information related to tidal influence, and then overlay additional information layers of varying spatial and temporal resolutions. The baseline elevation maps themselves rely upon GIS interpolation techniques for integrating source elevation contours and imagery. Chapter 1 of this report discusses these limitations and uncertainties. Although, these methodologies and processes are "state-of-the-art", the reader needs to use the resulting information in the context of the estimated uncertainty estimates.

Table 6.9 Information Provided in this Chapter and Its Limitations.

Question Analyzed	Population, Land use	Kilometers of Transportation Infrastructure
Format of Information	Result Tables	Maps and Result Tables
Key Assumptions	Population has uniform density within inhabited portion of census block.	Direct Overlay of Data
Underlying Study	N/A	[USDOT 2007]
Information Sources for Underlying Studies	Elevation Data (See Chapter 1) Shore Protection (See Chapter 5) Census Data on Population and Structures	Elevation Data (See Chapter 1) DOT data sets: [National Highway Planning Network; Federal Railroad Admin.; TelaAtlas; USGS DOQQ's]
Limitations of Study	Census Data provides no information on where in a particular block the population resides. Analysis assumes that all population is in highest x% of the dry land in a block, using different values of x.	Elevation of rails and roads are often higher than the surrounding land for which study had data. Interpolation of DEM elevation data required for the incremental scenarios.
Treatment of Uncertainty	Incorporates the uncertainties in the data layers (census block, elevation, etc..) Considers alternate values of "x".	Incorporates various SLR scenarios, with various estimates of storm surge effects. Estimates of uncertainties in elevation are not addressed.
Sea-Level Scenarios	Results based on elevation from 50 to 300 cm above spring high water.	Results based on elevations [from 6 to 48.5cm] above mean higher high

		water (regular inundation) ; and highest observed water level (storm surge)
Other Limitation of this Chapter	Does not assess economic activity. Assessment of infrastructure only includes DC, Maryland, Virginia and North Carolina only and is limited to transportation.	

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Chapter 7. Public Access

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Rising sea level does not inherently increase or decrease the public's access to the shore, but the response to sea-level rise can. Beach nourishment tends to increase public access along the shore, because federal (and some state) laws preclude beach nourishment funding unless the public has access to the beach that is being restored. Shoreline armoring, by contrast, can decrease public access along the shore, because the intertidal zone along which the public has access is eliminated.

This chapter describes existing public access to the shore, and the impact of shoreline changes and responses to sea-level rise on public access.

7.1 EXISTING PUBLIC ACCESS AND THE PUBLIC TRUST DOCTRINE

The right to access tidal waters and shores is well-established. Both access and the ownership of tidal wetlands and beaches is defined by the "public trust doctrine", which is part of the common law of all the mid-Atlantic states. According to the public trust doctrine, navigable waters and the underlying lands were publicly owned at the time of statehood and remain so today.

The public trust doctrine is so well-established that it often overrides specific governmental actions that seem to transfer ownership to private parties (Lazarus, 1986;

Rose, 1986). Many courts have invalidated state actions that extinguished public ownership or access to the shore (*Illinois Central R.R. v. Illinois; Arnold v. Mundy)*. Even if a land deed says that someone's property extends into the water, the public trust doctrine usually overrides that language and the public has access along the shore. Even when government agencies transfer coastal land to private owners, the public still has the right to use the shore unless the state explicitly indicates otherwise (Lazarus, 1986; Slade *et al.*, 1990).

Figure 7.1 illustrates some key terminology for this chapter. Along sandy shores with few waves, the wet beach lies between *mean high water* and *mean low water*. (Along shores with substantial waves, the beach at high tide is wet inland from the mean high water mark, as waves run up the beach). The *dry beach* extends from approximately mean high water inland to the seaward edge of the dune grass or other terrestrial plant life, sometimes called the *vegetation line* (Slade *et al.*, 1990). The dune grass generally extends inland from the point where a storm in the previous year struck with sufficient force to erode the vegetation, (Pilkey *et al.*, 1984) which is well above mean high water. Along marshy shores, mudflats are found between mean low water and mean sea level, *low marsh* is found between mean sea level and mean high water, and *high marsh* extends from mean high water to *spring high water*.[20] Collectively, the lands between mean high water and mean low water (mudflats, low marsh, and wet beaches) are commonly known as *tidelands*.

[20] See Text Box in Chapter 1 for a discussion of tides and wetland zonation.

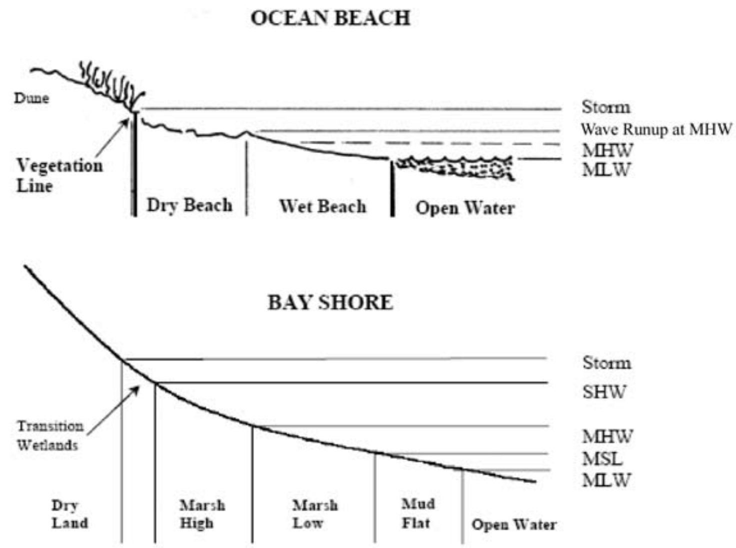
The public trust doctrine includes these wetlands and beaches because of the needs associated with hunting, fishing, transportation along the shore, and landing boats for rest or repairs. In most states, the public owns all land below the high water mark (Slade *et al.*, 1990) which is generally construed as mean high water. (The precise boundary varies in subtle ways from state to state. The portion of the wet beach inland of mean high water resulting from wave runup has also been part of the public trust lands in some cases. See *e.g. State v. Ibbison* and Freedman and Higgins (undated). Thus, in general, the public trust includes mudflats, low marsh, and wet beach, while private parties own the high marsh and dry beach. In New York the inland extent of the public trust varies; in some areas the public owns the dry beach as well.[21] In Pennsylvania, Delaware, and Virginia, by contrast, publicly owned land extends only up to the low water mark (Slade *et al.*, 1990). Figure 7.2 provides an overview for coastal states.

Ownership, however, is only part of the picture. In Pennsylvania, Delaware, and Virginia, the public trust doctrine provides an easement along the tidelands for hunting, fishing, and navigation. In New Jersey, the public trust doctrine includes access along the *dry* part of the beach for recreation, as well as the traditional public trust purposes (*Matthews v. Bay Head).* The other states have gradually obtained easements for access along some dry beaches either through purchases or voluntary assignment by the property owners in return for proposed beach nourishment. The federal policy precludes funding for beach nourishment unless the public has access (USACE, 1996). Some state laws specify that

[21] E.g. Dolphin Lane Assocs. v. Town of Southampton, 333 N.E.2d 358, 360 (N.Y. 1975)

any land created with beach nourishment belong to the state (*e.g.*, MD. CODE ANN., NAT. RES. II 8-1103 (1990)).

The right to access *along* the shore, however, does not mean that the public has a right to cross private land to get *to* the shore. (New Jersey is an exception in some cases.) Unless there is a public road or path to the shore, access along the shore is thus only useful to those who either reach the shore from the water or have permission to cross private land. Although the public has easy access to most ocean beaches and large embayments like Long Island Sound and Delaware Bay, the access points to the shores along most small estuaries are widely dispersed (*e.g.*, Titus, 1998 n. 49). Given the federal policy promoting access, the lack of access to the shore has held up several beach nourishment projects; and to secure the funding many communities have improved public access to the shore, not only with more access ways to the beach, but also by upgrading availability of parking, restrooms, and other amenities (*e.g.*, New Jersey 2006).



MSL = Mean Sea level
MLW = Mean Low Level
MHW = Mean High Water
SHW = Spring High Water
Storm = Average Annual Storm Tide

Figure 7.1 Legal and geological tideland zonation. The area below mean high water is usually publicly owned, and in all cases is subject to public access for fishing and navigation. Along the ocean, the dry beach above mean high water may be privately owned, but in several states the public has an easement; along the bay, the high marsh above mean high water is also privately owned, but wetland protection laws generally prohibit or discourage development.

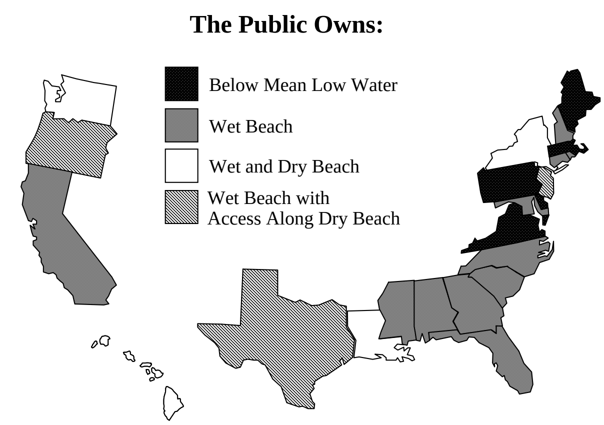


Figure 7.2 The public's common law interest in the shores of various coastal states.

7.2 IMPACT OF SHORE EROSION ON PUBLIC ACCESS

The rule that property lines retreat whenever shores erode has been part of the common law for over one thousand years (*St. Clair v. Lovingston; DNR v. Ocean City*), assuming that the shoreline change is natural. When riparian landowners cause the shorelines to advance seaward, the common law did not vest owners with title to land reclaimed from the sea, although legislatures sometimes have (ALR, 1941). A majority of states (*e.g.*, MD. CODE ANN., ENVIR. 16-201) award the riparian owner the artificially formed land if he or she is not responsible for the accretion, such as a federal navigation jetty causing the shore to advance seaward (Slade *et al.*, 1990); but some states (*e.g.*, New Jersey) vest the state public trust with the new land.

The literature does not evaluate whether states might change between the majority and minority rules in response to sea-level rise; but Slade *et al.* (1990) and others have evaluated the existing rules in the analogous context of shore erosion. The majority rule has two practical advantages. Determining what portion of a shoreline change resulted from artificial causes, such as sedimentation from a jetty or a river diversion, is much more difficult than determining how much the shoreline changed when the owner filled some wetlands. Moreover, the majority rule prevents the state from depriving shorefront owners of their riparian access by pumping sand onto the beach and creating new land (*e.g.*, Larmar Corp*)* But granting the newly created land to riparian owners delayed the beach nourishment project at Ocean City, Maryland when some of the owners insisted upon reaping the additional benefit of title to the newly created beach. (Titus, 1998 p. 373).

Sea-level rise causes shores to retreat both through inundation and erosion. Although the case law generally assumes that the shore is moving as a result of sediment being transported, inundation and shore erosion are legally indistinguishable. Among the causes of natural shoreline change, the major legal distinction has been between gradual and imperceptible" shifts, and sudden shifts that leave land intact but on the other side of a body of water, often known as "avulsion." Shoreline erosion changes ownership; avulsion does not. If an inlet formed 100 m north of one's home during a storm in which an existing inlet 100 m south of the home closed, an owner would still own her home because this shoreline change is considered to be avulsion. But if the inlet gradually migrated 200 m north, entirely eroding the property but later creating land in the same location, all of the newly created land will belong to the owner to the south.

Because the public has access to the intertidal zone as long as it exists, the direct effect of sea-level rise on public access depends on how the intertidal zone changes. Along an undeveloped or lightly developed ocean beach, public access is essentially unchanged as the beach migrates inland (except perhaps where a beach is in front of a rocky cliff, which is rare in the Mid-Atlantic). If privately owned high marsh becomes low marsh, then the public will have additional lands on which they may be allowed to walk (provided that environmental regulations to protect the marsh do not prohibit it). Conversely, if sea-level rise reduces the area of low marsh, then access may be less.

7.3 IMPACT OF REPONSES TO SEA-LEVEL RISE ON PUBLIC ACCESS

Although sea-level rise appears to have a small direct effect on public access to the shore, responses to sea-level rise can have a significant impact, especially in developed areas. Along developed bay beaches, by contrast, public access along the shore can be eliminated if the shorefront property owner erects a bulkhead, because the beach is eventually eliminated. A number of options are available for state governments that wish to preserve public access along armored shores, such as including public access in permits for shore protection structures. Connecticut has done so in some cases; but there is no general requirement in the Mid-Atlantic states. Therefore, sea-level rise has reduced public access along many estuarine shores and is likely to do so in the future as well.

Government policies related to beach nourishment, by contrast, set a minimum standard for public access (USACE, 1996), which often increases public access along the shore. Along the ocean shore from Delaware to North Carolina, the public would not have access along the dry beach under the public trust doctrine (except in New Jersey). But once a federal beach nourishment project takes place, the public has access. Beach nourishment projects increased public access *along* the shore in Ocean City, Maryland; and Sandbridge (Virginia Beach), Virginia, where property owners had to provide easements to the newly created beach before the projects began (Titus, 1998; Virginia Marine Resources Commission, 1988).

Areas where public access *to* the beach is currently limited by a small number of access points include the area along the Outer Banks from Southern Shores to Corolla; northern

Long Beach Township, New Jersey; and portions of East Hampton, South Hampton, Brookhaven, and Islip along the south shore of Long Island. In West Hampton, landowners had to provide 6 easements for perpendicular access from the street to the beach to meet the New York state requirement of public access every one-half mile. A planned $71 million beach restoration project for Long Beach Island has been stalled (Urgo, 2006) pending compliance with the New Jersey state requirement of perpendicular access every one-quarter mile (USACE, 1999). An additional 200 parking spaces for beachgoers must also be created (USACE, 1999). Private communities along Delaware Bay have granted public access to the beaches in return for state assistance for beach protection (Beach 2000 Planning Group, 1988).

If other communities with limited access seek federal beach nourishment in the future, public access would similarly increase. Improved access to the beach for the disabled may also become a requirement for future beach nourishment activities (*e.g.*, Rhode Island CRMC, 2007). This is not to say that all coastal communities would provide public access in return for federal funds. But the Mid-Atlantic has no privately owned gated barrier islands, unlike the Southeast, where some communities have chosen to expend their own funds on beach nourishment rather than give up their exclusivity.

Ultimately, the impact of sea-level rise on public access will depend on the policies and preferences that prevail over the coming decades. Sometimes the desire to protect property as shores erode will come at the expense of public access. Sometimes it will promote an entire re-engineering of the coast, which under today's policies generally favors public access. It is possible that rising sea level is already starting to cause people to rethink the best way to protect property along estuarine shores (NRC, 2007) to protect the environmental benefits of natural shores. If access along estuarine shores becomes a policy goal, techniques are available for preserving public access as sea level rises.

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Chapter 8. Coastal Flooding, Floodplains and Coastal Zone Management Issues

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This chapter examines the effects of sea level rise on coastal floodplains and on coastal flooding management issues confronting the U.S. Federal Emergency Management Agency (FEMA), the floodplain management community, the coastal zone management community, and the public, including private industry. Sea level rise is just one of numerous complex scientific and societal issues these floodplain groups face. The chapter is a status report and assessment of ongoing activities, and briefly discusses future needs and barriers to progress in addressing flood hazards.

The information in this chapter is an assessment of a range of complex activities of many state and federal agencies and other groups. Some key findings are:

- There is a clear need for integrated solutions to adequately understand and prepare for the impacts of sea level rise on coastal flooding. Rising sea level increases the vulnerability of coastal areas to flooding. The higher sea level provides a higher base for storm surges to build upon. It also diminishes the rate at which low-lying areas drain, thereby increasing the risk of flooding from rainstorms. Increases shore erosion can further increase flood damages, by removing protective dunes, beaches, and wetlands and by leaving particular properties closer to the water's edge. 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.

- Analysis of historical tide station records for the highest storm tides shows that storms today with slightly lesser storm surge than historical storms have had slightly higher storm tide elevations relative to the land due to sea level rise. This suggests that any given storm could have higher flooding potential in the future due to higher sea levels than it would if it occurred today.
- In a 1991 FEMA study, it was found that the projected rise in population and sea level rise scenarios would increase the expected annual flood damage by 2100 for an average NFIP insured property by 36–58 percent for a 0.30m (1-foot) rise and 102–200 percent for a 0.91m (3-foot) rise. This would lead to actuarial increases in insurance premiums for building subject to sea level rise of 58 percent for a 1-foot rise and 200 percent for a 0.91m (3-foot) rise. The study estimated that a 10.30m (1-foot) rise would gradually increase the expected annual national Flood Insurance Program (NFIP) flood losses by $150 million by 2100. Similarly, a 0.91m (3-foot) rise would gradually increase expected losses by about $600

million by 2100. Per policy holder, this increase would equate to $60 more than in 1990 for the 0.30m (1-foot) rise and $200 more for the 0.91m (3-foot) rise.

- The mid-Atlantic Coastal Zone Management community is increasingly recognizing sea level rise has a high risk coastal hazard, however to date only Maryland has performed the comprehensive analyses and studies need to make recommendations for state policy formulation.

This chapter first provides some more focused description and practical definition of floodplains and then describes some of the more detailed impacts of sea level rise on coastal flooding and the interaction with storm surge, the national floodplain management response, and closes with an assessment of the coastal zone management response.

8.1 PHYSICAL CHARACTERISTICS

8.1.1 Floodplain Definition

In general terms, a floodplain is any normally dry land surrounding a natural water body that holds the overflow of water during a flood. Because they border water bodies, floodplains have been popular sites to establish settlements, which subsequently become susceptible to flood-related disasters. Most management and regulatory definitions of floodplains apply to rivers; however, open-coast floodplains characterized by beach, dunes, and shrub-forest are also important since much of the problematic development and infrastructure is concentrated in these areas. Chapter 2 provides much more detailed description of this environment.

The federal regulations governing FEMA (2008) via Title 44 of the Code of Federal Regulations defines floodplains as "any land area susceptible to being inundated by flood waters from any source". The FEMA (2002) Guidelines and Specifications for flood hazard mapping partners Glossary of Terms defines floodplains as:

1. A flat tract of land bordering a river, mainly in its lower reaches, and consisting of alluvium deposited by the river. It is formed by the sweeping of the meander belts downstream, thus widening the valley, the sides of which may become some kilometers apart. In time of flood, when the river overflows its banks, sediment is deposited along the valley banks and plains.
2. Synonymous with the 100-year floodplain. The land area susceptible to being inundated by stream derived waters with a 1 percent annual chance of being equaled or exceeded in a given year.

The National Oceanic and Atmospheric Administration (NOAA) National Weather Service (NWS) defines floodplains as the portion of a river valley that has been inundated by the river during historic floods (NWS Glossary of Terms). None of the formal definitions of floodplains include the word "coastal". However, as river systems approach coastal regions, river base levels approach sea level, and the rivers become influenced not only by stream flow, but also by coastal processes such as tides, waves, and storm surges. This complex interaction takes place near the governing water body, either open ocean, estuaries, or the Great Lakes.

The slope and width of the coastal plain[22] determine the size and inland extent of coastal influences on river systems. Coastal regions are periodically inundated by tides, waves, and surges. Therefore, a good working definition of a coastal floodplain, borrowing from the river floodplain definition, is any normally dry land area in coastal regions that is susceptible to being inundated by water from any natural source, including oceans (*e.g.*, tsunami run-up, coastal storm surge, relative sea-level rise) in addition to rivers, streams, and lakes.

Floodplains generally contain unconsolidated sediments, often extending below the bed of the stream or river. These accumulations of sand, gravel, loam, silt, or clay are often important aquifers; the water drawn from them is prefiltered compared to the water in the river or stream. Geologically ancient floodplains are often revealed in the landscape by terrace deposits, which are old floodplain deposits that remain relatively high above the current floodplain and often indicate former courses of rivers and streams.

Floodplains can support particularly rich ecosystems, both in quantity and diversity. These are called riparian zones or systems. Wetting of the floodplain soil releases an immediate surge of nutrients, both those left over from the last flood and those from the rapid decomposition of organic matter that accumulated since the last flood. Microscopic organisms thrive and larger species enter a rapid breeding cycle. Opportunistic feeders (particularly birds) move in to take advantage. The production of nutrients peaks and falls away quickly; however, the surge of new growth endures for some time. This makes

[22] A coastal plain is an area of flat, low-lying land next to the coast and separated from the interior by other landscape features.

floodplains particularly valuable for agriculture. Markedly different species grow in floodplains than grow outside of floodplains. For instance, riparian trees species (that grow in floodplains) tend to be very tolerant of root disturbance and tend to be very quick-growing, compared to tree species growing some distance from a river.

8.2 WHAT ARE THE POTENTIAL IMPACTS OF SEA-LEVEL RISE ON COASTAL FLOODPLAINS?

Assessing the impacts of sea-level rise on coastal floodplains is an inherently complicated task, because the impacts are coupled with impacts of climate change on other coastal and riverine processes and can be offset by human actions to protect life and property. Impacts may range from extended periods of drought and lack of sediments to extended periods of above-normal freshwater runoff and associated sediment loading. Some seasons may have higher than normal frequency and intensity of coastal storms and flooding events. Impacts will also depend on construction and maintenance of dikes, levees, waterways, and diversions for flood management.

Assuming no human intervention for the moment, the hydrologic and hydraulic characteristics of coastal and river floodplain interactions will change with sea-level rise. Fundamentally, the floodplains will become increasingly subjected to inundation. In tidal areas, the tidal inundation characteristics of the floodplain may change with the range of tide and associated tidal currents increasing with sea-level rise. With this inundation, floodplains would be subjected to increased coastal erosion from waves, river and tidal currents, and storm induced and tidal flooding. Upland floodplain boundaries would be subject to horizontal movement. Coastal marshes could be subject to vertical buildup or inundation.

In a state study for Maine (Slovinsky and Dicksson, 2006), the impacts on coastal floodplains were characterized by marsh habitat changes and flooding implications. The coast of Maine has a significant tidal range (8.6 to 22.0 feet, spring range), so impacts of flooding are coupled with the timing of storms and the highest astronomical tides[23] on top of sea-level rise. The Maine study found increasing susceptibility to inlet and barrier island breaches where existing breach areas were historically found, increased stress on existing flood-prevention infrastructure (levees, dikes, roads), and a gradual incursion of low marsh into high marsh with development of a steeper bank topography. Increased overwash and erosion were the impacts on the outer coast.

In addition, the effects of significant local or regional subsidence[24] of the land will add to the effects of sea-level rise on coastal floodplains. Regional examples with significant subsidence are the Mississippi River Delta region and the area around the entrance to the Chesapeake Bay. Sea-level rise could also increase salt-water intrusion into the existing freshwater or brackish floodplains and could change the extent or reach of the saltwater wedge up into tidal river systems.

[23] The tides that result from the gravitational influence of the moon and sun on ocean waters; the highest astronomical tide is the highest level expected to occur under average meteorological conditions (*i.e.*, not extreme conditions) and under any combination of astronomical conditions.

[24] Subsidence is the lowering of land-surface elevation as a result of changes that take place underground, including human activities such as pumping of water, oil, and gas from underground reservoirs.

8.3 WHAT ARE THE POTENTIAL EFFECTS OF SEA-LEVEL RISE ON THE IMPACTS OF COASTAL STORMS?

The potential interaction among increased sea levels, storm surges, and upstream rivers is very complex. Storm surge can travel several hundred kilometers up rivers at more than 40 km per hour, as on the Mississippi River, where storm surge generated by land-falling hurricanes in the Gulf of Mexico can be detected on stream gauges upstream of Baton Rouge, Louisiana, more than 480 km from the mouth (Reed and Stucky, 2005).

Both NWS (for flood forecasting) and FEMA (for insurance purposes and land use planning) recognize the complexity of these interactions. In cases like this, the NWS uses both a hurricane storm surge model (the Sea, Lakes, and Overland Surge from Hurricanes (SLOSH) model, Jelesnianski *et al.*, 1992) and a riverine hydraulic model (the Operational Dynamic Wave Model) to forecast effects of storm surge on river stages on the Mississippi River. The two models are coupled together so that the output of the storm surge model is the downstream boundary of the river model. This type of model coupling is needed to determine the effects of sea-level rise and storm surge on riverine systems. Other modeling efforts are starting to take into account river and coastal physical process interactions. The NWS also uses a two-dimensional hydrodynamic model (the Advanced Circulation Model or ADCIRC; Luettich *et al.*, 1992) on the Wacammaw River in South Carolina to predict effects of storm surge on river stages as far inland as Conway, 80 km from the Atlantic Ocean (Hagen *et al.*, 2004). These model coupling routines are becoming increasingly more common and have been identified as future research needs by such agencies as NOAA and the U.S. Geological Survey (USGS), as scientists strive to model the complex interactions between coastal and riverine processes. As sea level rises, these interactions will become ever more important to the way the coastal and riverine floodplains respond (Pietrafesa *et al.*, 2006).

8.3.1 Historical Comparison at Tide Stations

In a post-hurricane NOAA report (Hovis, 2004) on the observed storm tides of Hurricane Isabel, the potential effects of sea-level rise on maximum observed storm tides were assessed for four long -term tide stations in the Chesapeake Bay. The NOAA tide stations examined were Baltimore, MD, Annapolis, MD, Washington, DC, and Sewells Point, VA, which have records beginning in 1902, 1928, 1931, and 1927, respectively. Before Hurricane Isabel, the highest water levels reached at Baltimore, Annapolis, and Sewells Point occurred during the passage of an unnamed hurricane in August, 1933. At Washington, the 1933 hurricane caused the third highest recorded water level, surpassed only by river floods in October 1942 and March 1936. Hurricane Isabel caused water levels to exceed the August 1933 levels at Baltimore, Annapolis and Washington by 0.14 m, 0.31 m, and 0.06 m, respectively. At Sewells Point, the highest water level from Hurricane Isabel was only 0.04 m below the level reached in August 1933. Zervas (2001) obtained sea-level trends for Baltimore, Annapolis, Washington, and Sewells Point of 3.12, 3.53, 3.13, and 4.42 mm/yr, respectively. Using these rates, the time series of monthly highest water level were adjusted for the subsequent sea-level rise up to the year 2003. The resulting time series summarized in the tables below indicate the highest level reached by each storm as if it had taken place in 2003, thus allowing an unbiased comparison of storms. Elevations are relative to the tidal datum of Mean Higher High Water (MHHW).

Table 8.1 Five Highest Water Levels for Baltimore, MD in meters above MHHW.
Absolute water level **Corrected for sea-level rise to 2003**

Hurricane Isabel	Sep 2003	1.98	Hurricane	Aug 1933	2.06
Hurricane	Aug 1933	1.84	Hurricane Isabel	Sep 2003	1.98
Hurricane Connie	Aug 1955	1.44	Hurricane Connie	Aug 1955	1.59
Hurricane Hazel	Oct 1954	1.17	Hurricane	Aug 1915	1.38
Hurricane	Aug 1915	1.11	Hur. Hazel	Oct 1954	1.32

Table 8.2 Five Highest Water Levels for Annapolis, MD in meters above MHHW.
Absolute water level. **Corrected for sea-level rise to 2003**

Hurricane Isabel	Sep 2003	1.76	Hurricane Isabel	Sep 2003	1.76
Hurricane	Aug 1933	1.45	Hurricane	Aug 1933	1.69
Hurricane Connie	Aug 1955	1.08	Hurricane Connie	Aug 1955	1.25
Hurricane Fran	Sep 1996	1.04	Hurricane Hazel	Oct 1954	1.19
Hurricane Hazel	Oct 1954	1.02	Hurricane Fran	Sep 1996	1.06

Table 8.3 Five Highest Water Levels for Washington, DC in meters above MHHW.
Absolute water level **Corrected for sea-level rise to 2003**

Flood	Oct 1942	2.40	Flood	Oct 1942	2.59
Flood	Mar 1936	2.25	Flood	Mar 1936	2.46
Hurricane Isabel	Sep 2003	2.19	Hurricane	Aug 1933	2.35
Hurricane	Aug 1933	2.13	Hurricane Isabel	Sep 2003	2.19
Flood	Apr 1937	1.70	Flood	Apr 1937	1.91

Table 8.4 Five Highest Water Levels for Sewells Point, VA in meters above MHHW.
Absolute water level **Corrected for sea-level rise to 2003**

Hurricane	Aug 1933	1.60	Hurricane	Aug 1933	1.91
Hurricane Isabel	Sep 2003	1.56	Hurricane Isabel	Sep 2003	1.56
Winter Storm	Mar 1962	1.36	Winter Storm	Mar 1962	1.54
Hurricane	Sep 1936	1.21	Hurricane	Sep 1936	1.50
Winter Storm	Feb 1998	1.16	Hurricane	Sep 1933	1.33

8.3.2 Typical 100-Year Storm Surge Elevations Relative to MHHW within the Multi-State Area

A useful application of long-term tide gauge data is a return frequency analysis of the monthly and annual highest and lowest observed water levels. On the east coast and Gulf of Mexico, hurricanes and winter storms interact with the wide, shallow, continental shelf to produce large extreme storm tides. On the west coast, the heights of extreme events, such as those caused by El Niño-related storms, are limited by the narrowness of the continental shelf. A generalized extreme value (GEV) distribution can be derived for each station after correcting the values for the long-term sea-level trend (Zervas 2005). Theoretical exceedance probability statistics give the 99%, 50%, 10%, and 1% annual exceedance probability levels shown in Figures 8.1 and 8.2. These levels correspond to average storm tide return periods of 1, 2, 10, and 100 years. The first figure (Figure 8.1) shows exceedance elevations above local mean sea level (LMSL) at each station relative to the 1983-2001 National Tidal Datum Epoch (NTDE). The second figure (Figure 8.2) is the same except the elevations are relative to Mean Higher High Water (MHHW) computed for the same 1983-2001 NTDE.

In the Figure 8.1, the elevations relative to LMSL are highly correlated with the range of tide at each station (Willets Point has a very high range of tide (2.2m)), except for the 1% level at Washington DC which is susceptible to high flows of the Potomac River. As expected due to their varying locations, the 1% elevation level varies the most among the stations of the mid-Atlantic Region. Figure 8.2 shows a slightly geographically decreasing trend in the elevations from north to south.

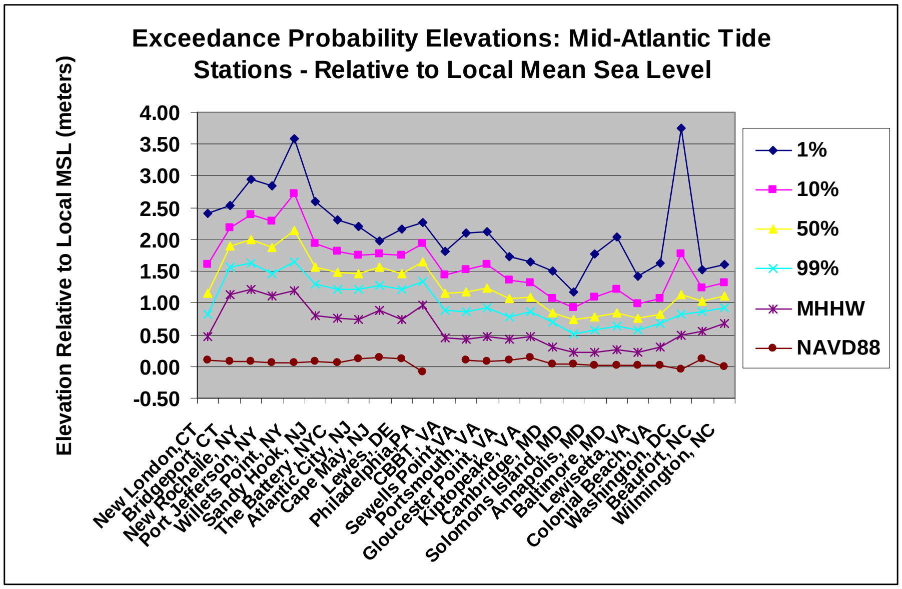


Figure 8.1 Exceedance Probabilities for Mid-Atlantic Tide Stations Relative to Local Mean Sea Level.

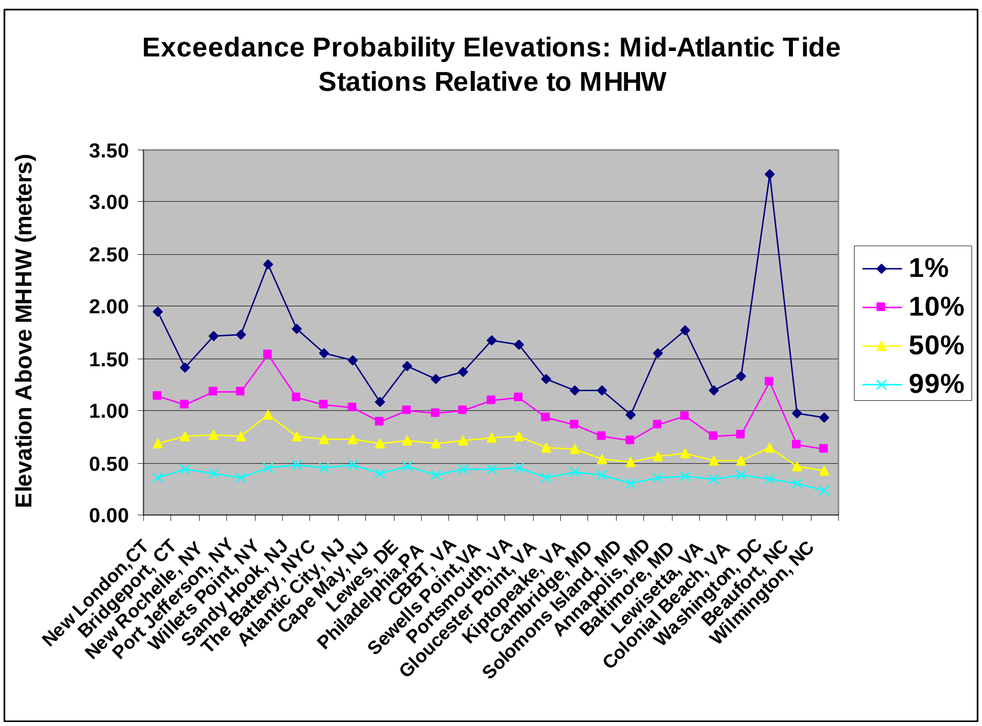


Figure 8.2 Exceedance Probabilities at Mid-Atlantic Tide Stations relative to MHHW.

8.4 FLOODPLAIN MAPPING AND SEA-LEVEL RISE

Given the potential for increased flooding with rising sea levels, there is a need for floodplain maps that take sea-level rise into account. FEMA (1991) performed a study in 1991 (Box 8.1) in which costs for remapping were estimated at $150,000 per county or $1,500 per map panel. With an estimated 283 counties (5,050 map panels) potentially affected, the total cost of restudies and remapping was estimated at $30 million in 1991 dollars. These estimated figures assume that maps and studies are revised on a regular basis and equates to about $46.5 million in 2006 dollars (FEMA, 1991). More current estimates have not been completed to reflect advancements in mapping capabilities."

Tidally and storm surge affected river models require the downstream boundary starting water surface elevation to be the "1 percent annual chance" Base Flood Elevation (BFE) from an adjacent coastal study. If the coastal study BFE is raised by 1 foot or even 3 feet because of sea-level rise, the river study flood profile will be changed as well and this will ultimately affect the resulting Flood Insurance Rate Maps (FIRMs) that are published. This is a complicated issue and points out the fact that simply raising the coastal BFEs to estimate a new 1 percent annual chance floodplain is not taking into account the more complex hydraulics that will have undetermined effects on the upstream 1 percent annual chance floodplains as well. In addition, the 1991 study does not factor in the complexity of different tidal regimes that would be occurring because of an increased sea level and how that would affect the geomorphology of the floodplains.

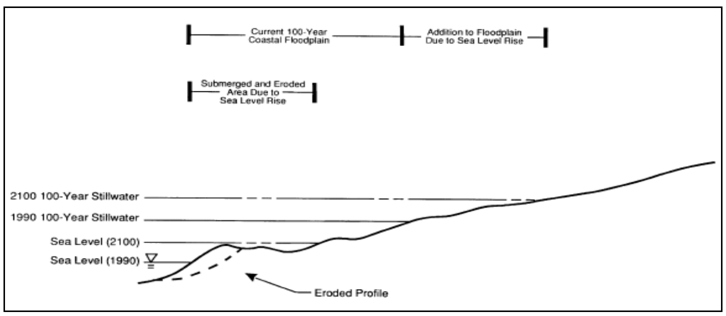
A recent historical overview of FEMA's Coastal Risk Assessment process is found in Crowell, Hirsch, and Hayes (2007) and includes overviews of the FEMA map modernization program, revised coastal guidelines, and FEMA's response to recommendations of a Heinz Center report *Evaluation of Erosion Hazards* (Heinz Center, 2000).

Box 8.1 1991 FEMA Study on Projected Impact of Sea-level Rise

In 1989, Congress authorized and signed into law a study of the impact of sea-level rise on the National Flood Insurance Program (NFIP). The legislation directed FEMA to determine the impact of sea-level rise on flood insurance rate maps and project the economic losses, associated with estimated sea-level rise. The final report was delivered to Congress in 1991. The primary objectives of the study were to quantify the impacts of relative sea-level rise on 1) the location and extent of the U.S. coastal floodplain, 2) the relationship between the elevation of insured properties and the 100-year BFE, and 3) the economic structure of the NFIP.

In the 1991 study FEMA used both a 1-foot and 3-foot increase in relative sea level by 2100 based on previous studies (Titus and Green, 1989; IPCC, 1990). For both scenarios it was assumed that the current 100-year floodplain would increase by the exact amount as the change in sea level. This assumption was made to simplify some of the second order dynamic interactions such as the effect of the increased water depth due to sea-level rise on storm surge, and how sea-level rise will propagate up tidally affected rivers to a point where sea-level rise will no longer affect water flood levels. The study did not attempt to model the effects of sea-level rise in upstream river areas, a task that would have required site-specific hydraulic calculations.

For each coastal county a still water flood level (SWFL) was estimated, as were the V-zone flood level, the estimated area covered by the Special Flood Hazard Area (SFHA), and the fraction for which coastal V zones were estimated. The equation divides the amount of sea level rise by the SWFL and multiplies the result by the current floodplain area. Another assumption was that shoreline erosion and inundation due to sea-level rise, causing a net loss in floodplain, would cancel out the net gain in floodplain associated with rising flood levels. Box Figure 8.1 shows this relationship. Coastal areas where shore protection measures such as beach nourishment and construction of groins, levees, bulkheads, and sea walls are used would obviously reduce the amount of land lost to sea-level rise and thus cause some overestimation in the amount of floodplain lost because of rising sea levels using this method (Titus, 1990).



Box Figure 8.1 Schematic diagram of the effect of sea level rise on the 100-year coastal floodplain (FEMA, 1991).

The study notes that these numbers differ slightly from previous sea-level rise studies (Titus and Green, 1989) but supports the conclusion from both studies that the size of the floodplain will not increase as sea level rises because of the balancing of land lost through submergence. Box Tables 8.1a and 8.1b show the breakdown of impacted land areas for 1-foot rise and 3-foot rise by regions in A zones vs. V zones (see Box 8.1 for definitions of A zones and V zones).

Box Table 8.1a Area Affected by a 1-foot Rise in Sea Level by 2100 (square miles)

Area	Floodplain 1990			Additional Area Affected Due to Sea level rise		
	A-Zone	V-Zone	Total	A-Zone	V-Zone	Total
Entire U.S.	16160	3335	19495	1806	362	2168
Mid-Atlantic	4163	344	4507	545	44	589

Box Table 8.1b Area Affected by a 3-foot Rise in Sea Level by 2100 (square miles)

Area	Floodplain 1990			Additional Area Affected Due to Sea level rise		
	A-Zone	V-Zone	Total	A-Zone	V-Zone	Total
Entire U.S.	16160	3335	19495	5423	1081	6504
Mid-Atlantic	4163	344	4507	1633	134	1767

The total land area nationwide estimated by the study to be in a floodplain was close to 19,500 square miles, with approximately 2,200 square miles added to the floodplain for a 1-foot rise scenario and an additional 6,500 added for a 3-foot rise. These numbers do not account for subsidence rates in the Louisiana region. For the mid-Atlantic region the floodplain was estimated to be about 4,500 square miles, with 590 square miles added to the floodplain for a 1-foot rise and 1,770 added for a 3-foot rise.

The study also estimated the number of households in the coastal floodplain. Based on the 1990 Census, 2.7 million households were currently in the 100-year floodplain, 624,000 of which were in the mid-Atlantic region. For the 1-foot and 3-foot rise scenarios respectively, 5.6 million and 6.6 million households would be in the floodplain, with 1.1 million and 1.3 million in the mid-Atlantic region. Much of this increase is from projected population and development increase in coastal areas and not just from sea level rise, with an estimated increase of 2.4 million households nationally and 382,000 in the mid-Atlantic region.

This projected rise in population and sea-level rise scenarios would increase the expected annual flood damage by 2100 for an average NFIP insured property by 36–58 percent for a 1-foot rise and 102–200 percent for a 3-foot rise. This would lead to actuarial increases in insurance premiums for building subject to sea-level rise of 58 percent for a 1-foot rise and 200 percent for a 3-foot rise. The study estimated that a 1-foot rise would gradually increase the expected annual NFIP flood losses by $150 million by 2100. Similarly, a 3-foot rise would gradually increase expected losses by about $600 million by 2100. Per policy holder, this increase would equate to $60 more than in 1990 for the 1-foot rise and $200 more for the 3-foot rise.

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8.5 STUDIES OF FUTURE COASTAL CONDITIONS AND FLOODPLAIN MAPPING

8.5.1 FEMA Coastal Studies

Currently communities can opt to use future conditions hydrology for mapping per FEMA rules established in December 2001 (Crowell, 2008). Showing future conditions flood boundaries has been accommodated for some communities in Flood Map Modernization, but not routinely provided. As outlined in the December 2001 rules, showing a future condition boundary in addition to the other boundaries normally shown on a DFIRM is acceptable. From the perspective of FEMA, showing a future condition boundary is for informational purposes only and carries with it no additional requirements for floodplain management, nor would insurance be rated using a future condition boundary. The benefits relate to the fact that future increases in flood risk can lead to significant increases in both calculated and experienced flood heights resulting in serious flood losses as well as loss of levee certification and loss of flood protection for compliant post-FIRM structures. Providing this information to communities may lead to them taking coordinated watershed wide actions to manage for or otherwise mitigate these future risks. The current coastal study process is discussed by Honeycutt and Mauriello (2005).

FEMA recognizes that there has been an increase in losses from coastal storms. Hurricane Katrina in 2005 illustrated this all too clearly, racking up the most losses of any U.S. natural disaster. This fact, coupled with the fact that new developments in modeling and mapping technology have allowed for more accurate flood hazard assessment over the past few years and that populations at risk are growing in coastal areas, has caused FEMA to develop a new national coastal strategy. This strategy consists of assessing coastal FISs on a national scope, and developing a nationwide plan for improved coastal flood hazard identification. The assessment will prioritize regional studies, look at funding allocations, and develop timelines for coastal study updates.

Crowell, Hirsch, and Hayes (2007) identify a need for a tide gauge analysis for FEMA Region III, which encompasses the Mid-Atlantic states similar to new studies being done currently on Chesapeake Bay by Maryland. Each coastal region is being evaluated and new guidelines and specifications are being developed by FEMA for future coastal restudies, the first of which is for the Pacific coast region. These guidelines outline new coastal storm surge modeling and mapping procedures that take new modeling technology into account and allow for new flooding and wave models to be used for generating coastal BFEs.

To aid in ongoing recovery and rebuilding efforts, FEMA initiated short-term projects in 2004 and 2005 to produce coastal flood recovery maps for the areas that were most severely affected by Hurricanes Ivan, Katrina, and Rita. The Katrina maps, for example, show high water marks surveyed after the storm, an inundation limit developed from these surveyed points, and FEMA’s Advisory Base Flood Elevations (ABFEs) and estimated zone of wave impacts.

These maps and associated ABFEs (generated for Katrina and Rita only) were based on new flood risk assessments that were done immediately following the storms to assist communities with rebuilding. The recovery maps provided a graphical depiction of ABFEs and coastal inundation associated with the observed storm surge high water mark values, in effect documenting the flood imprint of the event to be used in future studies and policy decisions. Adherence to the ABFEs following Katrina affected eligibility for certain FEMA-funded mitigation and recovery projects. They will be used until the FISs are updated for the Gulf region and are available as advisory information to assist communities in rebuilding efforts.

Future coastal studies may be affected by recent legislation that was submitted to Congress in late spring 2006 as part of the Flood Insurance Reform and Modernization Act of 2006 (109th Congress, 2006). The bill calls for changes to the way FEMA and the NFIP approach coastal studies and make recommendations that FEMA include coastal erosion information on the FIRMs. The Senate version calls for a description of coastal erosion areas to be included in new FISs and that any relevant information from NOAA or USACE on coastal inundation should be included on the maps as well.

FEMA cannot require the use of future conditions data based on planned land-use changes or proposed development for floodplain management or insurance rating purposes unless statutory and regulatory changes to the NFIP are made. In addition, using projected coastal erosion information for land-use management and insurance rating purposes through the NFIP would also require a legislative mandate and regulatory changes.

8.5.2 How Do We Capture or Map Potential Impacts of Sea-level Rise on Coastal Floodplains?

The concept of going above and beyond the current regulations to provide additional hazards information other than BFEs and the 1 percent annual chance flood (coastal erosion, and storm surge inundation potential) is something that the Association of State Floodplain Managers (ASFPM) has been advocating through their No Adverse Impact (NAI) program (Larson and Plasencia, 2002). No adverse impact floodplain management is essentially a "do no harm" policy based on the concept that the actions of any community or property owner should not adversely affect others. This concept was first developed by ASFPM for riverine floodplains and focused on exceeding the minimum requirements of federal programs such as the NFIP to provide vision, principles, and tools through which a community can effectively and permanently manage its land area. NAI helps a community or state achieve disaster resilience, which, in turn, contributes to long-term sustainability. An NAI toolkit was developed that outlines a strategy for communities to implement an NAI approach to floodplain management using these three basic building blocks (ASFPM, 2003).

The Basic Level

The basic level includes what is usually done to meet the minimum requirements of the NFIP or other state or federal requirements for managing floodplains and coastal zones and minimizing flood losses. However, even when rigorously implemented, these basic standards are not effective in all situations and can result in unintended negative consequences.

The Better Level

The better level adds floodplain management activities that are more effective than those of the basic level in protecting flood-prone properties, usually because they are tailored to specific situations, provide protection from larger floods, allow for margins of error, serve multiple purposes, require more diligent enforcement, or provide a combination of these. Even at this level, however, flood loss reduction measures tend not to take into account the effects that may be occurring elsewhere in the watershed or that may accrue after many years.

The NAI Level

The NAI level assumes that the basic activities are implemented and appropriate activities from the better level are used as well. But in addition, tools and techniques are employed that not only are the most effective at reducing flood losses but also prevent direct or indirect negative consequences for the surrounding landscape and watershed, nearby private property, and other communities. Equally important, the NAI techniques keep flood hazards and related problems from worsening in the future. The ASFPM recommends the NAI-level approaches because of their ability to minimize flood losses, preserve the viability of the ecosystem, foster disaster resilience, withstand legal challenges, and forestall increases in the problems in future years.

A coastal version of the NAI toolkit, called the Coastal NAI Handbook, is currently in press. It outlines this process for communities in coastal floodplains. This handbook illustrates how a community in a coastal floodplain can implement NAI concepts using the building blocks for several areas, including hazards identification and mapping, planning, regulation development standards, mitigation, infrastructure, emergency services, public outreach, and education.

8.6 HOW ARE COASTAL RESOURCE MANAGERS COPING WITH SEA-LEVEL RISE AND WHAT KIND OF ISSUES ARE THEY FACING?

8.6.1 Studies by the Association of State Floodplain Managers

The Association of State Floodplain Mangers (ASFPM) recently completed a study *National Flood Programs and Policies in Review–2007* that contains a broad spectrum of recommendations for improving the management of the nation's floodplains (ASFPM, 2007). In a discussion of the significant changes in social, environmental, and political realities and their impact on floodplain management, a changing climate was identified as one of the four major challenges.

> These current and expected (Climate) changes have widespread implications for the flood protection of human populations; their accompanying housing, commerce, and infrastructure; agricultural lands and production; and sensitive ecosystems throughout the planet. Further, climate change is altering the historic record of floods and storms that has formed the basis for the design of various protective measures, creating uncertainty about the adequacy of those measures to protect us from the storms that are expected in the future.

This same ASFPM document makes recommendations for strong federal leadership. Some of these are found in the following Box 8.2

Box 8.2

- USGS and NOAA should support and participate in domestic and international programs for the collection and analysis of data on climate change.
- Joint evaluation of populations centers should be conducted by NOAA's Sectoral Applications Research Program (SARR), the Department of Housing and Urban Development, and FEMA. This should include scenario-based analysis of the fragility of these areas in the face of a changing climate, the expected types and quantity of damage, its impact on the national economy, and responsible modifications to current management strategies.
- When states and communities update their all-hazard plans, FEMA should require that they include an evaluation of the impact of future climate change on their locales, including the potential impacts of sea level rise, extremes in precipitation and runoff, and more severe hurricanes —and include recommendations for adaptation as appropriate.
- The Office of the President should issue an Executive Order directing federal agencies to consider climate change, including adaptations to it, in all their planning, permitting, design, and construction.

Under data and technology for hydrology:

- Future-conditions and cumulative impacts should be incorporated into the identification, mapping, and regulation of flood risk areas under the NFIP
- .The future conditions should account for changes in the watershed, its floodplain, and its hydrology; climate change and variability, including sea level rise; subsidence; and other similar phenomena that alter future flood risk.

And under recommendations for dealing with coastal hazards:

- The closer buildings are sited to the water, the more likely they are to be affected by flooding, wave action, erosion, scour, debris impact, over wash, and high winds, which tend to be stronger along the coast. Repeated exposure to these hazards —even if the buildings are designed to reduce those impacts —leads to increased long-term costs for maintenance and damage repair, as well as to higher insurance rates. Simply siting buildings back a set distance from the water's edge allows for the natural protective systems to do their work and absorb or diminish wave impacts and other coastal energies.
- A national policy for setbacks for erosion, sea level rise, and other coastal hazards is needed. One option is that the NFIP require (or at least provide Community Rating System credit for) construction setbacks that account for the coastal conditions that are expected to exist 100 years into the future

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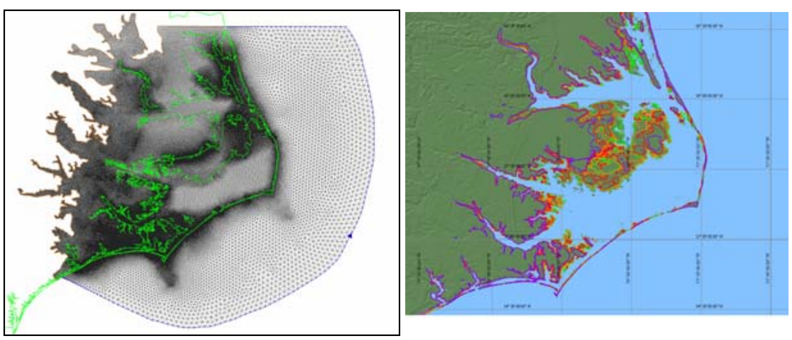
8.6.2 Other Federal Agency Coastal Flooding Studies

Other federal Agencies, such as NOAA, have been sponsoring applied research programs to bring into operations an integrated approach to understanding the effects of sea-level rise. One such study on the ecological effects of sea-level rise is discussed in the Box 8.3 below.

Box 8.3
An ongoing NOAA sponsored study on the ecological effects of sea-level rise is just one example of the type of integrated applied research that will be required to fully describe the effects of sea-level rise in the coming century. It incorporates and integrates features including high resolution data of the littoral zone, geography, ecology, biology and coastal process studies in a region of concern. A complete overview of the NOAA program can be found at:
http://www.cop.noaa.gov/stressors/climatechange/current/sea_level_rise.html
The North Carolina pilot study demonstrates the ability to design meaningful product delivery to the regional coastal manager that integrates capabilities in vertical reference frames, mapping, and modeling with targeted applied research led by the local academic marine science research community. The applied research program is designed to help coastal managers and planners better prepare for changes in coastal ecosystems due to land subsidence and sea level rise. Starting with southern Pamlico Sound, North Carolina, the approach is to simulate projected sea-level rise using a coastal flooding model that combines a hydrodynamic model of water levels with a high resolution digital elevation model (DEM). When completed, the coastal flooding model will be used to simulate long-term rises in water levels. Sub-models will then be developed to forecast ecological changes in coastal wetland and forested areas and these will be integrated with the coastal flooding model. The final goal of the program is to produce mapping and modeling tools that allow managers and planners to see projected shoreline changes and to display predictions of ecosystem impacts. Using these ecological forecasts, proactive mitigation will be possible.



Box Figure 8.3 The Coastal Flooding Model grid and one preliminary result of shoreline change due to various sea-level rise scenarios. **End of text box********

8.6.3 Other Floodplain Manager Activities

In a discussion of effects of sea-level rise on the National Flood Insurance Program, Hudgens (1999) suggested that a community's historical land subsidence and erosion rates as well as the area's projected rate of sea-level rise be incorporated on revised or new flood insurance rate maps. When FEMA remaps an area, they take into account subsidence and erosion as they exist at the time of the study. However, future conditions subsidence and erosion are not considered.

The discussion also recommended that the current mapped 1 percent annual chance floodplains be expanded to encompass the areas of land that would eventually become at risk of flooding after 30 years of sea-level rise, subsidence, or erosion. It called for FEMA to adapt the NFIP and the nation to the risks of sea-level rise and more extreme storms. To decrease the impact of near-future flood risks, FEMA could use the following adaptation techniques:

- Recalculate the 1 percent annual chance floodplains and BFEs to account for relative sea-level rise. Whenever a new study is done FEMA accounts for the relative sea-level rise that has occurred since the last study, however they do not account for future projected sea-level rise.
- Implement new regulations that would require subsidized property owners to flood-proof their homes
- Condition new development on the granting of "rolling easements" (Hudgens, 1999)
- Undertake education campaigns to communicate flood risks to stakeholders more effectively.

Slovinsky and Dickson (2006) recommend that FEMA flood insurance maps may need to be updated in the near future as changes in sea level become more dramatic, causing the 100-year floodplain to migrate upward and inland. Maryland has completed a comprehensive state strategy document in response to sea-level rise (MDDNR, 2000). Their analysis includes the following discussion:

> Issues associated with sea-level rise are significant with respect to the scope of Federal, State, and local management responsibilities under the NFIP. Flood Insurance Rate Maps (FIRMS) developed by FEMA designate areas of special flood risk and hazards, and insurance rates are calculated based on the level of flood risk associated with each designation. FIRMS and storm surge models prepared by FEMA, which guide State and local floodplain management efforts, do not evaluate future sea-level rise factors when establishing base flood elevations or storm surge risk zones. In fact, FEMA maps the 100-year floodplain as it exists at the time of the mapping effort. Future flood conditions, resulting from changes in land use, natural and human changes, or elevated flood levels due to sea-level rise, are not considered. To account for the subsequent uncertainty and degree of error present in the current Flood Insurance Rate Maps, MDDNR requires all communities to adopt standards that call for all structures in the non-tidal floodplain to be elevated one-foot above the 100-year floodplain elevation. However, MDDNR only encourages the adoption of the one-foot freeboard standard in the tidal floodplain. All coastal counties except Worcester, Somerset, and Dorchester, the three most vulnerable to exacerbated flooding due to sea-level rise, have adopted the one-foot freeboard standard. While one-foot of freeboard provides an added cushion of protection to guard against uncertainty in floodplain projections, it may not be enough in the event of two to three feet of sea-level rise. It is unlikely that the federal mapping efforts and floodplain management requirements will be modified to account for future sea-level rise. Therefore, State and local agencies need to take the initiative to address the potential for increased flooding due to sea-level rise.

FEMA does periodically update FIRMs and under the FEMA Map Mod and post-Map Mod, FEMA intends to assess the integrity of the flood hazard data by reviewing the flood map inventory every five years (Crowell, 2008). Where the review indicates the flood data integrity has degraded the flood maps, updates or new studies will be performed. Whenever FEMA updates or remap coastal areas, changes that had occurred in the interim due to sea-level rise will be accounted for.

8.6.4 Coastal Zone Management Act

Dramatic population growth along the coast brings new challenges to managing national coastal resources. Coastal and floodplain managers are challenged to strike the right balance between the growing population's desire to use coastal areas and a naturally changing shoreline. Challenges include protecting life and property from coastal hazards; protecting coastal wetlands and habitats while accommodating needed economic growth; and settling conflicts between competing needs such as dredged material disposal, commercial development, recreational use, national defense, and port development. Coastal land loss caused by chronic erosion has been an ongoing management issue in many coastal states, which have Coastal Zone Management (CZM) programs and legislation to mitigate erosion using a basic retreat policy. With the potential impacts of sea-level rise making current trends worse, coastal managers and lawmakers must now decide how or whether to adapt their current suite of tools and regulations to face prospect of an even greater amount of land loss in the decades to come.

The U.S. Congress recognized the importance of meeting the challenge of continued growth in the coastal zone and responded by passing the Coastal Zone Management Act (CZMA) in 1972. The act, administered by NOAA, provides for management of the nation's coastal resources, including the Great Lakes, and balances economic development with environmental conservation.

As a voluntary federal–state partnership, the CZMA is designed to encourage state tailored coastal management programs. It outlines two national programs, the National Coastal Zone Management Program and the National Estuarine Research Reserve System, and aims to balance competing land and water issues in the coastal zone, while estuarine reserves serve as field laboratories to provide a greater understanding of estuaries and how humans impact them. The overall program objectives of CZMA remain balanced to "preserve, protect, develop, and where possible, to restore or enhance the resources of the nation's coastal zone."

8.6.5 The CZMA and Sea-Level Rise Issues

The following are sections taken directly from the CZMA language and refer specifically to sea-level rise issues:

16 U.S.C. § 1451. Congressional findings (Section 302). The Congress finds that —
(l) Because global warming may result in a substantial sea-level rise with serious adverse effects in the coastal zone, coastal states must anticipate and plan for such an occurrence.

16 U.S.C. § 1452. Congressional declaration of policy (Section 303). The Congress finds and declares that it is the national policy —

(1) to preserve, protect, develop, and where possible, to restore or enhance, the resources of the Nation's coastal zone for this and succeeding generations;

(2) to encourage and assist the states to exercise effectively their responsibilities in the coastal zone through the development and implementation of management programs to achieve wise use of the land and water resources of the coastal zone, giving full consideration to ecological, cultural, historic, and esthetic values as well as the needs for compatible economic development, which programs should at least provide for —

> (B) the management of coastal development to minimize the loss of life and property caused by improper development in flood-prone, storm surge, geological hazard, and erosion-prone areas and in areas likely to be affected by or vulnerable to sea-level rise, land subsidence, and saltwater intrusion, and by the destruction of natural protective features such as beaches, dunes, wetlands, and barrier islands,

> (K) the study and development, in any case in which the Secretary considers it to be appropriate, of plans for addressing the adverse effects upon the coastal zone of land subsidence and of sea-level rise; and

(3) to encourage the preparation of special area management plans which provide for increased specificity in protecting significant natural resources, reasonable coastal-dependent economic growth, improved protection of life and property in hazardous areas,

including those areas likely to be affected by land subsidence, sea-level rise, or fluctuating water levels of the Great Lakes, and improved predictability in governmental decision-making.

8.6.6 The Coastal Zone Enhancement Program

The 1990 Reauthorization also established the Coastal Zone Enhancement Program (CZMA §309), which allows states to request additional funding to amend their coastal programs to support attainment of one or more coastal zone enhancement objectives. The program is designed to encourage states and territories to develop program changes in one or more of the following nine coastal zone enhancement areas of national significance: wetlands, coastal hazards, public access, marine debris, cumulative and secondary impacts, special area management plans, ocean/Great Lakes resources, energy and government facility citing, and aquaculture. Specifically from the CZMA 309 language:

6 U.S.C. § 1456b. Coastal Zone Enhancement Grants (Section 309)

(a) “Coastal zone enhancement objective” defined: For purposes of this section; the term “coastal zone enhancement objective” means any of the following objectives:

> (2) Preventing or significantly reducing threats to life and destruction of property by eliminating development and redevelopment in high-hazard areas, managing

development in other hazard areas, and anticipating and managing the effects of potential sea-level rise and Great Lakes level rise.

To help states target Section 309 Coastal Enhancement Program funds to identified program needs, every five years, coastal states and territories conduct an assessment of their coastal management activities within the nine enhancement areas. Through this self-assessment process, state coastal programs identify high-priority enhancement areas. In consultation with NOAA's Office of Ocean and Coastal Resource Management (OCRM), state coastal programs then develop five-year strategies to achieve changes (enhancements) to their coastal management programs within these high-priority areas. Program changes often include developing a new or revising an existing law, regulation or administrative guideline, developing or revising a special area management plan (SAMP), or creating a new program such as a coastal land acquisition or restoration program.

For coastal hazards, states base their evaluation on the following criteria:

1. What is the general level or risk from specific coastal hazards (*i.e.*, hurricanes, storm surge, flooding, shoreline erosion, sea-level rise, Great Lakes level fluctuations, subsidence, and geological hazards) and risk to life and property due to inappropriate development in the state?
2. Have there been significant changes to the state's hazards protection programs (*e.g.*, changes to building setbacks/restrictions, methodologies for determining building setbacks, restriction of hard shoreline protection structures, beach/dune

protection, inlet management plans, local hazard mitigation planning, or local post-disaster redevelopment plans, mapping/GIS/tracking of hazard areas)?

3. Does the state need to direct future public and private development and redevelopment away from hazardous areas, including the high hazard areas delineated as FEMA V-zones and areas vulnerable to inundation from sea and Great Lakes level rise?
4. Does the state need to preserve and restore the protective functions of natural shoreline features such as beaches, dunes, and wetlands?
5. Does the state need to prevent or minimize threats to existing populations and property from both episodic and chronic coastal hazards?

The following table is a summary of the state Coastal Program characterization of coastal hazards for the mid-Atlantic region (NOAA, 2006). Sea-level rise is characterized as a medium or high coastal hazard risk by each of the state coastal managers.

Table 8.5 Coastal Hazard Risk Characterization (H, M, L).

State	Hurricanes/ Typhoons	Flooding	Storm Surge	Episodic Erosion	Chronic Erosion	Sea Level Rise	Subsidence	Geologic Hazards	Nor'easters	Other
North Carolina	H	H	H	H	H	M	M	L		
Virginia	H	H	H	M	M	M	M	L	N/A	Shoreline Hardening — M
Delaware	M	H	H	M	H	M	L	L	N/A	Tsunamis — L
Maryland	M	H	H	H	H	H	M	L	N/A	Extra tropical Storms — H
New Jersey	M	H	H	H	H	H	M	L	H (extra-tropical storms)	

8.6.7 Coastal States Strategies

Organizations such as the Coastal States Organization have recently become more proactive in how coastal zone management programs consider adaptation to climate change, including sea-level rise (Coastal States Organization, 2007) and are actively leveraging each others experiences and approach to how best obtain baseline elevation information and inundation maps, to assess impacts of sea-level rise on social and economic resources and coastal habitats, and to develop public policy.

There have also been several individual state-wide studies on the impact of sea-level rise on local state coastal zones. Most notably see Z. Johnson (2000) for Maryland; Cooper, Beevers and Oppenheimer (2005) for New Jersey. Many states coastal management web-sites show an active public education program with regards to providing information on impacts of sea-level rise:

New Jersey: http://www.nj.gov/dep/njgs/enviroed/infocirc/sealevel.pdf

Delaware: http://www.dnrec.delaware.gov/Climate+change+shoreline+erosion.htm

Maryland: http://www.dnr.state.md.us/Bay/czm/sea_level_rise.html

8.6.7.1 Maryland's Strategy

One of the most progressive state designing strategies for dealing with sea-level rise is Maryland. The evaluation of sea-level rise response planning in Maryland and the resulting strategy document referenced in previous sections constituted the bulk of the States CZMA §309 Coastal Hazard Assessment and Strategy for 2000 – 2005 and again in their 2006 – 2010 Assessment and Strategy. Other mid-Atlantic states mention sea-level rise as a concern in their assessments, but have not developed a comprehensive strategy.

The Maryland strategy development, funded through CZM, included review of technology, data, and research; a comprehensive assessment of Maryland's vulnerability to sea-level rise; and an assessment of existing response capability. It was developed recognizing the need to begin advance planning and the recognition that management measures, programs, and policies were fragmented within the state for response to sea-level rise issues.

The strategy is comprised of four components, listed below, designed to build upon the others to achieve the desired outcome within a five-year time horizon. The cornerstone of the proposed strategy is designation of one or more staff within the Department of Natural Resources with expertise in sea-level rise planning to oversee implementation.

Outreach and Engagement: Engage the general public, State and local planners and elected officials in the process of implementing a sea-level rise response strategy.

Technology, Data and Research Support: Gain a better understanding of the regional impacts of sea-level rise and applicable policy response alternatives.

Critical Applications: Incorporate sea-level rise planning mechanisms into existing State and local management programs and on-going coastal initiatives.

Statewide Policy Initiatives: Enhance, and where necessary, modify key State statues to remedy barriers and advance sea-level rise planning initiatives.

Implementation of the strategy is evolving over time. It is a process that requires a sizeable commitment of time and financial resources. However, this process is crucial to the State's ability to achieve sustainable management of its coastal zone. The State recognizes that a "do nothing" approach will lead to unwise decisions and increased risk over time. Moreover, the strategy states that planners and legislators should realize that the implementation of measures to mitigate impacts associated with erosion, flooding, and wetland inundation will also enhance the State's ability to protect coastal resources and communities whether the sea level rises significantly or not.

The report conclusion lists the concrete steps that the State is undertaking as well as a statement as to what is a stake in successful implementation of a strategy. Maryland is one of the first states to take the first proactive step towards addressing a growing problem by committing to implementation of this strategy by increasing awareness and consideration of sea-level rise issues in both public and governmental arenas. The strategy suggests that Maryland will achieve true success in planning for sea-level rise by establishing effective response mechanisms at the State and local levels. Innumerable social and environmental resources are at stake. Sea-level rise response planning is crucial to ensure future survival of Maryland's diverse and invaluable coastal resources.

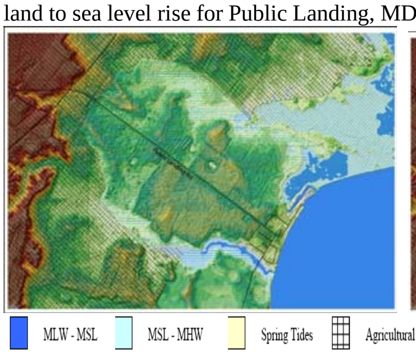
Since the release of Maryland's Sea-level Rise Response Strategy in 2000 (Johnson, 2000), the State has continued to progressively plan for sea-level rise. The strategy is being used to guide the State's current sea-level rise research, data acquisition, and planning and policy development efforts at both the State and local level. The State set forth a design vision for "resilient coastal communities" in its CZMA §309 Coastal Hazard Strategy for 2006 – 2010. The focus of the approach is to integrate the use of recently acquired sea-level rise data and technology based products into both state and local decision-making and planning processes. The State's Coastal Program is currently working one-on-one with local governments and other State agencies to: (1) build the capacity to integrate data and mapping efforts into land-use and comprehensive planning efforts; (2) identify specific opportunities (*i.e.*, statutory changes, code changes, comprehensive plan amendments) for advancing sea-level rise at the local level; and, (3) improve State and local agency coordination of sea-level rise planning and response activities (MDDNR, 2006)

In April 2007, Maryland's Governor, Martin O'Malley signed an Executive Order establishing a Commission on Climate Change (Maryland, 2007). The Commission is charged with advising both the Governor and Maryland's General Assembly on matters related to climate change and is charged with developing a Plan of Action that will address climate change on all fronts, including both the drivers and the consequences. Three working groups, comprised of a broad set of stakeholders and representatives of all levels of government, are working together to develop various components of the Plan of Action. The Adaptation and Response Working Group is responsible for developing a

Comprehensive Strategy for Reducing Maryland's Climate Change Vulnerability. Efforts of this Working Group will further greatly the implementation of Maryland's Sea-level Rise Response Strategy. The Adaptation and Response Working Group is developing specific strategies for reducing the vulnerability of the Maryland's coastal, natural and cultural resources and communities to the impacts of climate change, with a initial focus being given to sea-level rise and coastal hazards (*e.g.*, shore erosion, coastal flooding). Another element of the Comprehensive Strategy will be the development of appropriate guidance to assist local governments with identifying specific measures (*e.g.*, local land use regulations and ordinances) to adapt to sea-level rise and increasing coastal hazards. The Comprehensive Strategy and Plan of Action, including recommendations and draft legislation, will be presented to the Maryland's Governor and General Assembly in April 2008.

Box 8.4 A Maryland Case Study – Implications for Decision-makers: *Worcester County Sea Level Rise Inundation Modeling*

The Maryland Department of Natural Resources (MDDNR) and USGS completed the development of a Worcester County Sea Level Rise Inundation Model in November 2006[1]. Taking advantage of recent LIDAR coverage for the county, a Digital Elevation Model(DEM) was produced as the base layer on which to overlay various sea-level rise scenarios modeled for three time periods: 2025, 2050, and 2100. The three scenarios were the historic rate of regional sea-level rise estimated from tide station records (3.1 mm/yr), the average accelerated rate of sea-level rise projected by the 2001 IPCC report, and the worst case scenario using the maximum projection of accelerated sea-level rise by the 2001 IPCC report (85-90 cm by 2100). The scenarios were applied to present day elevations of Mean Sea Level (MSL), Mean High Water (MHW), and Spring tides derived at local tide stations. Box Figures 8.4a and 8.4b below show a typical result for year 2100 using an accelerated rate of sea-level rise scenario from the IPCC 2001 Report. There is an agricultural block overlay that depicts the potential loss of agricultural land to sea level rise for Public Landing, MD.



Box Figure 8.4a Day Public landing. **Box Figure 8.4b Public landing at 2100 with current rate of sea level rise.**

Box Figure 8.4c Sea level rise in 2100 using present day sea level trends coupled with a category 2 hurricane storm surge.

Development of the tool was completed in November 2006 and the results of the analyses will not be fully realized until it begins to be used by the Worcester County and Ocean City Planning and Emergency Management offices. Prior to final release of this study, the MDDNR and USGS study team met with Worcester County planners to discuss the model and how it could be applied to understanding of how existing structures and proposed growth areas could be affected by future sea-level rise. The tool is only now being used by county planners to make decisions on development and growth in the implementation of the March 2006 Comprehensive Plan for Worcester County. For Emergency Response Planning, the county is considering next steps and how to best utilize this tool. The county, as part of the Comprehensive Plan[2], already is directing future growth to outside of the category 3 hurricane storm surge zone and the sea level overlays will be used to perform risk assessments for existing and proposed development.

1 Johnson, Zoe, *et al.*, 2006. Worcester County Sea Level Rise Inundation Model, Technical Report, Maryland DNR Publication No. 14-982006-166, www.dnr.state.md.us, November 2007 15pp.
2 Worcester County Planning Commission. 2006. Comprehensive Plan, Worcester County Maryland. Worcester County Commissioners, Snow Hill, MD.

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