# Part III Overview. Preparing for Sea-Level Rise

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For at least the last four centuries, people have been erecting permanent settlements in the coastal zone of the Mid-Atlantic without regard to the fact that the sea is rising. Because the sea has been rising slowly and only a small part of the coast was developed, the consequences have been relatively isolated and manageable. Part I of this Product suggests, however, that a 2 millimeter per year acceleration of sea-level rise *could* transform the character of the mid-Atlantic coast, with a large scale loss of tidal wetlands and possible disintegration of barrier islands. A 7 millimeter per year acceleration is likely to cause such a transformation, although shore protection may prevent some developed barrier islands from disintegrating and low-lying communities from being taken over by wetlands.

For the last quarter century, scientific assessments have concluded that regardless of possible policies to reduce emissions of greenhouse gases, people will have to adapt to a changing climate and rising sea level. Adaptation assessments differentiate "reactive adaptation" from "anticipatory adaptation".

Part III focuses on what might be done to prepare for sea-level rise. Chapter 10 starts by asking whether preparing for sea-level rise is even necessary. In many cases, reacting later is more justifiable than preparing now, both because the rate and timing of future sea-level rise is uncertain and the additional cost of acting now can be high when the impacts are at least several decades in the future. Nevertheless, for several types of impacts, the cost of preparing now is very small compared to the cost of reacting later. Examples where preparing can be justified include:

- *Coastal wetland protection*. It may be possible to reserve undeveloped lands for wetland migration, but once developed, it is very difficult to make land available for wetland migration. Therefore, it is far more feasible to aid wetland migration by setting aside land before it is developed, than to require development to be removed as sea level rises.
- *Some long-lived infrastructure*. Whether it is beneficial to design coastal infrastructure to anticipate rising sea level depends on economic analysis of the incremental cost of designing for a higher sea level now, and the retrofit cost of modifying the structure at some point in the future. Most long-lived infrastructure in the threatened areas is sufficiently sensitive to rising sea level to warrant at least an assessment of the costs and benefits of preparing for rising sea level.
- *Floodplain management*. Rising sea level increases the potential disparity between rates and risk. Even without considering the possibility of accelerated sea-level rise, the National Academy of Sciences and a Federal Emergency Management Agency (FEMA)-supported study by the Heinz Center recommended to Congress that insurance rates should reflect the changing risks resulting from coastal erosion.

Chapter 11 discusses organizations that are preparing for a possible acceleration of sea-level rise. Few organizations responsible for managing coastal resources vulnerable to sea-level rise have modified their activities. Most of the best examples of preparing for the environmental impacts of sea-level rise are in New England, where several states have enacted policies to enable wetlands to migrate inland as sea-level rise. Ocean City, Maryland is an example of a town considering future sea-level rise in its infrastructure planning.

Chapter 12 examines the institutional barriers that make it difficult to take the potential impacts of future sea-level rise into account for coastal planning. Although few studies have discussed the challenge of institutional barriers and biases in coastal decision making, their implications for sea-level rise are relatively straightforward:

- *Inertia and short-term thinking*. Most institutions are slow to take on new challenges, especially those that require preparing for the future rather than fixing a current problem.
- *The interdependence of decisions* reinforces institutional inertia. In many cases, preparing for sea-level rise requires a decision as to whether a given area will ultimately be given up to the sea, protected with structures and drainage systems, or elevated as the sea rises. Until communities decide which of those three pathways they will follow in a given area, it is difficult to determine which anticipatory or initial response measures should be taken.
- *Policies favoring protection of what is currently there*. In some cases, longstanding preferences for shore protection (as discussed in Chapter 6) discourage planning measures that foster retreat. Because retreat may require a greater lead time than shore protection, the presumption that an area will be protected may imply that

planning in unnecessary. On the other hand, these preferences may help accelerate the response to sea-level rise in areas where shore protection is needed.

- *Policies Favoring Coastal Development*. One possible response to sea-level rise is to invest less in the lands likely to be threatened. However, longstanding policies that encourage coastal development can discourage such a response. On the other hand, increasingly dense coastal development improves the ability to raise funds required for shore protection. Therefore, policies that encourage coastal development may be part of an institutional bias favoring shore protection, but they are not necessarily a barrier to responding to sea-level rise.

Although most institutions have not been preparing for a rising sea, (Chapter 11) , that may be changing. As these chapters were drafted, several states have started to seriously examine possible responses. For example, Maryland enacted a statute to limit the adverse environmental impact of shore protection structures as sea level rises; and FEMA is beginning to assess possible changes to the National Flood Insurance Program. It is too soon to tell whether the increased interest in the consequences of climate change will overtake—or be thwarted by—the institutional barriers that have discouraged actionuntil now.

# Chapter 10. Implications for Decisions

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## KEY FINDINGS

- In many cases, it is difficult to determine whether taking a specific action to prepare for sea-level rise is justified, due to uncertainty in the timing and magnitude of impacts, and difficulties in quantifying projected benefits and costs. Nevertheless, published literature has identified some cases where acting now can be justified.
- Key opportunities for preparing for sea-level rise concern coastal wetland protection, flood insurance rates, and the location and elevation of coastal homes, buildings, and infrastructure.
- Incorporating sea-level rise into coastal wetlands programs can be justified because the Mid-Atlantic still has substantial vacant land onto which coastal wetlands could migrate as sea level rises. Policies to ensure that wetlands are able to migrate inland are likely to be less expensive and more likely to succeed if the planning takes place before people develop these dry lands than after the land becomes developed. Possible tools include rolling easements, density restrictions, coastal setbacks, and vegetative buffers.

- Sea-level rise does not threaten the financial integrity of the National Flood Insurance Program. Incorporating sea-level rise into the program, however, could allow flood insurance rates to more closely reflect changing risk and enable participating local governments to more effectively manage coastal floodplains.
- Long-term shoreline planning is likely to yield benefits greater than the costs; the more sea level rises, the greater the value of that planning.

## 10.1 INTRODUCTION

Most decisions of everyday life in the coastal zone have little to do with the fact that the sea is rising. Some day-to-day decisions depend on today's water levels. For example, sailors, surfers, and fishermen all consult tide tables before deciding when to go out. People deciding whether to evacuate during a storm consider how high the water is expected to rise above the normal level of the sea. Yet the fact that the normal sea level is rising about 0.01 millimeters (mm) per day does not affect such decisions.

Sea-level rise can have greater impacts on the outcomes of decisions with long-term consequences. Those impacts do not all warrant doing things differently today. In some cases, the expected impacts are far enough in the future that people will have ample time to respond. For example, there is little need to anticipate sea-level rise in the construction of docks, which are generally rebuilt every few decades, because the rise can be considered when they are rebuilt (NRC, 1987). In other cases, the adverse impacts of sea-level rise can be more effectively addressed by preparing now than by reacting later. If a dike will eventually be required to protect a community, for example, it can be more cost-effective to leave a vacant right-of-way when an area is developed or redeveloped, rather than tear buildings down later.

People will have to adapt to a changing climate and rising sea level (NRC, 1983; Hoffman *et al.*, 1983; IPCC 1990, 1996, 2001, 2007). The previous chapters (as well as Appendix 1) discuss vulnerable private property and public resources, including ecosystems, real estate, infrastructure (*e.g.*, roads, bridges, parks, playgrounds, government buildings), and commercial buildings (*e.g.*, hotels, office buildings, industrial facilities). Those responsible for managing those assets will have to adapt to changing climate and rising sea level regardless of possible efforts to reduce greenhouse gases, because society has already changed the atmosphere and will continue to do so for at least the next few decades (NRC, 1983; Hoffman *et al.*, 1983; IPCC 1990, 1996, 2001, 2007). Some of these assets will be protected or preserved in their current locations, while others must be moved inland or be lost. Chapters 6, 8, and 9 examine government policies that are, in effect, the current response to sea-level rise. Previous assessments have emphasized the need to distinguish the problems that can be solved by future generations reacting to changing climate from problems that could be more effectively solved by preparing today (Titus, 1990; Scheraga and Grambsch, 1998; Klein *et al.*, 1999; Frankhauser *et al.*, 1999; OTA 1993). Part III (*i.e.*, this Chapter and the next two chapters) makes that distinction.

This Chapter addresses the question: “Which decisions and activities (if any) have outcomes sufficiently sensitive to sea-level rise so as to justify doing things differently, depending on how much the sea is expected to rise?” (CCSP, 2006). Doing things differently does not always require novel technologies or land-use mechanisms; most measures for responding to erosion or flooding from sea-level rise have already been used to address erosion or flooding caused by other factors (see Section 6.1 in Chapter 6). Section 10.2 describes some categories of decisions that may be sensitive to sea-level rise, focusing on the idea that preparing now is not worthwhile unless the expected present value of the benefits of preparing is greater than the cost. Sections 10.3 to 10.7 examine five issues related to rising sea level: wetland protection, shore protection, long-lived structures, elevating homes, and floodplain management.

The examples discussed in this Chapter focus on activities by governments and homeowners, not by corporations. Most published studies about responses to sea-level rise have been funded by governments, with a goal to improve government programs, communicate risk, or provide technical support to homeowners and small businesses. Corporations also engage in many of the activities discussed in this Chapter. It is possible that privately funded (and unpublished) strategic assessments have identified other near-term decisions that are sensitive to sea-level rise.

A central premise of this Chapter is that the principles of economics and risk management provide a useful paradigm for thinking about the implications of sea-level rise for decision making. In this paradigm, decision makers have a well-defined objective concerning potentially vulnerable coastal resources, such as maximizing return on an investment (for a homeowner or investor) or maximizing overall social welfare (for a government). Box 10.1 elaborates on this analytical framework. Although economic analysis is not the only method for evaluating a decision, emotions, perceptions, ideology, cultural values, family ties, and other non-economic factors are beyond the scope of this Chapter.

This Chapter is not directly tied to specific sea-level rise scenarios. Instead, it considers a wide range of plausible sea-level rise over periods of time ranging from decades to centuries, depending on the decision being examined. The Chapter does not quantify the extent to which decisions might be affected by sea-level rise. All discussions of costs assume constant (inflation-adjusted) dollars.

**BOX 10.1: Conceptual Framework for Decision Making with Sea-Level Rise**

This Chapter's conceptual framework for decision making starts with the basic assumption that homeowners or governments with an interest in coastal resources seek to maximize the value of those resources to themselves (homeowners) or to the public as a whole (governments), over a period of time (planning horizon). Each year, coastal resources provide some value to its owner. In the case of the homeowner, a coastal property might provide rental income, or it might provide "imputed rent" that the owner derives from owning the home rather than renting a similar home. The market value of a property reflects an expectation that property will generate similar income over many years. Because a dollar of income today is worth more than a dollar in the future, however, the timing of the income stream associated with a property also affects the value (see explanation of "discounting" in Section 10.2).

Natural hazards and other risks can also affect the income a property provides over time. Erosion, hurricane winds, episodic flooding, and other natural hazards can cause damages that reduce the income from the property or increase the costs of maintaining it, even without sea-level rise,. These risks are taken into account by owners, buyers, and sellers of property to the extent that they are known and understood.

Sea-level rise changes the risks to coastal resources, generally by increasing existing risks. This Chapter focuses on investments to mitigate those additional risks.

In an economic framework, investing to mitigate coastal hazards will only be worthwhile if the cost of the investment (incurred in the short term) is less than net expected returns (which accrue over the long-term). Therefore, these investments are more likely to be judged worthwhile when: (1) there is a large risk of near-term damage (and it can be effectively reduced); (2) there is a small cost to effectively reduce the risk; or (3) the investment shifts the risk to future years.

## 10.2 DECISIONS WHERE PREPARING FOR SEA-LEVEL RISE IS WORTHWHILE

Sea-level rise justifies changing what people do today if the outcome from considering sea-level rise has an expected net benefit, that is, the benefit is greater than the cost. Thus, when considering decisions where sea-level rise justifies doing things differently, one can exclude from further consideration those decisions where either (1) the administrative costs of preparing are large compared to the impacts, or (2) the net benefits are likely to be small or negative. Few, if any, studies have analyzed the administrative costs of preparing for sea-level rise. Nevertheless, one can infer that administrative costs exceed any benefits from preparing for a very small rise in sea level.[25] Most published studies that investigate which decisions are sensitive to sea-level rise (IPCC, 1990; NRC 1987; Titus and Narayanan, 1996) concern decisions whose consequences last decades or longer, during which time a significant rise in sea level might occur. Those decisions mostly involve long-lived structures, land-use planning, or infrastructure, which can influence the location of development for centuries, even if the structures themselves do not remain that long.

For what type of decision is a net benefit likely from considering sea-level rise? Most analyses of this question have focused on cases where (1) the more sea level rises, the greater the impact; (2) the impacts will mostly occur in the future and are uncertain because the precise impact of sea-level rise is uncertain; and (3) preparing now will reduce the eventual adverse consequences (see Figure 10.1).

[25] Administrative costs (*e.g.*, studies, regulations, compliance, training) of addressing a new issue are roughly fixed regardless of how small the impact may be, while the benefits of addressing the issue depend on the magnitude of sea-level rise. Therefore, there would be a point below which the administrative costs would be greater than any benefits from addressing the issue.

In evaluating a specific activity, the first question is whether preparing now would be better than never preparing. If so, a second question is whether preparing now is also better than preparing during some future year. Preparing now to avoid possible effects in the future involves two key economic principles: uncertainty and discounting.

*Uncertainty*. Because projections of sea-level rise and its precise effects are uncertain, preparing now involves spending today for the sake of uncertain benefits. If sea level rises less than expected, then preparing now may prove, in retrospect, to have been unnecessary. Yet if sea level rises more than expected, whatever one does today may prove to be insufficient. That possibility tends to justify waiting to prepare later, if people expect that a few years later (1) they will know more about the threat and (2) the opportunity to prepare will still be available[26]. Given these reasons to delay, responding now may be difficult to justify, unless preparing now is either fairly inexpensive, or part of a "robust" strategy (*i.e.*, it works for a wide range of possible outcomes). For example, if protecting existing development is important, beach nourishment is a robust way to prepare, because the sand will offset some shore erosion no matter how fast or slow the sea rises.

[26] There is an extensive economic literature on decision-making and planning under uncertainty, particularly where some effects are irreversible. A review of this literature on the topic of "quasi-option value" can be found in Freeman (2003),. Quasi-option value arises from the value of information gained by delaying an irreversible decision (*e.g.*, to rebuild a structure to withstand higher water levels). In the sea-level rise context, it applies because the costs and benefits of choosing to retreat or protect are uncertain, and it is reasonable to expect that uncertainty will narrow over time concerning rates of sea level rise, the effects, how best to respond, and the costs of each response option. Two influential works in this area include Arrow and Fisher (1974) and Fisher and Hanemann (1987); an application to climate policy decisions can be found in Ha-Duong (1998).

*Discounting*. Discounting is a procedure by which economists determine the "present value" of something given or received at a future date (U.S. EPA, 2000). A dollar today is preferred over a dollar in the future, even without inflation (Samuelson and Nordhaus, 1989); therefore, a future dollar must be discounted to make costs and benefits received in different years comparable. Economists generally agree that the appropriate way to discount is to choose an assumed annual interest rate and compound it year-by-year (just as interest compounds) and use the result to discount future dollars (U.S. EPA, 2000; Congressional Research Service, 2003; OMB, 1992; Nordhaus, 2007a, b; Dasgupta, 2007).

Most of the decisions where preparing now has a positive net benefit fall into at least one of three categories: (1) the near-term impact may be large; (2) preparing now costs little compared to the cost of the possible impact; or (3) preparing now involves options that reallocate (or clarify) risk.

### 10.2.1 Decisions that Address Large Near-Term Impacts

If the near-term impact of sea-level rise is large, preparing now may be worthwhile. Such decisions might include:

- *Beach nourishment* to protect homes that are in imminent danger of being lost. The cost of beach nourishment is often less than the value of the threatened structures (USACE, 2000a).

- *Enhancing vertical accretion* (build-up) of wetlands that are otherwise in danger of being lost in the near term (Kentula, 1999; Kussler, 2006). Once wetlands are lost, it can be costly (or infeasible) to bring them back.
- *Elevating homes* that are clearly below the expected flood level due to historic sea-level rise (see Sections 10.6 and 10.7). If elevating the home is infeasible (*e.g.*, historic row houses), flood-proofing walls, doors, and windows may provide a temporary solution (see Chapter 9).
- *Fortifying dikes* to the elevation necessary to protect from current floods. Because sea level is rising, dikes that once protected against a 100-year storm would be overtopped by a similar flood on top of today's higher sea level (see *e.g.*, IPET, 2006).

### 10.2.2 Decisions Where Preparing Now Costs Little

These response options can be referred to as "low regrets" and "no regrets", depending on whether the cost is little or nothing. The measures are justifiable, in spite of the uncertainty about future sea-level rise, because little or nothing is invested today, in return for possibly averting or delaying a serious impact. Examples include:

- *Setting a new home back from the sea within a given lot.* Setting a home back from the water can push the eventual damages from sea-level rise farther into the future, lowering their expected present value[27]. Unlike the option of not building, this approach retains almost the entire value of using the property—especially if nearby homes are also set back so that all properties retain the complete panorama

[27] The present value of a dollar T years in the future is $1/(1+i)^T$ , where i is the interest rate (discount rate) used for the calculations (see Samuelson and Nordhaus, 1989).

view of the waterfront—provided that the lot is large enough to build the same house as would have been built without the setback requirement.

- *Building a new house with a higher floor elevation*. While elevating an existing house can be costly, building a new house on pilings one meter (a few feet) higher only increases the construction cost by about 1 percent (Jones *et al*., 2006).
- *Designing new coastal drainage systems with larger pipes to incorporate future sea-level rise*. Retrofitting or rebuilding a drainage system can cost 10 to 20 times as much as including larger pipes in the initial construction (Titus *et al.*, 1987).
- *Rebuilding roads to a higher elevation during routine reconstruction.* If a road will eventually be elevated, it is least expensive to do so when it is rebuilt for other purposes.
- *Designing bridges and other major facilities.* As sea level rises, clearance under bridges declines, impairing navigation (TRB, 2008). Building the bridge higher in the first place can be less expensive than rebuilding it later.

**Figure 10.1** Homes set back from the shore. Myrtle Beach, South Carolina. (April, 2004)

### 10.2.3 Options That Reallocate or Clarify Risks from Sea-Level Rise

Instead of imposing an immediate cost to avoid problems that may or may not occur, these approaches impose a future cost, but only if and when the problem emerges. The premise for these measures is that current rules or expectations can encourage people to behave in a fashion that increases costs more than necessary. People make better decisions when all of the costs of a decision are internalized (Samuelson and Nordhaus, 1989). Changing rules and expectations can avoid some costs, for example, by establishing today that the eventual costs of sea-level rise will be borne by a property owner making a decision sensitive to sea-level rise, rather than by third parties (*e.g.*, governments) not involved in the decision. Long-term shoreline planning and rolling easements are two example approaches.

Long-term shoreline planning can reduce economic or environmental costs by concentrating development in areas that will not eventually have to be abandoned to the rising sea. People logically invest more along eroding shores if they assume that the government will provide subsidized shore protection (see Box 10.2) than in areas where owners must pay for the shore protection or where government rules require an eventual abandonment. The value to a buyer of that government subsidy is capitalized into higher land prices, which can further encourage increased construction. Identifying areas that will not be protected can avoid misallocation of both financial and human resources. If residents wrongly assume that they can expect shore protection and the government does not provide it, then real estate prices can decline; in extreme cases, people can lose their homes unexpectedly. People's lives and economic investments can be disrupted if dunes or dikes fail and a community is destroyed. A policy that clearly warns that such an area will *not* be protected (see Section 12.3 in Chapter 12) could lead owners to strategically depreciate the physical property[28] and avoid some of the noneconomic impacts that can occur after an unexpected relocation (see Section 6.4.1). (see Section 12.3 for further discussion).

**BOX 10.2: Erosion, Coastal Programs, and Property Values**

Do government shore protection and flood insurance programs increase property values and encourage coastal development? Economic theory would lead one to expect that in areas with high land values, the benefits of coastal development are already high compared to the cost of development, and thus most of these areas will become developed unless the land is acquired for other purposes. In these areas, government programs that reduce the cost of maintaining a home should generally be reflected in higher land values; yet they would not significantly increase development because development would occur without the programs. By contrast, in marginal areas with low land prices, coastal programs have the potential to reduce costs enough to make a marginal investment profitable.

Several studies have investigated the impact of flood insurance on development, with mixed results. Leatherman (1997) examined North Bethany Beach, Delaware, a community with a checkerboard pattern of lands that were eligible and ineligible for federal flood insurance due to the Coastal Barrier Resources Act. He found that ocean-front lots generally sold for $750,000, with homes worth about $250,000. Development was indistinguishable between areas eligible and ineligible for flood insurance. In the less affluent areas along the back bays, however, the absence of federal flood insurance was a deterrent to developing some of the lower-priced lots. Most other studies have not explicitly attempted to distinguish the impact of flood insurance on low- and high-value lands. Some studies (*e.g.*, Cordes and Yezer, 1998; Shilling *et al.*, 1989) have concluded that the highly subsidized flood insurance policies during the 1970s increased development, but the actuarial policies since the early 1980s have had no detectable impact on development. Others have concluded that flood insurance has a minimal impact on development (*e.g.*, GAO 1982; Miller, 1981). The Heinz Center (2000) examined the impacts of the National Flood Insurance Program (NFIP) and estimated that "the density of structures built within the V Zone after 1981 may be 15 percent higher than it would have been if the NFIP had not been adopted. However, the expected average annual flood and erosion damage to these structures dropped close to 35 percent. Thus, overall, the damage to V Zone structures built after 1981 is between 25 and 30 percent lower than it would have been if development had occurred at the lower densities, but higher expected damage that would have occurred absent the NFIP". A report to the Federal Emergency Management Agency (FEMA) reviewed 36 published studies and commentaries concerning the impacts of flood insurance on development and concluded that none of the studies offer irrefutable evidence that the availability, or the lack of availability, of flood insurance is a primary factor in floodplain development today (Evatt, 1999, 2000).

Considering shore protection and flood insurance together, The Heinz Center (2000) estimated that "in the absence of insurance and other programs to reduce flood risk, development density would be about 25 percent lower in areas vulnerable to storm wavers ( *i.e.*, V Zones ) than in areas less susceptible to damage

[28] Yohe *et al.* (1996) estimated that the nationwide value of "foresight" regarding response to sea-level rise is $20 billion, based largely on the strategic depreciation that foresight makes possible.

from coastal flooding". Cordes and Yezer (1998) modeled the impact on new building permit activity in coastal areas of shore protection activity in 42 coastal counties, including all of the counties with developed ocean coasts in New York, New Jersey, Maryland, and Virginia. They did not find a statistically significant relationship between shore protection and building permits.

The impact of federal programs on property values has not been assessed to the same extent. The Heinz Center (2000) reported that along the Atlantic coast, a house with a remaining lifetime of 10 to 20 years before succumbing to erosion is worth 20 percent less than a home expected to survive 200 years. Landry *et al.* (2003) found that property values tend to be higher with wide beaches and low erosion risk. It would therefore follow that shore protection programs that widen beaches, decrease erosion risk, and lengthen a home's expected lifetime would increase property values. Nevertheless, estimates of the impact on property values are complicated by the fact that proximity to the shore increases the risk of erosion but also improves access to the beach and views of the water (Bin *et al.*, 2008).

Rolling easements can also reallocate or clarify the risks of sea-level rise, depending on the pre-existing property rights of a given jurisdiction (Titus, 1998). A rolling easement is an arrangement under which property owners have no right or expectation of holding back the sea if their property is threatened. Rolling easements have been implemented by regulation along ocean and sheltered shores in three New England states (see Section 11.2 in Chapter 11 and along ocean shores in Texas and South Carolina. Rolling easements can also be implemented as a type of conservation easement, with the easement donated, purchased at fair market value, or exacted as a permit condition for some type of coastal development (Titus, 1998). In either case, they prevent property owners from holding back the sea but otherwise do not alter what an owner can do with the property. As the sea advances, the easement automatically moves or "rolls" landward. Without shoreline armoring, sediment transport remains undisturbed and wetlands and other tidal habitat can migrate naturally. Because the dry beach and intertidal land continues to exist, the rolling easement also preserves the public's lateral access right to walk along the shore[29] (*Matcha versus Mattox*, 1986).

[29]Another mechanism for allowing wetlands and beaches to migrate inland are setbacks, which prohibit development near the shore. Setbacks can often result in successful "takings" claims if a property is

Under a rolling easement, the property owner bears all of the risk of sea-level rise. Without a rolling easement, property owners along most shores invest as if their real estate is sustainable, and then expend resources—or persuade governments to expend resources—to sustain the property. The overall effect of the rolling easement is that a community clearly decides to pursue retreat instead of shore protection in the future. The same result could also be accomplished by purchasing (or prohibiting development on) the land that would potentially be eroded or submerged as sea level rises. That approach, however, would have a large near-term social cost because the coastal land would then be unavailable for valuable uses. By contrast, rolling easements do not prevent the property from being used for the next several decades while the land remains dry. (Even if the government purchases the rolling easement, the purchase price is a transfer of wealth, not a cost to society[30].) The landward migration from the rolling easement should also have lower eventual costs than having the government purchase property at fair market value as it becomes threatened (Titus, 1991). Property owners can strategically depreciate their property and make other decisions that are consistent with the eventual abandonment of the property (Yohe *et al.*, 1996; Titus, 1998), efficiently responding to information on sea-level rise as it becomes available. Figure 10.1 shows how a rolling easement might work over time in an area already developed when rolling easements are obtained.

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deemed undevelopable due to the setback line. By contrast, rolling easements place no restrictions on development and hence are not constitutional takings (see, *e.g.*, Titus [1998]).

[30]A social cost involves someone losing something of value (*e.g*,. the right to develop coastal property) without a corresponding gain by someone else. A wealth transfer involves one party losing something of value with another party gaining something of equal value (*e.g.*, the cost of a rolling easement being transferred from the government to a land owner). For additional details, see Samuelson and Nordhaus (1989).

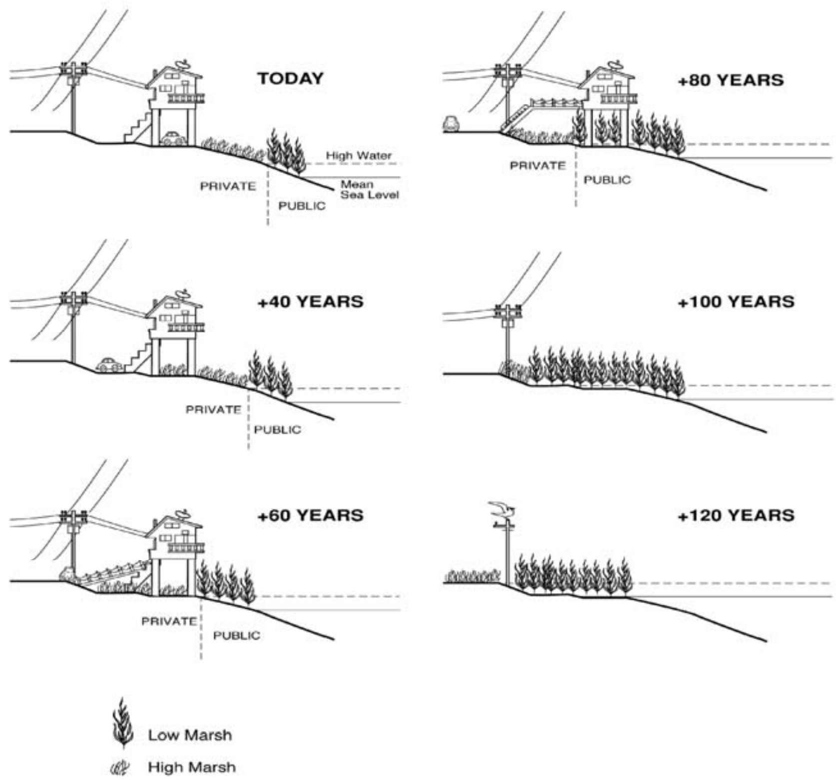


**Figure 10.2** The landward migration of wetlands onto property subject to a rolling easement. A rolling easement allows construction near the shore, but requires the property owner to recognize nature's right-of-way to advance inland as sea level rises. In the case depicted, the high marsh reaches the footprint of the house 40 years later. Because the house is on pilings, it can still be occupied (assuming that it is hooked to a sewerage treatment plant. A flooded septic system would probably fail, because the drainfield must be a minimum distance above the water table). After 60 years, the marsh has advanced enough to require the owner to park their car along the street and construct a catwalk across the front yard. After 80 years, the marsh has taken over the entire yard; moreover, the footprint of the house is now seaward of mean high water and hence, on public property. At this point, additional reinvestment in the property is unlikely. Twenty years later, the particular house has been removed, although other houses on the same street may still be occupied. Eventually, the entire area returns to nature. A home with a rolling easement would depreciate in value rather than appreciate like other coastal real estate. But if the loss is expected to occur 100 years from today, it would only offset the current property value by 1 to 5 percent, which could be compensated or offset by other permit considerations (Titus, 1998).

## 10.3 PROTECTING COASTAL WETLANDS

The nation's wetland programs generally protect wetlands in their current locations, but they do not explicitly consider retreating shorelines. As sea level rises, wetlands can adapt by accreting vertically (Chapter 4) and migrating inland. Most tidal wetlands are likely to keep pace with the current rate of sea-level rise but could become marginal with an acceleration of 2 millimeters (mm) per year, and are likely to be lost if sea-level rise accelerates by 7 mm per year (see Chapter 4). Although the dry land available for potential wetland migration or formation is estimated to be less than 20 percent of the current area of wetlands (see Titus and Wang 2008), these lands could potentially become important wetland areas in the future. However, given current policies and land-use trends, they may not be available for wetland migration and formation (Titus 1998, 2001). Much of the coast is developed or being developed, and those who own developed dry land adjacent to the wetlands increasingly take measures to prevent the wetlands from migrating onto their property (see Figure 10.4 and Chapter 6).

**Figure 10.3** Coastal Wetlands migrating onto previously dry lowland. Webbs Island, just east of Machipongo, in Northampton County, Virginia (June, 2007).

**Figure 10.4** Wetland Migration thwarted by development and shore protection. Elevating the land surface with fill prevents wetlands from migrating into the back yard with a small or modest rise in sea level. The bulkhead prevents waves from eroding the land, which would otherwise provide sand and other soil materials to help enable the wetlands to accrete with rising sea level (Monmouth New Jersey, August, 2003).

Continuing the current practice of protecting almost all developed estuarine shores could reverse the accomplishments of important environmental programs (*e.g.*, Titus 1991, 2001, 2005). Until the mid-twentieth century, tidal wetlands were often converted to dredge-and-fill developments (see Section 6.1.1.2 in Chapter 6 for an explanation of these developments and their vulnerability to sea-level rise). By the 1970s, the aggregate result of the combination of federal and state regulations had, for all practical purposes, halted that practice. Today, most tidal wetlands in the Mid-Atlantic are off-limits to development. Coastal states generally prohibit the filling of low marsh, which is publicly owned in most states under the Public Trust Doctrine (see Section 8.2).

A landowner who wants to fill tidal wetlands on private property must usually obtain a permit from the U.S. Army Corps of Engineers (USACE)[31]. These permits are generally not issued unless the facility is inherently water-related, such as a marina[32]. Even then,

[31] 33 U.S.C. §§ 403, 409, 1344(a)
[32] 40 C.F.R. § 230.10(a)(3)

the owners usually must mitigate the loss of wetlands by creating or enhancing wetlands elsewhere (U.S. EPA and USACE, 1990). (Activities with small impacts on wetlands, however, are often covered by a nationwide permit, which exempts the owner from having to obtain a permit [see Section 12.2]). The overall effect of wetland programs has been to sharply reduce the rate of coastal wetland loss (*e.g.*, Stockton and Richardson, 1987; Hardisky and Klemas, 1983) and to preserve an almost continuous strip of marshes, beaches, swamps, and mudflats along the U.S. coast. If sea-level rise accelerates, these coastal habitats could be lost by submergence and—in developed areas where shores are protected—by prevention of their natural inland migration (Reed *et al.*, 2008), unless future generations use technology to ensure that wetland surfaces rise as rapidly as the sea (NRC, 2007).

Current approaches would *not* protect wetlands for future generations if sea level rises beyond the ability of wetlands to accrete, which is likely for most of Chesapeake Bay's wetlands if sea level rises 50 centimeters (cm) in the next century, and for most of the Mid-Atlantic if sea level rises 100 cm (see Figure 4.4).

Current federal statutes are designed to protect existing wetlands, but the totality of the nation's wetland protection program is the end result of decisions made by many actors. Federal programs discourage destruction of most *existing* coastal wetlands, but the federal government does little to allow tidal wetlands to migrate inland (Titus, 2000). North Carolina, Maryland, New Jersey, and New York own the tidal wetlands below Mean High Water; and Virginia, Delaware, and Pennsylvania have enough ownership interest under the Public Trust Doctrine to preserve them (Titus, 1998). However, most states give property owners a near-universal permit to protect property by preventing wetlands from migrating onto dry land. Farmers rarely erect shore protection structures, but homeowners usually do (Titus, 1998; NRC, 2007). Only a few coastal counties and states have decided to keep shorefront farms and forests undeveloped, (see Sections A1.D, A1.E, and A1.F in Appendix 1). Government agencies that hold land for conservation purposes are not purchasing the land or easements necessary to enable wetlands to migrate inland (Section 11.2.1 discusses private conservancies). In effect, the nation has decided to *save* its existing wetlands. Yet the overall impact of the decisions made by many different agencies is very likely to *eliminate* wetlands by blocking their landward migration as a rising sea erodes their outer boundaries.

Not only is the long-term success of wetland protection sensitive to sea-level rise, it is also sensitive to when people decide to prepare. The political and economic feasibility of allowing wetlands to take over a given parcel as sea level rises is much greater if appropriate policies are in place before that property is intensely developed. Many coastal lands are undeveloped today, but development continues. Deciding now that wetlands will have land available to migrate inland could protect more wetlands at a lower cost than deciding later (Titus, 1991). In some places, such policies might discourage development in areas onto which wetlands may be able to migrate. In other areas, development could occur with the understanding that eventually land will revert to nature if sea level rises enough to submerge it. As with beach nourishment, artificially elevating the surfaces of tidal wetlands would not always require a lead-time of several decades;

but developing technologies to elevate the wetlands, and determining whether and where they are appropriate, could take decades. Finally, in some areas, the natural vertical accretion (build-up) of tidal wetlands is impaired by human activities, such as water flow management, development that alters drainage patterns, and beach nourishment and inlet modification, which thwarts barrier island overwash. In those areas, restoring natural processes before the wetlands are lost is more effective than artificially re-creating them (U.S. EPA, 1995; U.S. EPA and USACE, 1990; Kruczynski, 1990).

Although the long-term success of the nation's efforts to protect wetlands is sensitive to sea-level rise, most of the individual decisions that ultimately determine whether wetlands can migrate inland depend on factors that are not sensitive to sea-level rise. The desire of bay-front homeowners to keep their homes is strong, and unlikely to diminish even with a significant acceleration of sea-level rise[33]. State governments must balance the public interest in tidal wetlands against the well-founded expectations of coastal property owners that they will not have to yield their property. Only a few states (none in the Mid-Atlantic) have decided in favor of the wetlands (see Section 11.2.1). Local government decisions regarding land use reflect many interests. Objectives such as near-term tax revenues (often by seasonal residents who make relatively few demands for services) and a reluctance to undermine the economic interests of landowners and commercial establishments are not especially sensitive to rising sea level.

[33] See Weggel *et al.* (1989), Titus *et al.* (1991), and NRC (2007) for an examination of costs and options for estuarine shore protection.

Today's decentralized decision-making process seems to protect existing coastal wetlands reasonably well at the current rate of sea-level rise; however, it will not enable wetlands to migrate inland as sea-level rise continues or accelerates. A large-scale landward migration of coastal wetlands is very unlikely to occur in most of the Mid-Atlantic unless a conscious decision is made for such a migration by a level of government with authority to do so. Tools for facilitating a landward migration include coastal setbacks, density restrictions, rolling easements, vegetation buffers, and building design standards (see Sections 6.1.2 and A1.D, and A1.F in Appendix 1 for further details).

## 10.4 SHORE PROTECTION

The case for anticipating sea-level rise as part of efforts to prevent erosion and flooding has not been as strong as the case for wetland protection. Less lead time is required for shore protection than for a planned retreat and wetland migration (NRC, 1987). Dikes, seawalls, bulkheads, and revetments can each be built within a few years. Beach nourishment is an incremental periodic activity; if the sea rises more than expected, communities can add more sand.

The U.S. Army Corps of Engineers (USACE) has not evaluated whether sea-level rise will ultimately require fundamental changes in shore protection; such changes do not appear to be urgent. Since the early 1990s, USACE has recommended robust strategies: "Feasibility studies should consider which designs are most appropriate for a range of possible future rates of rise. Strategies that would be appropriate for the entire range of uncertainty should receive preference over those that would be optimal for a particular rate of rise but unsuccessful for other possible outcomes" (USACE, 2000a). To date, this guidance has not significantly altered USACE's approach to shore protection. Nevertheless, there is some question as to whether continued beach nourishment would be sustainable in the future if the rate of sea-level rise accelerates. It may be possible to double or triple the rate at which USACE nourishes beaches and to elevate the land surfaces of barrier islands 50 to 100 cm, and thereby enable land surfaces to keep pace with rising sea level in the next century. Yet continuing such a practice indefinitely would eventually leave back-barrier bays much deeper than today (see Chapter 5), with unknown consequences for the environment and the barrier islands themselves. Similarly, it may be possible to build a low bulkhead along mainland shores as sea level rises 50 to 100 cm; however, it could be more challenging to build a tall dike along the same shore because it would block waterfront views, require continual pumping, and expose people behind the dike to the risk of flooding should that dike fail (Titus, 1990).

## 10.5 LONG-LIVED STRUCTURES: SHOULD WE PLAN NOW OR LATER?

The fact that eventually a landowner will either hold back the sea or allow it to inundate a particular parcel of land does not, by itself, imply that the owner must respond today. A community that will not need a dike until the sea rises 50 to 100 cm has little reason to build that dike today. Nevertheless, if the land where the dike would eventually be constructed is vacant now, the prospect of future sea-level rise might be a good reason to leave that land vacant. A homeowner whose house will be inundated (or eroded) in 30 to 50 years has little reason to move the house back today, but if it is damaged by fire or storms, it might be advisable to rebuild the house on a higher (or more inland) part of the lot to provide the rebuilt structure a longer lifetime.

Whether one must be concerned about long-term sea-level rise ultimately depends on the lead time of the response options and on the costs and benefits of acting now *versus* acting later. A fundamental premise of cost-benefit analysis is that resources not yet deployed can be invested profitably in another activity and yield a return on investment. Delaying the response is economically efficient if the most effective response can be delayed with little or no additional cost, which is the case with most engineering responses to sea-level rise. For a given level of protection, dikes, seawalls, beach nourishment, and elevating structures and roadways are unlikely to cost more in the future than they cost today (USACE, 2000b, 2007). Moreover, these approaches can be implemented within the course of a few years. If shore protection is the primary approach to sea-level rise, responding now may not be necessary, with two exceptions.

The first exception could be called the "retrofit penalty" for failure to think long-term. It may be far cheaper to design for rising sea level in the initial design of a new (or rebuilt) road or drainage system than to modify it later because modifying it later requires the facility, in effect, to be built twice. For example, in a particular watershed in Charleston, South Carolina, if sea level rises 30 cm (1 ft), the planned drainage system would fail and need to be rebuilt, but it would only cost an extra 5 percent to initially design the system for a 30-cm rise (Titus *et al.*, 1987). Similarly, bridges are often designed to last for 100 years, and although roads are paved every 10 to 20 years, the location of a road may stay the same for centuries. Thus, choices made today about the location and design of transportation infrastructures can have a large impact on the feasibility and cost of accommodating rising sea level in the future (TRB, 2008). The design and location of a house is yet another example. If a house is designed to be movable, it can be relocated away from the shore; but non-moveable houses, such as a brick house on a slab foundation, could be more problematic. Similarly, the cost of building a house 10 meters (m) farther from the shore may be minor if the lot is large enough, whereas the cost of moving it back 10 m could be substantial (U.S. EPA, 1989).

The second exception concerns the incidental benefits of acting sooner. If a dike is not needed until the sea rises 0.5 m, because at that point a 100-year storm would flood the streets with 1 m of water, the decision to not build the dike today implicitly accepts the 0.5 m of water that such a storm would provide today. If a dike is built now, it would stop this smaller flood as well as protect from the larger flood that will eventually occur. This reasoning was instrumental in leading the British to build the Thames River Barrier, which protects London. Some people argued that this expensive structure was too costly given the small risk of London flooding, but rising sea level implied that such a structure would eventually have to be built. Hence, the Greater London Council decided to build it during the 1970s (Gilbert and Horner, 1984). As expected, the barrier closed 88 times to prevent flooding between 1983 and 2005 (Lavery and Donovan 2005).

While most engineering responses can be delayed with little penalty, failure to consider sea-level rise when making land-use decisions could be costly. Once an area is developed, the cost of vacating it as the sea rises is much greater than that cost would have been if the area was not developed. This does not mean that eventual inundation should automatically result in placing land off-limits to development. Even if a home has to be torn down 30 to 50 years hence, it might still be worth building. In some coastal areas where demand for beach access is great and land values are higher than the value of the structures, rentals may recover the cost of home construction in less than a decade. However, once an area is developed, it is unlikely to be abandoned unless either the eventual abandonment was part of the original construction plan, or the owners can not afford to hold back the sea. Therefore, the most effective way to preserve natural shores is to make such a decision before an area is developed. Because the coast is being developed today, a failure to deal with this issue now is, in effect, a decision to allow the loss of wetlands and bay beaches along most areas where development takes place.

Many options can be delayed, because the benefits of preparing for sea-level rise would still accrue later. Delaying action decreases the present value of the cost of acting and may make it easier to tailor the response to what is actually necessary. Yet delay can also increase the likelihood that people do not prepare until it is too late. One way to address this dilemma is to consider the lead times associated with particular types of adaptation (IPCC CZMG, 1992; O'Callahan, 1994). Emergency beach nourishment and bulkheads along estuarine shores can be implemented in less than a year. Large-scale beach nourishment generally takes a few years. Major engineering projects to protect London and the Netherlands took a few decades to plan, gain consensus, and construct (*e.g.*, Gilbert and Horner, 1984). To minimize the cost of abandoning an area, land use planning requires a lead time of 50 to 100 years (Titus, 1991, 1998).

## 10.6 DECISIONS BY COASTAL PROPERTY OWNERS ON ELEVATING HOMES

People are increasingly elevating homes to reduce the risk of flooding during severe storms and, in very low-lying areas, people are also elevating their yards. The cost of elevating even a small wood-frame cottage on a block foundation is likely to be $15,000 to $20,000; larger houses cost proportionately more (Jones *et al*., 2006; FEMA, 1998). If it is necessary to drill pilings, the cost is higher because the house must be moved to the side and then moved back onto the pilings. If elevating the home prevents its subsequent destruction within a few decades, it will have been worthwhile. At a 5 percent discount rate, for example, it is worth investing 25 percent of the value of a structure to avoid a guaranteed loss 28 years later[34]. In areas where complete destruction is unlikely, people sometimes elevate homes to obtain lower insurance rates and to avoid the risk of water damages to walls and furniture. The decision to elevate involves other factors, both positive and negative, including better views of the water, increased storage and/or parking spaces, and greater difficulty for the elderly or disabled to enter their homes. Rising sea level can also be a motivating factor when an owner is uncertain about whether the current risks justify elevating the house, because rising water levels would

[34] *i.e.*, \$25 invested today would be worth \$25 x $(1.05)^{28}$ = \$98 twenty eight years hence. Therefore, it is better to invest \$25 today than to face a certain loss of \$100 28 years hence (see glossary for definition of discount rate).

eventually make it necessary to elevate it (unless there is a good chance that the home will be rebuilt or replaced before it is flooded).

In cases where a new home is being constructed, or an existing home is elevated for reasons unrelated to sea-level rise (such as a realization of the risk of flooding), rising sea level would justify a higher floor elevation that would otherwise be the case. For example, elevating a $200,000 home on pilings to 30cm above the base flood elevation when the home is built would increase the construction cost by approximately $500-1000 more than building the home at the base flood elevation (Jones *et al*., 2006). Yet a 30 cm rise in sea level would increase the actuarial annual flood insurance premium by more than $2000 if the home was not elevated the extra 30 cm (NFIP, 2008).

## 10.7 FLOODPLAIN MANAGEMENT

The Federal Emergency Management Agency (FEMA) works with state and local governments on a wide array of activities that are potentially sensitive to rising sea level, including floodplain mapping, floodplain regulations, flood insurance rates, and the various hazard mitigation activities that often take place in the aftermath of a serious storm. Although the outcomes of these activities are clearly sensitive to sea-level rise, previous assessments have focused on coastal erosion rather than on sea-level rise. Because implications of sea-level rise and long-term erosion overlap in many cases, previous efforts provide insights on cases where the risks of future sea-level rise may warrant changing the way things are done today.

### 10.7.1 Floodplain Regulations

The flood insurance program requires new or substantially rebuilt structures in the coastal floodplain to have the first floor above the base flood elevation, *i.e.*, 100-year flood level. (see Chapter 9). The program vests considerable discretion in local officials to tailor specific requirements to local conditions, or to enact regulations that are more stringent than FEMA's minimum requirements. Several communities have decided to require floor levels to be 30 cm (or more) above the base flood elevation (*e.g.*, Township of Long Beach, 2008; Town of Ocean City, 1999; see also Box A1.5 in Appendix 1). In some cases, past or future sea-level rise has been cited as one of the justifications for doing so (Cape Cod Commission, 2002). There is considerable variation in both the costs and benefits of designing buildings to accommodate future sea-level rise. If local governments believe that property owners need an incentive to optimally address sea-level rise, they can require more stringent (*i.e.*, higher) floor elevations. A possible reason for requiring higher floor elevations in anticipation of sea-level rise (rather than allowing the owner to decide) is that, under the current structure of the program, the increased risk from sea-level rise does not lead to proportionately higher insurance rates (see Section 10.7.3.1) (although rates can rise for other reasons).

### 10.7.2 Floodplain Mapping

Local jurisdictions have pointed out (see Box A1.6 in Appendix 1) that requiring floor elevations above the base flood elevation to prepare for sea level rise can create a disparity between property inside and outside the existing 100-year floodplain.

Unless floodplain mapping also takes sea-level rise into account, a building in the current floodplain would have to be higher than adjacent buildings on higher ground just outside the floodplain (see Figure 10.5). Thus, the ability of local officials to voluntarily prepare for rising sea level is somewhat constrained by the lack of floodplain mapping that takes sea-level rise into account. Incorporating sea-level rise into floodplain maps would be a low-regrets activity, because it is relatively inexpensive and would enable local officials to modify requirements where appropriate.

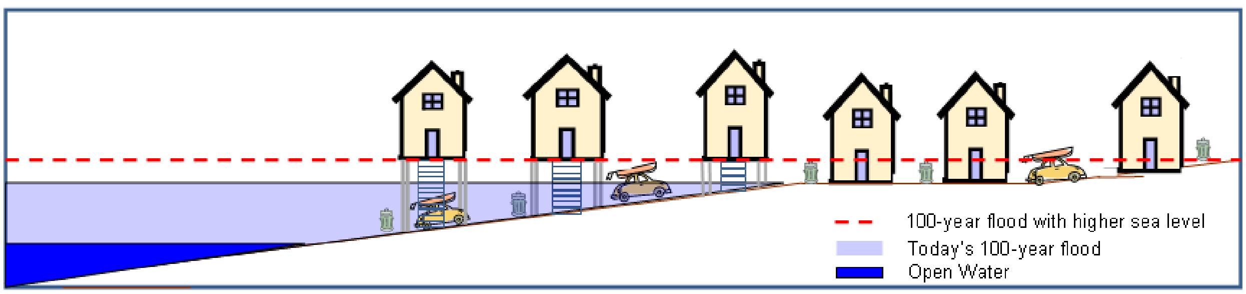


**Figure 10.5** Rationale for incorporating sea-level rise into floodplain mapping**.** In this figure, the (left) three houses in the existing floodplain have first floor elevations about 80 centimeters (cm) above the level of the 100-year storm, to account for a projected 50-cm rise in sea level and the standard requirement for floors to be 30 cm above the base flood elevation. The (right) three homes outside of the regulated floodplain are exempt from the requirement. Actual floods, however, do not comply with floodplain regulations. A 100-year storm on top of the higher sea level would thus flood the buildings to the right which are outside of today's floodplain, while the regulated buildings would escape the flooding. This potential disparity led the city of Baltimore to suggest that floodplain mapping should account for sea level rise as part of any process to increase the freeboard requirement (see Box A1.7, Section A1.F in Appendix 1).

### 10.7.3 Federal Flood Insurance Rates

The available reports on the impacts of rising sea level or shoreline retreat on federal flood insurance have generally examined one of two questions:

- What is the risk to the financial integrity of the flood insurance program?
- Does the program discourage policyholders from preparing for sea-level rise by shielding them from the consequences of increased risk?

No assessment has found that sea-level rise threatens the federal program's financial integrity. A 1991 report to Congress by FEMA, for example, concluded that there was little need to change the Flood Insurance Program because rates would be adjusted as sea level rises and flood maps are revised (FEMA, 1991). Nevertheless, the current rate structure can discourage some policyholders from preparing for increases in flood risks caused by sea-level rise, shore erosion, and other environmental changes. For new and rebuilt homes, the greater risks from sea-level rise cause a roughly proportionate increase in flood insurance premiums. For existing homes, however, the greater risks from sea-level rise cause premiums to rise much less than proportionately, and measures taken to reduce vulnerability to sea-level rise do not necessarily cause rates to decline.

Flood insurance policies can be broadly divided into actuarial and subsidized. "Actuarial" means that the rates are designed to cover the expected costs; "subsidized" means that the rates are designed to be less than the cost, with the government making up the difference. Most of the subsidized policies apply to "pre-FIRM" construction, that is, homes that were built before the Flood Insurance Rate Map (FIRM) was adopted for a given locality[35]; and most actuarial policies are for post-FIRM construction. Nevertheless, there are also a few small classes of subsidized policies for post-FIRM construction; and some owners of pre-FIRM homes pay actuarial rates. The following subsections discuss these two broad categories in turn.

### 10.7.3.1 Actuarial (Post-FIRM) Policies

[35] Flood Insurance Rate Maps display the flood hazards of particular locations for purposes of setting flood insurance rates. The maps do not show flood insurance rates (see Chapter 9 for additional details).

Flood Insurance Rate Maps show various hazard zones, such as V (wave velocity) Zone, A (stillwater flooding during a 100-year storm) Zone and the "shaded X Zone"[36] (stillwater flooding during a 500-year storm) (see Chapter 9). These zones are used as classes for setting rates. The post-FIRM classes pay actuarial rates. For example, the total premiums by all post-FIRM policyholders in the A Zone equals FEMA's estimate of the claims and administrative costs for the A Zone[37]. Hypothetically, if sea-level rise were to double flood damage claims in the A Zone, then flood insurance premiums would double (ignoring administrative costs)[38]. Therefore, the impact of sea-level rise on post-FIRM policy holders would not threaten the program's financial integrity under the current rate structure.

The rate structure can, however, insulate property owners from the effects of sea-level rise, removing the market signal[39] that might otherwise induce a homeowner to prepare or respond to sea-level rise. Although shoreline erosion and rising sea level increase the expected flood damages of a given home, the increased risk to a specific property does not cause the rate on that specific property to rise. Unless a home is substantially

[36] The shaded X Zone was formerly known as the B Zone.
[37] Owners of pre-FIRM homes can also pay the actuarial rate, if it is less than the subsidized rate.
[38] The National Flood Insurance Program (NFIP) modifies flood insurance rates every year based on the annual "Actuarial Rate Review". Rates can either be increased, decreased, or stay the same, for any given flood insurance class. The rates for post-FIRM policies are adjusted based on the risk involved and accepted actuarial principals. As part of this rate adjustment, hydrologic models are used to estimate loss exposure in flood-prone areas. These models are rerun every year using the latest hydrologic data available. As such, the models incorporate the retrospective effects of sea level rise. The rates for pre-FIRM (subsidized) structures are also modified every year based in part on a determination of what is known as the "Historical Average Loss Year". The goal of the NFIP is for subsidized policyholders to pay premiums that are sufficient, when combined with the premium paid by actuarially priced (post-FIRM) policyholders, to provide the NFIP sufficient revenue to pay losses associated with the historical average loss year.
[39] In economics, "market signal" refers to information passes indirectly or unintentionally between participants in a market. For example, higher flood insurance rates convey the information that a property is viewed as being riskier than previously thought.

changed, its assumed risk is grandfathered[40], that is, FEMA assumes that the risk has not increased when calculating the flood insurance rate (*e.g.*, NFIP, 2007; Heinz Center, 2000)[41]. Because the entire class pays an actuarial rate, the grandfathering causes a "cross-subsidy" between new or rebuilt homes and the older grandfathered homes.

Grandfathering can discourage property owners from either anticipating or responding to sea-level rise. If anticipated risk is likely to increase, for example, by about a factor of 10 and a total loss would occur eventually (*e.g.*, a home on an eroding shore), grandfathering the assumed risk may allow the policy holder to secure compensation for a total loss at a small fraction of the cost of that loss. For instance, a $250,000 home built to base flood elevation in the A Zone would typically pay about $900 per year (NFIP, 2008); but if shore erosion left the property in the V Zone, the annual rate would rise to more than $10,000 (NFIP, 2008)[42], if the property was not grandfathered. Under such circumstances, the $9,000 difference in eventual insurance premiums might be enough of a subsidy to encourage owners to build in locations more hazardous than where they might have otherwise built had they anticipated that they would bear the entire risk (*cf.*

[40] Under the NFIP grandfathering policy, whenever FEMA revises the flood risk maps used to calculate the premium for specific homes, a policy holder can choose between the new map and the old map, whichever results in the lower rate (NFIP, 2007).

[41] Although rates for individual policies may be grandfathered, rates for the entire A or V Zone (or any flood zone) can still increase each year up to a maximum of 10 percent; therefore a grandfathered policy may still see annual rate increases. For example, a post-FIRM structure might be originally constructed in an A Zone at 30 cm (1 ft) above base flood elevation. If shore erosion, sea-level rise, or a revised mapping procedure leads to a new map that shows the same property to be in the V Zone and 60 cm (2 ft) below base flood elevation, the policy holder can continue to pay as if the home was 30 cm above base flood elevation in the A Zone. However, the entire class of A Zone rates could still increase as a result of annual class-wide rate adjustments based on the annual "Actuarial Rate Review". Those class-wide increases could be caused by long-term erosion, greater flooding from sea-level rise, increased storm severity, higher reconstruction or administrative costs, or any other factors that increase the cost of paying claims by policyholders.

[42] This calculation assumes a storm-wave height adjustment of 90 cm and no sea-level rise (see NFIP, 2008).

Heinz Center, 2000). For homes built in the A Zone, the effect of grandfathering is less, but still potentially significant (see Figure 10.6).

Grandfathering can also remove the incentive to respond as sea level rises. Consider a home in the A Zone that is originally 30 cm (about 1 ft) above the base flood elevation. If sea level rises 30 to 90 cm (almost 1 to 3 ft), then the actuarial rates would typically rise by approximately two to ten times the original amount (NFIP, 2008), but because of grandfathering, the owners would continue to pay the same premium. Therefore, if the owner were to elevate the home 30 to 90 cm, the insurance premium would not decline because the rate already assumes that the home is 30 cm above the flood level (see the bottom four panels of Figure 10.6).

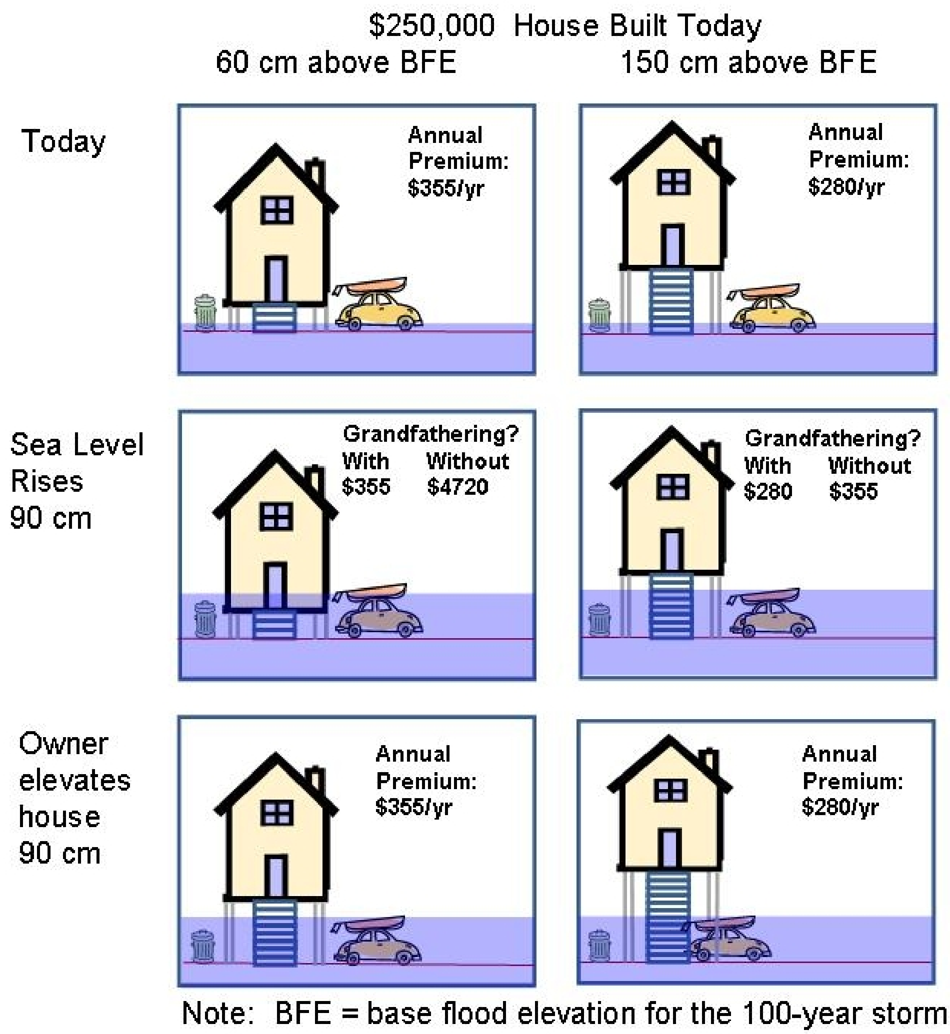


**Figure 10.6** Impact of grandfathering and floor elevation on flood insurance rates in the A Zone as sea level rises. Without grandfathering, a 90-centimeter (cm) rise in sea level would increase the flood insurance rate from $355 to $4720, for a home built 60 cm above today's 100-year flood elevation (left column); if the home is built 150 cm above the 100-year flood, sea level rise increases the rate from $280 to $355. Elevating the house 90 cm after sea level rise lowers the rate to what it had been originally, Thus, if the 90 cm rise is expected during the owner's planning horizon, there would be a significant incentive to either build the house higher or elevate it later. With grandfathering, however, sea-level rise does not increase the rate and elevating the home later does not reduce the rate. Thus, grandfathering reduces the incentive to anticipate sea level rise or react to it after the fact.
*Caveat*: The numerical example is based on rates published in NFIP (2008), Table 3B, and does not include the impact of the annual changes in the rate structure. Such rate changes would complicate the numerical illustration, but would not fundamentally alter the incentives illustrated, because the annual rate changes are across-the-board within a given class. For example, if rates increased by 50 percent by the time sea level rises 90 cm, then all of the premiums shown in the bottom four boxes would rise 50 percent.

The importance of grandfathering is sensitive to the rate of sea-level rise. At the current rate of sea-level rise (3 mm per year), most homes would be rebuilt (and thus lose the grandfathering benefit) before the 100 to 300 years it takes for the sea to rise 30 to 90 cm. By contrast, if sea level rises 1 cm per year, this effect would only take 30 to 90 years—and many coastal homes survive that long.

Previous assessments have examined this issue (although they were focused on shoreline erosion from all causes, rather than from sea-level rise). The National Academy of Sciences (NAS) has recommended that the Flood Insurance Program create mechanisms to ensure that insurance rates reflect the increased risks caused by long-term coastal erosion (NAS, 1990). NAS pointed out that Congress has explicitly included storm-related erosion as part of the damages covered by flood insurance (42 U.S.C. §4121), and that FEMA's regulations (44 CFR Part 65.1) have already defined special "erosion zones", which consider storm-related erosion (NAS, 1990)[43]. A FEMA-supported report to Congress by The Heinz Center (2000) and a theme issue in the *Journal of Coastal Research* (Crowell and Leatherman, 1999) also concluded that, because of existing long-term shore erosion, there can be a substantial disparity between actual risk and insurance rates.

[43] Note that: (1) the NFIP insures against damages caused by flood-related-erosion; (2) the probability of flood-related erosion is considered in defining the landward limit of V Zones; and (3) flood insurance rates in the V Zone are generally much higher than A Zone rates. Part of the reason for this is consideration of the potential for flood-related erosion.

Would sea-level rise justify changing the current approach? Two possible alternatives would be to (1) shorten the period during which the assumed risk is kept fixed so that rates can respond to risk and property owners can respond, or (2) lengthen the duration of the insurance policy to the period of time between risk calculations, that is, instead of basing rates on the risk when the house is built, which tends to increasingly underestimate the risk, base the rate on an estimate of the average risk over the lifetime of the structure, using “erosion-hazard mapping” with assumed rates of sea-level rise, shore erosion, and structure lifetime. Both of these alternatives address changing risk by estimating risk over a time horizon equal to the period of time between risk recalculation. The erosion-hazard mapping approach has received considerable attention; the Heinz Center study also recommended that Congress authorize erosion-hazard mapping. Although Congress has not provided FEMA with authority to base rates on erosion hazard mapping, FEMA has raised rates in the V Zone by 10 percent per year (during most years) as a way of anticipating the increased flood damages resulting from the long-term erosion that The Heinz Center evaluated (Crowell *et al.*, 2007).

The Heinz Center study and recent FEMA efforts have assumed current rates of sea-level rise. FEMA has not investigated whether accelerated sea-level rise would increase the disparity between risks and insurance rates enough to institute additional changes in rates; nor has it investigated the option of relaxing the grandfathering policy so that premiums on existing homes rise in proportion to the increasing risk. Nevertheless, the Government Accountability Office (2007) recently recommended that FEMA analyze the potential long-term implications of climate change for the National Flood Insurance Program

(NFIP). FEMA agreed to undertake such a study (Buckley, 2007) and initiated it in September 2008 (Department of Homeland Security, 2008).

#### 10.7.3.2 Pre-FIRM and other Subsidized Policies

Since the 1970s, the flood insurance program has provided a subsidized rate for homes built before the program was implemented, that is, before the release of the first flood insurance rate map for a given location (Hayes *et al.*, 2006). The premium on a $100,000 home, for example, is generally $650 and $1170 for the A and V Zones, respectively—regardless of how far above or below the base flood elevation the structure may be (NFIP, 2008). Not all pre-FIRM homes obtain the subsidized policy. The subsidized rate is currently greater than the actuarial rate in the A and V Zones for homes that are at least 30 cm and 60 cm, respectively, above the base flood elevation (NFIP, 2008). But the subsidy is substantial for homes that are below the base flood elevation. Homes built in the V Zone between 1975 and 1981 also receive a subsidized rate; which is about $1500 for a $100,000 home built at the base flood elevation (NFIP, 2008).

Does sea-level rise justify changing the rate structure for subsidized policies? Economics alone can not answer that question because the subsidies are part of the program for reasons other than risk management and economic efficiency, such as the original objective of providing communities with an incentive to join the NFIP and the policy goal of not pricing people out of their homes (Hayes *et al.*, 2006). Moreover, the implications depend in large measure on whether the NFIP responds to increased damages from sea-level rise by increasing premiums or the subsidy, a question that rests on decisions that have not yet been made. Sea-level rise elevates the base flood elevation; and the subsidized rate is the same regardless of how far below the base flood elevation a home is built. Considering those factors alone, sea-level rise increases expected damages, but not the subsidized rate. However, the NFIP sets the subsidized rates to ensure that the entire program covers its costs during the average non-catastrophic year[44]. Therefore, if total damages (which include inland flooding) rise by the same proportion as damages to subsidized policies, the subsidized portion would stay the same as sea level rises.

FEMA has not yet quantified whether climate change is likely to increase total damages by a greater or smaller proportion than the increase due to sea-level rise. Without an assessment of whether the subsidy would increase or decrease, it would be premature to conclude that sea-level rise warrants a change in FEMA's rate structure. Nevertheless, sea-level rise is unlikely to threaten the financial integrity of the flood insurance program as long as subsidized rates are set high enough to cover claims during all but the catastrophic loss years, and Congress continues to provide the program with the necessary funds during the catastrophic years. Because the pre-FIRM subsidies only apply to homes that are several decades old, they do not encourage hazardous construction. As with grandfathering, the subsidized rate discourages owners of homes below the base flood elevation from elevating or otherwise reducing the risk to their homes as sea level rises, because the premium is already as low as it would be from elevating the home to the base flood elevation[45].

[44] The year 2005 (Hurricanes Katrina, Rita, and Wilma) is excluded from such calculations.
[45] Pre-FIRM owners of homes a few feet *below* the base flood elevation could achieve modest saving by elevating homes a few feet *above* the base flood elevation; but those savings are small compared to the savings available to the owner of a post-FIRM home at the same elevation relative to base flood elevation.

The practical importance of the pre-FIRM subsidy is sensitive to the future rate of sea-level rise. Today, pre-FIRM policies account for 24 percent of all policies (Hayes *et al.*, 2006). However, that fraction is declining (Crowell *et al.*, 2007) because development continues in coastal floodplains, and because the total number of homes eligible for pre-FIRM rates is declining, as homes built before the 1970s are lost to fire and storms, enlarged, or replaced with larger homes. A substantial rise in sea level over the next few decades would affect a large class of subsidized policy holders by the year 2100. Nevertheless, the portion of pre-FIRM houses is likely to be very small, unless there is a shift in the factors that have caused people to replace small cottages with larger houses and higher-density development (see Section 12.2.3).

Two other classes, which together account for 2 percent of policies, also provide subsidized rates. The A99 Zone consists of areas that are currently in the A Zone, but for which structural flood protection such as dikes are at least 50 percent complete. Policyholders in such areas pay a rate as if the structural protection was already complete (and successful). The AR Zone presents the opposite situation: locations where structural protection has been decertified. Provided that the structures are on a schedule for being rebuilt, the rates are set to the rate that applies to the X Zone or the pre-FIRM subsidized rate, whichever is less. As sea level rises, the magnitude of these subsidies may increase, both because the base flood elevations (without the protection) will be higher, and because more coastal lands may be protected with dikes and other structural measures. Unlike the pre-FIRM subsidies, the A99 and AR Zone subsidies may encourage construction in hazardous areas; but unlike other subsidies, the A99 and AR Zone subsidies encourage protection measures that reduce hazards.

### 10.7.4 Post-Disaster Hazard Mitigation

If a coastal community is ultimately going to be abandoned to the rising sea, a major rebuilding effort in the current location may be less useful than expending the same resources to rebuild the community on higher ground. On the other hand, if the community plans to remain in its current location despite the increasing costs of shore protection, then it is important for people to understand that commitment. Unless property owners know which path the community is following, they do not know whether to reinvest. Moreover, if the community is going to stay in its current location, owners need to know whether their land will be protected with a dike or if land surfaces are likely to be elevated over time (see Section 12.3).

## 10.8 CONCLUSIONS

The need to prepare for rising sea level depends on the length of time over which the decision will continue to have consequences; how sensitive those consequences are to sea level; how rapidly the sea is expected to rise and the magnitude of uncertainty over that expectation; the decision maker's risk tolerance; and the implications of deferring a decision to prepare. Considering sea-level rise may be important if the decision has outcomes over a long period of time and concerns an activity that is sensitive to sea level, especially if what can be done to prepare today would not be feasible later. Those making decisions with outcomes over a short period of time concerning activities that are not sensitive to sea level probably need not consider sea-level rise, especially if preparing later is as effective as preparing today.

Instances where the existing literature provides an economic rationale for preparing for accelerated sea-level rise include:

- *Coastal wetland protection*. Wetlands and the success of wetland-protection efforts are almost certainly sensitive enough to sea-level rise to warrant examination of some changes in coastal wetland protection efforts, assuming that the objective is to ensure that most estuaries that have extensive wetlands today will continue to have tidal wetlands in the future. Coastal wetlands are sensitive to rising sea level, and many of the possible measures needed to ensure their survival as sea level rises are least disruptive with a lead time of several decades. Changes in management approaches would likely involve consideration of options at various levels of authority.
- *Coastal infrastructure*. Whether it is beneficial to design coastal infrastructure to anticipate rising sea level depends on the ratio of the incremental cost of designing for a higher sea level now, compared with the retrofit cost of modifying the structure later. No general statement is possible because this ratio varies and relatively few engineering assessments of the question have been published. However, because the cost of analyzing this question is very small compared with the retrofit cost, it is likely that most long-lived infrastructure in the coastal zone is sufficiently sensitive to rising sea level to warrant an analysis of the comparative cost of designing for higher water levels now and retrofitting later.

- *Building along the coast.* In general, the economics of coastal development alone does not currently appear to be sufficiently sensitive to sea-level rise to avoid construction in coastal areas. Land values are so high that development is often economic even if a home is certain to be lost within a few decades. The optimal location and elevation of new homes may be sensitive to how rapidly sea level is expected to rise.
- *Shoreline planning.* A wide array of measures for adapting to rising sea level depend on whether a given area will be elevated, protected with structures, or abandoned to the rising sea. Several studies have shown that in those cases where the shores will retreat and structures will be removed, the economic cost will be much less if people plan for that retreat. The human toll of an unplanned abandonment may be much greater than if people gradually relocate when it is convenient to do so. Conversely, people may be reluctant to invest in an area without some assurance that lands will not be lost to the sea. Therefore, long-term shoreline planning is generally justified and will save more than it costs; the more the sea ultimately rises, the greater the value of that planning.
- *Rolling easements, density restrictions, and coastal setbacks.* Several studies have shown that, in those cases where the shores will retreat and structures will be removed, the economic cost will be much less if people plan for that retreat. Along estuaries, a retreat in developed areas rarely occurs and thus is likely to only occur if land remains lightly developed. It is very likely that options such as rolling easements, density restrictions, coastal setbacks, and vegetative buffers, would increase the ability of wetlands and beaches to migrate inland.

- *Floodplain management: Consideration of reflecting actual risk in flood insurance rates.* Economists and other commentators generally agree that insurance works best when the premiums reflect the actual risk. Even without considering the possibility of accelerated sea-level rise, the National Academy of Sciences (NAS, 1990) and a FEMA-supported study by The Heinz Center (2000) concluded and recommended to Congress that insurance rates should reflect the changing risks resulting from coastal erosion. Rising sea level increases the potential disparity between rates and risks of storm-related flooding.

## CHAPTER 10 REFERENCES

* Indicates non-peer reviewed literature; available upon request

**Arrow**, K.J. and A.C. Fisher, 1974: Environmental preservation, uncertainty, and irreversibility. *Quarterly Journal of Economics,* **88(1)**, 312-319.

**Bin**, O., T. Crawford, J.B. Kruse, and C.E. Landry, 2008: Viewscapes and flood hazard: coastal housing market response to amenities and risk. *Land Economics,* **84(3)**, 434-448.

**Buckley**, M., 2007: Testimony of Michael Buckley, U.S. Senate Committee on Homeland Security and Government Affairs, April 19, 2007.

**Cape Cod Commission**, 2002: *Model Floodplain District Bylaw*. Cape Cod Commission, Barnstable, MA, § 06.1. <http://www.capecodcommission.org/bylaws/floodplain.html>

**CCSP** (Climate Change Science Program), 2006: *Coastal Elevations and Sensitivity to Sea level Rise Final Prospectus for Synthesis and Assessment Product 4.1*. United States Climate Change Science Program, Washington, DC, 19 pp.

**Congressional Research Service**, 2003: *Benefit-Cost Analysis and the Discount Rate for the Corps of Engineers' Water Resource Projects: Theory and Practice*. [Power, K. (analyst)]. RL31976. Congressional Research Service, Washington, DC, 26 pp.

**Cordes**, J.J. and A.M.J. Yezer, 1998: In harm's way: does federal spending on beach enhancement and protection induce excessive development in coastal areas? *Land Economics*, **74(1)**, 128-145.

**Crowell**, M. and S.P. Leatherman (eds.), 1999: Coastal erosion mapping and management. *Journal of Coastal Research*, **Special Issue 28**, 196 pp.

**Crowell**, M., E. Hirsch, and T.L. Hayes, 2007: Improving FEMA's coastal risk assessment through the National Flood Insurance Program: an historical overview. *Marine Technology Society Journal*, **41(1)**, 18-27.

**Dasgupta**, P., 2007: Commentary: The Stern Review's economics of climate change. *National Institute Economic Review*, **199**, 4-7.

**Department of Homeland Security**, 2008: *Impact of Climate Change on the National Flood Insurance Program*. Solicitation number HSFEHQ-08-R-0082. <http://www.FedBizOpps.gov>

**Evatt**, D.S., 1999: *National Flood Insurance Program: Issues Assessment*. Federal Emergency Management Agency, Washington, DC, 123 pp.

**Evatt**, D.S., 2000: Does the national flood insurance program drive floodplain development? *Journal of Insurance Regulation*, **18(4)**, 497-523.

**FEMA** (Federal Emergency Management Agency), 1991: *Projected Impact of Relative Sea Level Rise on the National Flood Insurance Program.* FEMA Flood Insurance Administration, Washington DC, 72 pp.

**FEMA** (Federal Emergency Management Agency), 1998: *Homeowner's guide to retrofitting: six ways to protect your house from flooding*. FEMA 312. Federal Emergency Management Agency, Washington, DC, 177 pp.

**Fisher**, A.C. and W.M. Hanemann, 1987: Quasi-option value: some misconceptions dispelled. *Journal of Environmental Economics and Management*, **14(2)**, 183-190.

**Frankhauser**, S., J.B. Smith, and R.S.J. Tol, 1999: Weathering climate change: Some simple rules to guide adaptation decisions. *Ecological Economics,* **30(1)**, 67-78.

**Freeman**, A.M., 2003: *The Measurement of Environmental and Resource Values: Theory and Methods*. Resources for the Future, Washington, DC, 2nd edition, 491 pp.

**Gilbert**, S. and R. Horner, 1984: *The Thames Barrier*. Thomas Telford, London, 182 pp.

**GAO (**General Accounting Office), 1982: *National Flood Insurance: Marginal Impact on Floodplain Development, Administrative Improvements Needed*. Report to the

Subcommittee on Consumer Affairs, Committee on Banking, Housing, and Urban Affairs, U.S. Senate. General Accounting Office, Washington, DC, 59 pp.

**GAO** (Government Accountability Office), 2007: *Climate Change: Financial Risks to Federal and Private Insurers in Coming Decades are Potentially Significant*. GAO-07-285. Government Accountability Office, Washington DC, 68 pp. <http://www.gao.gov/new.items/d07285.pdf>

**Ha-Duong**, M., 1998: Quasi-option value and climate policy choices. *Energy Economics*, **20(5/6)**, 599-620.

**Hardisky**, M.A. and V. Klemas, 1983: Tidal wetlands natural and human-made change from 1973 to 1979 in Delaware: mapping techniques and results. *Environmental Management*, **7(4)**, 339-344.

**Hayes**, T.L., D.R. Spafford, and J.P. Boone, 2006: *Actuarial Rate Review*. National Flood Insurance Program, Washington DC, 34 pp. <http://www.fema.gov/library/viewRecord.do?id=2363>

**Heinz Center**, 2000: *Evaluation of Erosion Hazards.* The H. John Heinz III Center for Science, Economics, and the Environment, Washington, DC, 252 pp. <http://www.heinzctr.org/publications.shtml#erosionhazards>

**Hoffman**, J.S., D. Keyes, and J.G. Titus, 1983: *Projecting Future Sea Level Rise; Methodology, Estimates to the Year 2100, and Research Needs*. U.S. Environmental Protection Agency, Washington DC, 121 pp.

**IPCC** (Intergovernmental Panel on Climate Change), 1990: *Strategies for Adaptation to Sea Level Rise*. Report of the Coastal Zone Management Subgroup, IPCC Response Strategies Working Group. Ministry of Transport and Public Works, The Hague, the Netherlands, 131 pp. <http://yosemite.epa.gov/OAR%5Cglobalwarming.nsf/content/ResourceCenterPublicationsSLRAdaption.html>

**IPCC** (Intergovernmental Panel on Climate Change), 1996: *Climate Change 1995: The Science of Climate Change.* Contribution of Working Group I to the Second Assessment Report of the Intergovernmental Panel on Climate Change. [Houghton, J.J., L.G. Meiro Filho, B.A. Callander, N. Harris, A. Kattenberg, and K. Maskell (eds.)]. Cambridge University Press, Cambridge, UK, and New York, 572 pp.

**IPCC** (Intergovernmental Panel on Climate Change), 2001: *Climate Change 2001: The Scientific Basis.* Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change [Houghton, J.T., Y. Ding, D.J. Griggs, M. Noguer, P.J. van der Linden, X. Dai, K. Maskell, and C.A. Johnston (eds.)]. Cambridge University Press, Cambridge, UK, and New York, 881 pp.

**IPCC** (Intergovernmental Panel on Climate Change), 2007: *Climate Change 2007: The Physical Science Basis.* Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor, and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, UK, and New York, 996 pp.

**IPCC CZMS** (Intergovernmental Panel on Climate Change Coastal Zone Management Subgroup), 1992: *Global Climate Change and the Rising Challenge of the Sea.* IPCC Response Strategies Working Group, Rijkswaterstaat, The Hague, the Netherlands.

**IPET** (Interagency Performance Evaluation Task Force), 2006: *Performance Evaluation of the New Orleans and Southeast Louisiana Hurricane Protection System*. U.S. Army Corps of Engineers, Washington, DC. <https://ipet.wes.army.mil/>

**Jones**, C.P., W.L. Coulbourne, J. Marshall, and S.M. Roger Jr., 2006: *Evaluation of the National Flood Insurance Program's Building Standards.* American Institutes for Research, Washington, DC.

**Kentula**, M., 1999: *Restoration, creation, and recovery of wetlands: wetland restoration and creation.* In: *National Water Summary on Wetland* Resources. [Fretwell, J.D., R.J. Redman, and J.S. Williams (eds.)]. United States Geological Survey water supply paper 2425. U.S. Geological Survey, [Reston, VA]. <http://water.usgs.gov/nwsum/WSP2425/restoration.html>

**Klein**, R.J.T., R.J. Nicholls, and N. Mimura, 1999: Coastal adaptation to climate change: Can the IPCC technical guidelines be applied? *Mitigation and Adaptation Strategies for Global Change,* **4(3-4)**, 239-252.

**Kruczynski**, W.L., 1990: Options to be considered in preparation and evaluation of mitigation plans. In: *Wetland Creation and Restoration: The Status of the Science* [Kusler, J.A. and M.E. Kentula (eds.)]. Island Press, Washington, DC, 594 pp.

**Kussler**, J., 2006: *Common Questions: Wetland Restoration, Creation, and Enhancement*. Association of State Wetland Managerss, Berne, NY, 15 pp. <http://www.aswm.org/propub/20_restoration_6_26_06.pdf>

**Lavery**, S. and B. Donovan, 2005: Flood risk management in the Thames Estuary looking ahead 100 years. *Philosophical Transactions of the Royal Society A*, **363**, 1455-1474.

**Landry**, C.E., A.G. Keeler, and W. Kriesel, 2003: An economic evaluation of beach erosion management alternatives. *Marine Resource Economics*, **18(2)**, 105-127.

**Leatherman**, S., 1997: *Flood Insurance Availability in Coastal Areas: The Role It Plays in Encouraging Development Decisions*. Federal Emergency Management Agency, Washington, DC.

***Matcha vs Maddox***, 711 S.W.2d 95, 100 (Tex. App. 1986).

**Miller**, H.C., 1981: *Coastal Flood Hazards and the National Flood Insurance Program*. Federal Emergency Management Agency, Washington, DC, 50 pp.

**NAS** (National Academy of Sciences), 1990: *Managing Coastal Erosion*. National Academy Press, Washington, DC, 182 pp.

**NFIP** (National Flood Insurance Program), 2007: *Fact Sheet: Saving on Flood Insurance Information about the NFIP's Grandfathering Rule.* FEMA, [Washington DC], 2 pp. <http://www.fema.gov/library/viewRecord.do?id=2497>

**NFIP** (National Flood Insurance Program)**,** 2008: *Flood Insurance Manual*. Federal Emergency Management Agency, Washington DC.

**Nordhaus**, W.D., 2007a: Critical assumptions in the Stern Review on Climate Change. *Science*, **317(5835)**, 201-202.

**Nordhaus**, W.D., 2007b: A review of the Stern Review on *The Economics of Climate Change*. *Journal of Economic Literature*, **45**, 686-702.

**NRC** (National Research Council), 1983: *Changing Climate*. National Academy Press, Washington, DC, 496 pp.

**NRC** (National Research Council), 1987: *Responding to Changes in Sea Level: Engineering Implications*. National Academy Press, Washington, DC, 148 pp.

**NRC** (National Research Council), 2007: *Mitigating Shore Erosion Along Sheltered Coasts*. National Academies Press, Washington, DC, 174 pp.

**O'Callahan**, J. (ed.), 1994: *Global Climate Change and the Rising Challenge of the Sea.* Proceedings of the third IPCC CZMS workshop, Isla de Margarita, Venezuela, 9–13 March 1992. National Oceanic and Atmospheric Administration, Silver Spring, MD, 691 pp.

**OMB** (Office of Management and Budget), 1992: *Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs.* OMB Circular A-94, Office of Management and Budget, Washington, DC. <http://www.whitehouse.gov/omb/circulars/a094/a094.html>

**OTA** (Office of Technology Assessment), 1993: *Preparing for an Uncertain Climate – Volume I.* OTA-O-567. U.S. Government Printing Office, Washington, DC, 359 pp.

**Reed**, D.J., D. Bishara, D. Cahoon, J. Donnelly, M. Kearney, A. Kolker, L. Leonard, R.A. Orson, and J.C. Stevenson, 2008: Site-specific scenarios for wetlands accretion as sea level rises in the mid-Atlantic region. Section 2.1 in: *Background Documents Supporting Climate Change Science Program Synthesis and Assessment Product 4.1: Coastal Elevations and Sensitivity to Sea Level Rise* [Titus, J.G. and E.M. Strange (eds.)]. EPA 430R07004. U.S. Environmental Protection Agency, Washington, DC, pp. 134-174. <http://epa.gov/climatechange/effects/coastal/background.html>

**Samuelson**, P.A. and W.D. Nordhaus, 1989: *Economics.* McGraw-Hill, New York, 13th ed., 1013 pp.

**Scheraga**, J.D. and A.E. Grambsch, 1998: Risks, opportunities, and adaptation to climate change. *Climate Research,* **11(1)**, 85-95.

**Shilling**, J.D., C.E. Sirmans, and J.D. Benjamin, 1989: Flood insurance, wealth redistribution, and urban property values. *Journal of Urban Economics*, **26(1)**, 43-53.

**Stockton**, M.B. and C.J. Richardson, 1987: Wetland development trends in coastal North Carolina, USA, from 1970 to 1984. *Environmental Management,* **11(5)**, 649-657.

**Titus**, J.G., 1990: Greenhouse effect, sea level rise, and barrier islands: case study of Long Beach Island, New Jersey. *Coastal Management,* **18(1)**, 65-90.

**Titus**, J.G., 1991: Greenhouse effect and coastal wetland policy: how Americans could abandon an area the size of Massachusetts at minimum cost. *Environmental Management*, **15(1)**, 39-58.

**Titus**, J.G., 1998: Rising seas, coastal erosion and the takings clause: how to save wetlands and beaches without hurting property owners. *Maryland Law Review*, **57(4)**, 1279-1299.

**Titus**, J.G., 2000: Does the U.S. government realize that the sea is rising? How to restructure federal programs so that wetlands and beaches survive. *Golden Gate Law Review,* **30(4)**, 717–786.

**Titus**, J.G., 2005: Does shoreline armoring violate the Clean Water Act? Rolling easements, shoreline planning, and other responses to sea level rise. In: *America's Changing Coasts: Private Rights and Public Trust* [Whitelaw, D.M. and G.R. Visgilio (eds.)]. Edward Elgar Publishing, Cheltenham, UK, and Northampton, MA, 248 pp.

**Titus**, J.G. and V. Narayanan, 1996: The risk of sea level rise. *Climatic Change,* **33(2),** 151-212.

**Titus**, J.G. and J. Wang, 2008: Maps of lands close to sea level along the middle Atlantic coast of the United States: an elevation data set to use while waiting for LIDAR. Section 1.1 in: *Background Documents Supporting Climate Change Science Program Synthesis and Assessment Product 4.1: Coastal Elevations and Sensitivity to Sea Level Rise* [Titus, J.G. and E.M. Strange (eds.)]. EPA 430R07004. U.S. Environmental Protection Agency, Washington, DC, pp. 2-44.

**Titus**, J.G., C.Y. Kuo, M.J. Gibbs, T.B. LaRoche, M.K. Webb, and J.O. Waddell, 1987: Greenhouse effect, sea level rise, and coastal drainage systems. *Journal of Water Resources Planning and Management,* **113(2)**, 216-227.

**Titus**, J.G., R.A. Park, S.P. Leatherman, J.R. Weggel, M.S. Greene, P.W. Mansel, S. Brown, G. Gaunt, M. Treehan, and G. Yohe, 1991: Greenhouse effect and sea level rise: the cost of holding back the sea. *Coastal Management*, **19(2)**, 171-204.

**Town of Ocean City, Maryland**, 1999: City Code § 38-71.

**Township of Long Beach (New Jersey)**, 2008: *Important Flood Information.* <http://longbeachtownship.com/importantfloofing information.html>

**TRB** (Transportation Research Board), 2008: *Potential Impacts of Climate Change on U.S. Transportation*. National Academies Press, Washington, DC, 234 pp.

**USACE** (U.S. Army Corps of Engineers), 2000a: *Planning Guidance Notebook: Appendix E: Civil Works Missions and Evaluation Procedures*. ER 1105-2-100. U. S. Army Corps of Engineers, Washington, DC, 310 pp. <http://www.usace.army.mil/publications/eng-regs/er1105-2-100/toc.htm>

**USACE** (U.S. Army Corps of Engineers), 2000b: *Civil Works Construction Cost Index System (CWCCIS)*. EM 1110-2-1304. U.S. Army Corps of Engineers, Washington, DC. For updated CWCCIS data tables, see: <http://www.usace.army.mil/publications/eng-manuals/em1110-2-1304/toc.htm>

**USACE** (U.S. Army Corps of Engineers), 2007: *Civil Works Construction Cost Index System (CWCCIS): Revised Tables*. EM 1110-2-1304. U.S. Army Corps of Engineers, Washington, DC. Tables revised 30 September 2007. <http://www.usace.army.mil/publications/eng-manuals/em1110-2-1304/toc.htm>

**U.S. EPA** (Environmental Protection Agency), 1989: *Potential Effects of Global Climate Change on the United States: Report to Congress*. EPA 230-05-89-050. U.S. Environmental Protection Agency, Washington, DC.

**U.S. EPA** (Environmental Protection Agency), 1995: Federal guidance for the establishment, use and operation of mitigation banks. *Federal Register*, **60(228)**, 58605-58614.

**U.S. EPA** (Environmental Protection Agency), 2000: *Guidelines for Preparing Economic Analyses*. EPA 240-R-00-003. EPA Office of the Administrator, [Washington DC]. <http://yosemite.epa.gov/ee/epa/eed.nsf/webpages/Guidelines.html>

**U.S. EPA** (Environmental Protection Agency) **& USACE** (U.S. Army Corps of Engineers), 1990: Mitigation Memorandum of Agreement 4 (Feb. 6, 1990).

**Weggel**, J.R., S. Brown, J.C. Escajadillo, P. Breen, and E. Doheyn, 1989: The cost of defending developed shorelines along sheltered waters of the United States from a two meter rise in mean sea level. In: *Potential Effects of Global Climate Change on the United States. Appendix: B, Sea Level Rise*. U.S. Environmental Protection Agency, Washington, DC, pp. 3-1 to 3-90. <http://epa.gov/climatechange/effects/coastal/appB.html>

**Yohe**, G., J.E. Neumann, P. Marshall, and H. Ameden, 1996: The economic cost of greenhouse-induced sea-level rise for developed property in the United States. *Climatic Change*, **32(4)**, 387-410.

# Chapter 11. Ongoing Adaptation

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## KEY FINDINGS

- Most organizations are not yet taking specific measures to prepare for rising sea level. Recently, however, many public and private organizations have begun to assess possible response options.
- Most of the specific measures that have been taken to prepare for accelerated sea-level rise have had the purpose of reducing the long-term adverse environmental impacts.

## 11.1 INTRODUCTION

Preparing for the consequences of rising sea level has been the exception rather than the rule in the Mid-Atlantic. Nevertheless, many coastal decision makers are now starting to consider how to prepare.

This Chapter examines those cases in which organizations are taking specific measures to consciously anticipate the effects of sea-level rise. It does not include most cases in which an organization has authorized a study but not yet acted upon the study. Nor does it catalogue the activities undertaken for other reasons that might also help to prepare for accelerated sea-level rise[46], or cases where people responded to sea level rise after the fact (see Box 11.1). Finally, it only considers measures that had been taken by March

[46] Appendix 1, however, does examine such policies.

2008. Important measures may have been adopted between the time this Product was drafted and its final publication.

## 11.2 ADAPTATION FOR ENVIRONMENTAL PURPOSES

Many organizations that manage land for environmental purposes are starting to anticipate the effects of sea-level rise. Outside the Mid-Atlantic, some environmental regulators have also begun to address this issue.

### 11.2.1 Environmental Regulators

Organizations that regulate land use for environmental purposes generally have not implemented adaptation options to address the prospects of accelerated sea-level rise. Congress has given neither the U.S. Army Corps of Engineers (USACE) nor the U.S. Environmental Protection Agency (EPA) a mandate to modify existing wetland regulations to address rising sea level; nor have those agencies developed approaches for moving ahead without such a mandate (see Chapter 12). For more than a decade, Maine[47], Massachusetts[48], and Rhode Island[49] have had statutes or regulations that restrict shoreline armoring to enable dunes or wetlands to migrate inland with an explicit recognition of rising sea level (Titus, 1998).

None of the eight mid-Atlantic states require landowners to allow wetlands to migrate inland as sea level rises (NOAA, 2006). During 2008, however, the prospect of losing ecosystems to a rising sea prompted Maryland to enact the "Living Shoreline Protection

[47] 06-096 Code of Maine Rules §355(3)(B)(1) (2007).
[48] 310 Code Mass Regulations §10.30 (2005).
[49] Rhode Island Coastal Resource Management Program §210.3(B)(4) and §300.7(D) (2007).

Act"[50]. Under the Act, the Department of Environment will designate certain areas as appropriate for structural shoreline measures (*e.g.*, bulkheads and revetments). Outside of those areas, only nonstructural measures (*e.g.*, marsh creation, beach nourishment) will be allowed unless the property owner can demonstrate that nonstructural measures are infeasible[51]. The new statute does not ensure that wetlands are able to migrate inland; but Maryland's coastal land use statute limits development to one home per 8.09 hectares (ha) (20 acres [ac]) in most rural areas within 305 meters (m) (1000 feet [ft]) of the shore (see Section A1.F.2.1 in Appendix 1). Although that statute was enacted in the 1980s to prevent deterioration of water quality, the state now considers it to be part of its sea-level rise adaptation strategy.[52]

### 11.2.2 Environmental Land Managers

Those who manage land for environmental purposes have taken some initial steps to address rising sea level.

*Federal Land Managers*

The Department of Interior (Secretarial Order 3226, 2001) requires climate change impacts be taken into account in planning and decision making (Scarlett, 2007). The National Park Service has worked with the United States Geological Survey (USGS) to examine coastal vulnerability on 25 of its coastal parks (Pendleton *et al*., 2004). The U.S. Fish and Wildlife Service is incorporating studies of climate change impacts, including sea-level rise, in their Comprehensive Conservation Plans where relevant.

[50] Maryland House Bill 273-2008.
[51] MD Code Environment §16-201(c)
[52] Maryland House Bill 273-2008.

The National Park Service and the U.S. Fish and Wildlife Service each have large coastal landholdings that could erode or become submerged as sea level rises (Thieler *et al*., 2002; Pendleton *et al*., 2004). Neither organization has an explicit policy concerning sea-level rise, but both are starting to consider their options. The National Park Service generally favors allowing natural shoreline processes to continue (NPS Management Policies §4.8.1), which allows ecosystems to migrate inland as sea level rises (see Figure 11.1). In 1999, this policy led the Park Service to move the Cape Hatteras Lighthouse inland 900 m (2900 ft) at a cost of $12 million. The U.S. Fish and Wildlife Service generally allows dry land to convert to wetlands, but it is not necessarily passive as rising sea level erodes the seaward boundary of tidal wetlands. Blackwater National Wildlife Refuge, for example, has used dredge material to rebuild wetlands on a pilot basis, and is exploring options to recreate about 3000 ha (7000 ac) of marsh (see Figure 11.2). Neither agency has made land purchases or easements to enable parks and refuges to migrate inland.

**Figure 11.1** Allowing beaches and wetlands to migrate inland in the national parks (a) Cape Hatteras National Seashore. (June 2002) Until it was relocated inland in 1999, the lighthouse was just to the right of the stone groin in the foreground. (b) Jamestown Island ,Virginia (September 2004). As sea level rises, marshes have taken over land that was cultivated during colonial times.

**Figure 11.2** Responding to sea-level rise at Blackwater National Wildlife Refuge, Maryland (October 2002). (a) Marsh Deterioration. (b) Marsh Creation. The dredge fills the area between the stakes to create land at an elevation flooded by the tides, after which marsh grasses are planted

*The Nature Conservancy*

The Nature Conservancy (TNC) is the largest private holder of conservation lands in the Mid-Atlantic. It has declared as a matter of policy that it is trying to anticipate rising sea level and climate change. Its initial focus has been to preserve ecosystems on the Pamlico-Albemarle Peninsula, such as those shown in Figure 11.3 (Pearsall and Poulter, 2005; TNC, 2007). Options under consideration include: plugging canals to prevent subsidence-inducing saltwater intrusion, planting cypress trees where pocosins have been converted to dry land, and planting brackish marsh grasses in areas likely to be inundated. As part of that project, TNC undertook the first attempt by a private conservancy to purchase rolling easements (although none were purchased). TNC owns the majority of barrier islands along the Delmarva Peninsula, but none of the mainland shore. TNC is starting to examine whether preserving the ecosystems as sea level rises would be best facilitated by purchasing land on the mainland side as well, to ensure sediment sources for the extensive mudflats so that they might keep pace with rising sea level.

State conservation managers have not yet started to prepare for rising sea level (NOAA, 2006). But at least one state (Maryland) is starting to refine a plan for conservation that would consider the impact of rising sea level.

**Figure 11.3** The Albemarle Sound environment that the Nature Conservancy seeks to preserve as sea level rises (June 2002). (a) Nature Conservancy lands on Roanoke Island depict effects of rising sea level. Tidal wetlands (juncas and spartina patens) have taken over most of the area depicted as sea level rises, but a stand of trees remains in a small area of higher ground. (b) Mouth of the Roanoke River, North Carolina. Cypress trees germinate on dry land; but continue to grow in the water after the land is eroded or submerged by rising sea level.

## 11.3 OTHER ADAPTATION OPTIONS BEING CONSIDERED BY FEDERAL, STATE, AND LOCAL GOVERNMENTS

### 11.3.1 Federal Government

Federal researchers have been examining how best to adapt to sea-level rise for the last few decades, and those charged with implementing programs are also now beginning to consider implications and options. The longstanding assessment programs will enable federal agencies to respond more rapidly and reasonably if and when policy decisions are made to begin preparing for the consequences of rising sea level.

The Coastal Zone Management Act is a typical example. The Act encourages states to protect wetlands, minimize vulnerability to flood and erosion hazards, and improve public access to the coast. Since 1990, the Act has included sea-level rise in the list of hazards that states should address. This congressional mandate has induced NOAA to fund state-specific studies of the implications of sea-level rise, and encouraged states to periodically designate specific staff to keep track of the issue. But it has not yet altered what people actually do along the coast (New York, 2006; New Jersey, 2006; Pennsylvania, 2006; Delaware, 2005; Maryland, 2006; Virginia, 2006; North Carolina, 2006). Titus (2000) and CSO (2007) have examined ways to facilitate implementation of this statutory provision, such as federal guidance and/or additional interagency coordination. Similarly, the U.S. Army Corps of Engineers (USACE) has formally included the prospect of rising sea level for at least a decade in its planning guidance for the last decade (USACE, 2000), and staff have sometimes evaluated the implications for specific decisions (*e.g.*, Knuuti, 2002). But the prospect of accelerated sea-level rise has not caused a major change in the agency's overall approach to wetland permits and shore protection (see Chapter 12).

### 11.3.2 State Government

Maryland has considered the implications of sea-level rise in some decisions over the last few decades. Rising sea level was one reason that the state gave for changing its shore protection strategy at Ocean City from groins to beach nourishment (see Section A1.F in Appendix 1). Using NOAA funds, the state later developed a preliminary strategy for dealing with sea-level rise. As part of that strategy, the state also recently obtained a complete lidar dataset of coastal elevations.

Delaware officials have long considered how best to modify infrastructure as sea level rises along Delaware Bay, although they have not put together a comprehensive strategy (CCSP, 2007).

Because of the vulnerability of the New Jersey coast to flooding, shoreline erosion, and wetland loss (see Figure 11.4), the coastal management staff of the New Jersey Department of Environmental Protection have been guided by a long-term perspective on coastal processes, including the impacts of sea-level rise. So far, neither Delaware nor New Jersey has specifically altered their activities because of projected sea-level rise. Nevertheless, New Jersey is currently undertaking an assessment that may enable it to factor rising sea level into its strategy for preserving the Delaware Estuary (CCSP, 2007).

In the last two years, states have become increasingly interested in addressing the implications of rising sea level. A bill in the New York General Assembly would create a sea-level rise task force (Bill AO9002 2007-2008 Regular Session). Maryland and

Virginia have climate change task forces that have focused on adapting to rising sea level. (For a comprehensive survey of what state governments are doing in response to rising sea level, see Coastal States Organization, 2007.)

**Figure 11.4** Vulnerability of New Jersey's coastal zone (a) Wetland fringe lacks room for wetland migration (Monmouth August 2003). (b) Low bay sides of barrier islands are vulnerable to even a modest storm surge. (Ship Bottom, September 2, 2006). (c) Gibbstown Levee and (d) associated tide gate protect lowlying areas of Greenwich Township (March 2003).

### 11.3.3 Local Government

A few local governments have considered the implications of rising sea level for roads, infrastructure, and floodplain management (see Boxes A1.4 and A1.6 in Appendix 1). New York City's plan for the year 2030 includes adapting to climate change (City of New York, 2008). The New York City Department of Environmental Protection is looking at ways to decrease the impacts of storm surge by building flood walls to protect critical infrastructure such as waste plants, and is also examining ways to prevent the sewer system from backing up more frequently as sea level rises (Rosenzweig *et al*., 2006). The city has also been investigating the possible construction of a major tidal flood gate across the Verizano Narrows to protect Manhattan (Velasquez-Manoff, 2006).

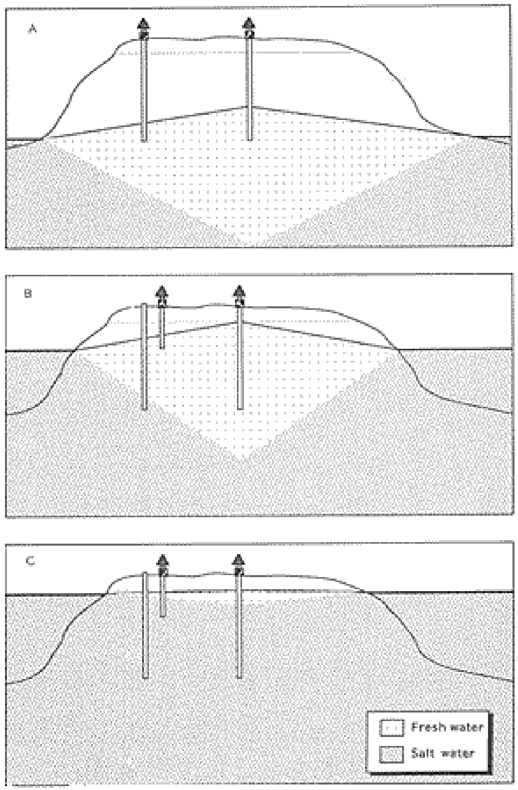
Outside of the Mid-Atlantic, Miami-Dade County in Florida has been studying its vulnerability to sea-level rise, including developing maps to indicate which areas are at greatest risk of inundation. The county is hardening facilities to better withstand hurricanes, monitoring the salt front, examining membrane technology for desalinating seawater, and creating a climate advisory task force to advise the county commission (Yoder, 2007).

**Box 11.1. Jamestown: An Historic Example of Retreat in Response to Sea Level Rise**

Established in 1607 along the James River, Jamestown was the capital of Virginia until 1699, when a fire destroyed the statehouse. Nevertheless, rising sea level was probably a contributing factor in the decision to move the capital to Williamsburg, because it was making the Jamestown peninsula less habitable than it had been during the previous century. Fresh water was scarce, especially during droughts (Blanton, 2000). The James River was brackish, so groundwater was the only reliable source of freshwater. But the low elevations on Jamestown limited the thickness of the freshwater table—especially during droughts. As Box Figure 11.1 shows, a 10 centimeter (cm) rise in sea level can reduce the thickness of the freshwater table by four meters on a low-lying island where the freshwater lens floats atop the salt water.

Rising sea level has continued to alter Jamestown. Two hundred years ago, the isthmus that connected the peninsula to the mainland eroded, creating Jamestown Island (Johnson and Hobbs, 1994). Shore erosion also threatened the location of the historic town itself, until a stone revetment was constructed (Johnson and Hobbs, 1994). As the sea rose, the shallow valleys between the ridges on the island became freshwater marsh, and then tidal marsh (Johnson and Hobbs, 1994). Maps from the seventeenth century show agriculture on lands that today are salt marsh. Having converted mainland to island, the rising sea will eventually convert the island to open water, unless the National Park Service continues to protect it from the rising water.

Other shorelines along Chesapeake Bay have also been retreating over the last four centuries. Several bay island fishing villages have had to relocate to the mainland as the islands on which they were located eroded away (Leatherman *et al*., 1995). Today, low-lying farms on the Eastern Shore are converting to marsh, while the marshes in wildlife refuges convert to open water.




**Box Figure 11.1** Impact of sea-level rise on an island freshwater table. *(*a) According to the Ghyben-Herzberg relation, the freshwater table extends below sea level 40 cm for every 1 cm by which it extends above sea level (Ghyve [1889] and Herzberg [1901], as cited by Freeze and Cherry [1979]). (b) For islands with substantial elevation, a 1-m rise in sea level simply shifts the entire water table up 1 meter, and the only problem is that a few wells will have to be replaced with shallower wells. (c) However, for very low islands the water table cannot rise because of runoff, evaporation, and transpiration. A rise in sea level would thus narrow the water table by 40 cm for every 1 cm that the sea level rises, effectively eliminating groundwater supplies for the lowest islands.

# CHAPTER 11 REFERENCES

* Indicates non-peer reviewed literature; available upon request

**Blanton**, D.B., 2000: Drought as a factor in the Jamestown colony, 1607-1612. *Historical Archaeology*, **34(4)**, 74-81.

**CCSP** (Climate Change Science Program), 2007: *Stakeholder Meetings Final Report: Climate Change Science Program Synthesis and Assessment Product 4.1*. [National Oceanic and Atmospheric Administration, Silver Spring, MD], 81 pp. <http://www.climatescience.gov/Library/sap/sap4-1/stakeholdermeetingfinalreport.pdf>

**City of New York**, 2008: *PlaNYC*: *A Greater, Greener New York*. City of New York, New York, 155 pp. <http://home2.nyc.gov/html/planyc2030/downloads/pdf/full_report.pdf>

**CSO (**Coastal States Organization), 2007: *The Role of Coastal Zone Management Programs in Adaptation to Climate Change*. Coastal States Organization, Washington, DC, 27 pp. <http://www.coastalstates.org/documents/CSO%20Climate%20Change%20Final%20Report.pdf>

**Delaware** (Delaware Coastal Programs), 2005: *Delaware Coastal Programs: Section 309 Enhancement Assessment*. Department of Natural Resources and Environmental Control, Dover, DE, 46 pp.

**Freeze**, R.A. and J.A. Cherry, 1979: *Groundwater*. Prentice-Hall, Englewood Cliffs, NJ, 604 pp.

**Johnson**, G.H. and C.H. Hobbs, 1994: The geological history of Jamestown Island. *Jamestown Archaeological Assessment Newsletter*, **1(2/3)**, 9-11.

**Knuuti**, K., 2002: Planning for sea level rise: U.S. Army Corps of Engineers policy. In: *Solutions to Coastal Disasters '02* [Ewing, L. and L. Wallendorf (eds.)]. American Society of Civil Engineers, Reston, VA, pp. 549-560.

* **Leatherman**, S.P., R. Chalfont, E.C. Pendleton, and T.L. McCandless, 1995: *Vanishing Lands: Sea Level, Society, and Chesapeake Bay*. Laboratory of Coastal Research, University of Maryland, College Park, and Department of the Interior, [Washington, DC], 47 pp.

**Maryland**, 2006: *CZMA, Secton 309 Assessment and Strategy*. Maryland Department of Natural Resources, Coastal Zone Management Division, Watershed Services Center, Annapolis, 70 pp. <http://www.dnr.state.md.us/bay/czm/assessment.html>

**New Jersey**, 2006: *New Jersey Coastal Management Program: Assessment and Enhancement Strategy, FY2006-2010*. New Jersey Department of Environmental Protection Coastal Management Office, Trenton, 84 pp. <http://www.state.nj.us/dep/cmp/czm_309.html>

**New York**, 2006: *New York State Coastal Management Program: 309 Assessment and Strategies, July 1, 2006 through June 30, 2010*. Department of State, New York State, Albany, 98 pp.

**North Carolina**, 2006: *Assessment and Strategy of the North Carolina Coastal Management Program.* North Carolina Department of Environment and Natural Resources, Raleigh, 90pp.

**NOAA** (National Oceanic and Atmospheric Administration), 2006: Responses to Section 309 of the Coastal Zone Management Act. Coastal Zone Enhancement Program compiled by NOAA Office of Ocean and Coastal Resource Management, Silver Spring, MD. <http://coastalmanagement.noaa.gov/enhanc.html>

**Pearsall**, S.H., III, and B. Poulter, 2005: Adapting coastal lowlands to rising seas: a case study. In: *Principles of Conservation Biology* [Groom, M.J., G.K. Meffe, and C.R. Carroll (eds.)]. Sinauer Associates, Sunderland, MA, 3rd edition, pp. 366-370.

**Pendleton**, E.A., S.J. Williams, and E.R. Thieler, 2004: *Coastal Vulnerability Assessment of Assateague Island National Seashore (ASIS) to Sea-level Rise*. U.S. Geological Survey open-file report 2004-1020. U.S. Geological Survey, Reston, VA, 20 pp. <http://pubs.usgs.gov/of/2004/1020/>

**Pennsylvania**, 2006: Section 309 Assessment and Strategy: Pennsylvania's Coastal Resources Management Program. Pennsylvania Department of Environmental ProtectionWater Planning Office, Harrisburg, 69 pp. <http://www.dep.state.pa.us/river/docs/309_FINAL_June30_06.pdf>

**Rosenzweig**, C., D. Majors, M. Tults, and K. Demong, 2006: New York City Climate Change Task Force. In: *Adapting to Climate Change: Lessons for London.* Greater London Authority, London, pp. 150-153. <http://www.london.gov.uk/climatechangepartnership/>

* **Scarlett**, L., 2007: Testimony of P. Lynn Scarlett, Deputy Secretary Department of the Interior, before the House Appropriations Subcommittee on Interior, Environment and Related Agencies Regarding Climate Change. April 26, 2007.

**Thieler**, E.R., S.J. Williams, and R. Beavers, 2002: *Vulnerability of U.S. National Parks to Sea-Level Rise and Coastal Change*. U.S. Geological Survey fact sheet FS 095-02. [U.S. Geological Survey, Reston, VA], 2 pp. <http://pubs.usgs.gov/fs/fs095-02/>

**Titus**, J.G., 1998: Rising seas, coastal erosion, and the takings clause: how to save wetlands and beaches without hurting property owners. *Maryland Law Review,* **57(4)**, 1376-1378.

**Titus**, J.G., 2000: Does the US government realize that the sea is rising? How to restructure federal programs so that wetlands and beaches survive. *Golden Gate University Law Review,* **30(4)**, 717-778.

* **TNC** (The Nature Conservancy), 2007: *Save of the Week: Climate Change Action on North Carolina's Albemarle Peninsula*. The Nature Conservancy, Arlington, VA. <http://www.nature.org/success/art14181.html>

**USACE** (U.S. Army Corps of Engineers), 2000: *Planning Guidance Notebook Appendix E: Civil Works Missions and Evaluation Procedures*. Army Corps of Engineers document # ER 1105-2-100. Department of the Army, U. S. Army Corps of Engineers, Washington, DC, 310 pp. <http://www.usace.army.mil/publications/eng-regs/er1105-2-100/toc.htm>

* **Velasquez-Manoff**, M., 2006: How to keep New York afloat. *The Christian Science Monitor*, November 9, 2006, p. 13.

**Virginia**, 2006: *Virginia Coastal Zone Management Program: Section 309 Needs Assessment and Strategy*. Virginia Coastal Zone Management Program, Richmond, 104 pp. <http://www.deq.state.va.us/coastal/assess.html>

* **Yoder**, D., 2007: Miami Dade Water and Sewer Department presentation to American Water Works Association webcast, *Global Climate Impacts*, March 14, 2006.

# Chapter 12. Institutional Barriers

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## KEY FINDINGS

- Most coastal institutions were designed without considering sea-level rise.
- Some regulatory programs were created in order to respond to a demand for hard shoreline structures (*e.g.*, bulkheads) to hold the coast in a fixed location, and have generally not shifted to retreat or soft shore protection (*e.g.*, beach nourishment).
- The interdependence of decisions made by property owners and federal, state, and local governments creates an institutional inertia that currently impedes preparing for sea-level rise, as long as no decision has been made regarding whether particular locations will be protected or yielded to the rising sea.

## 12.1 INTRODUCTION

Chapter 10 described several categories of decisions where the risk of sea-level rise can justify doing things differently today. Chapter 11, however, suggested that only a few organizations have started to prepare for rising sea level since the 1980s when projections of accelerated sea-level rise first became widely available.

It takes time to respond to new problems. Most coastal institutions were designed before the 1980s. Therefore, land-use planning, infrastructure, home building, property lines, wetland protection, and flood insurance all were designed without considering the dynamic nature of the coast (see Chapters 6, 8, 9, 10). A common mindset is that sea level and shores are stable, or that if they are not then shores should be stabilized (NRC, 2007). Even when a particular institution has been designed to account for shifting shores, people are reluctant to give up real estate to the sea. Although scientific information can quickly change what people expect, it takes longer to change what people want.

Short-term thinking often prevails. The costs of planning for hazards like sea-level rise are apparent today, while the benefits may not occur during the tenure of current elected officials (Mileti, 1999). Local officials tend to be responsive to citizen concerns, and the public is generally less concerned about hazards and other long-term or low-probability events than about crime, housing, education, traffic, and other issues of day-to-day life (Mileti, 1999; Depoorter, 2006). Land-use and transportation planners generally have horizons of 20 to 25 years (TRB, 2008), while the effects of sea-level rise may emerge over a period of several decades. Although federal law requires transportation plans to have a time horizon of *at least* 20 years[53], some officials view that time horizon as the maximum (TRB, 2008). Uncertainty about future climate change is a logical reason to prepare for the range of uncertainty (see Chapter 10) but cognitive dissonance[54] can lead people to disregard the new information instead (Kunreuther *et al.,* 2004; Bradshaw and

[53] 23 U.S.C. §135(f)(1) (2008).

[54] Cognitive dissonance is a feeling of conflict or anxiety caused by holding two contradictory ideas simultaneously, especially when there is a discrepancy between one's beliefs or actions and information that contradicts those beliefs or actions. When confronted with information (*e.g.*, about risk) that contradicts one's pre-existing beliefs or self-image (*e.g.*, that they are acting reasonably), people often respond by discounting, denying, or ignoring the information (*e.g.*, Festinger [1957], Harmon-Jones and Mills, [1999]).

Borchers, 2000; Akerlof and Dickens, 1982). Some officials resist changing procedures unless they are provided guidance (TRB, 2008).

Finally, a phenomenon known as “moral hazard” can discourage people from preparing for long-term consequences. Moral hazard refers to a situation in which insurance or the expectation of a government bailout reduces someone’s incentive to prevent or decrease the risk of a disaster (Pauly, 1974). The political process tends to sympathize with those whose property is threatened, rather than allowing them to suffer the consequences of the risk they assumed when they bought the property (Burby, 2006). It can be hard to say “no” to someone whose home is threatened (Viscusi and Zeckhauser, 2006).

This Chapter explores some of the institutional barriers that discourage people and organizations from preparing for the consequences of rising sea level. “Institution” refers to governmental and nongovernmental organizations and the programs that they administer. “Institutional barriers” refer to characteristics of an institution that prevent actions from being taken. This discussion has two general themes. First, institutional *biases* are more common than actual *barriers*. For example, policies that encourage higher densities in the coastal zone may be barriers to wetland migration, but they improve the economics of shore protection. Such a policy might be viewed as creating a bias in favor of shore protection over wetland migration, but it is not really a barrier to adaptation from the perspective of a community that prefers protection anyway. A bias encourages one path over another; a barrier can block a particular path entirely.

Second, interrelationships between various decisions tend to reinforce institutional inertia For instance, omission of sea-level rise from a land-use plan may discourage infrastructure designers from preparing for the rise, and a federal regulatory preference for hard structures may prevent state officials from encouraging soft structures. Although inertia has slowed current acts to respond to the risk of sea-level rise, it could just as easily help to sustain momentum toward a response once key decision makers decide which path to follow.

The barriers and biases examined in this Chapter mostly concern governmental rather than private sector institutions. Private institutions do not always exhibit foresight. In fact, their limitations have helped motivate the creation of government flood insurance (Kunreuther *et al.*, 1978), wetland protection (Scodari, 1997), shore protection, and other government programs (Bator, 1958; Arrow, 1970). This Chapter omits an analysis of private institutions for two reasons. First, there is little literature available on private institutional barriers to preparing for sea-level rise. It is unclear whether this absence implies that the private barriers are less important, or simply that private organizations keep their affairs private. Second, the published literature provides no reason to expect that private institutions have important barriers different from those of public institutions. The duty of for-profit corporations to maximize shareholder wealth, for example, may prevent a business from giving up property to facilitate future environmental preservation as sea level rises. At first glance, this duty might appear to be a barrier to responding to sea-level rise, or at least a bias in favor of shore protection over retreat. Yet that same duty would lead a corporation to sell the property to an organization willing to offer a profitable price, or invest money for shore protection. Thus, the duty to maximize shareholder wealth is a bias in favor of profitable responses over money-losing responses, but not a barrier to preparing for sea level rise.

## 12.2 SOME SPECIFIC INSTITUTIONAL BARRIERS AND BIASES

Productive institutions are designed to accomplish a mission, and rules and procedures are designed to help accomplish those objectives. These rules and procedures are inherently biased toward achieving the mission, and against anything that thwarts the mission. By coincidence more than design, the rules and procedures may facilitate or thwart the ability of others to achieve other missions.

No catalogue of institutional biases in the coastal zone is available; but three biases have been the subject of substantial commentary: (1) shore protection *versus* retreat; (2) hard structures *versus* soft engineering solutions; and (3) coastal development *versus* preservation.

### 12.2.1 Shore Protection *versus* Retreat

Federal, state, local, and private institutions generally have a strong bias *favoring* shore protection over retreat in developed areas. Many institutions also have a bias *against* shore protection in undeveloped areas.

*U.S. Army Corps of Engineers (USACE) Civil Works***.** Congressional appropriations for shore protection in coastal communities generally provide funds for various engineering projects to limit erosion and flooding (see Figure 12.1). The planning guidance documents for USACE appear to provide the discretion to relocate or purchase homes if a policy of retreat is the locally preferred approach and is more cost-effective than shore protection (USACE, 2000). In part because the federal government generally pays for 65 percent of the initial cost[55], retreat is rarely the locally preferred option (Lead and Meiners, 2002; NRC, 2004). USACE's environmental policies discourage its Civil Works program from seriously considering projects to foster the landward migration of developed barrier islands (see *Wetland Protection* discussed further below). Finally, the general mission of this agency, its history (Lockhart and Morang, 2002), staff expertise, and funding preferences combine to make shore protection far more common than a retreat from the shore.

*State Shore Protection*. North Carolina, Virginia, Maryland, Delaware, and New Jersey all have significant state programs to support beach nourishment along the Atlantic Ocean (see Figure 12.1 and Sections A1.C.2, A1.E.2, and A1.G.4 in Appendix 1). Virginia, Maryland, Delaware, and New Jersey have also supported beach nourishment in residential areas along estuaries (see Figure 12.2). Some agencies in Maryland encourage private shore protection to avoid the environmental effects of shore erosion (see Section A1.F.2 in Appendix 1), and the state provides interest-free loans for up to 75 percent of the cost of nonstructural erosion control projects on private property (MD DNR, 2008). Although a Maryland guidance document for property owners favors retreat over shore protection structures (MD DNR, 2006), none of these states has a program to support a retreat in developed areas.

[55] 33 USC §2213.

**Figure 12.1** Recently nourished beach and artificially created dune in Surf City, New Jersey, with recent plantings of dune grass. (June 2007).

**Figure 12.2** Beach nourishment along estuaries. (a) The Department of Natural Resources provided an interest-free loan to private landowners for a combined breakwater and beach nourishment project to preserve the recreational beach and protect homes in Bay Ridge, Maryland (July 2008). (b) The Virginia Beach Board and Town of Colonial Beach nourished the public beach along the Potomac River for recreation and to protect the road and homes to the left (October 2002).

*FEMA Programs.* Some aspects of the National Flood Insurance Program (NFIP) encourage shore protection, while others encourage retreat. The Federal Emergency Management Agency (FEMA) requires local governments to ensure that new homes along the ocean are built on pilings sunk far enough into the ground so that the homes will remain standing even if the dunes and beach are largely washed out from under the house during a storm[56]. The requirement for construction on pilings can encourage larger homes; after a significant expense for pilings, people rarely build a small, inexpensive cottage. These larger homes provide a better economic justification for government-funded shore protection than the smaller homes.

Beaches recover to some extent after storms, but they frequently do not entirely recover. In the past, before homes were regularly built to withstand the 100-year storm, retreat from the shore often occurred after major storms (*i.e.*, people did not rebuild as far seaward as homes had been before the storm). Now, many homes can withstand storms, and the tendency is for emergency beach nourishment operations to protect oceanfront homes. A FEMA emergency assistance program often funds such nourishment in areas where the beach was nourished before the storm[57] (FEMA, 2007a). For example, Topsail Beach, North Carolina received over $1 million for emergency beach nourishment after Hurricane Ophelia in 2005, even though it is ineligible for USACE shore protection projects and flood insurance under the Coastal Barrier Resources Act (GAO, 2007a). In portions of Florida that receive frequent hurricanes, these projects are a significant

[56] 44 Code of Federal Regiulations §60.3(e)(4)
[57] 44 CFR §206.226(j)

portion of total beach nourishment (see Table 12.1). They have not yet been a major source of funding for beach nourishment in the Mid-Atlantic.

Several FEMA programs are either neutral or promote retreat. In the wake of Hurricane Floyd in 1999, one county in North Carolina used FEMA disaster funds to elevate structures, while an adjacent county used those funds to help people relocate rather than rebuild (see Section A1.G in Appendix 1.). Repetitively flooded homes have been eligible for relocation assistance under a number of programs. Because of FEMA's rate map grandfathering policy (see Section 10.7.3.1 in Chapter 10), a statutory cap on annual flood insurance rate increases, and limitations of the hazard mapping used to set rates, some properties have rates that are substantially less than the actuarial rate justified by the risk. As a result, relocation programs assist property owners and save the flood insurance program money by decreasing claims. From 1985 to 1995, the Upton-Jones Amendment to the National Flood Insurance Act helped fund the relocation of homes in imminent danger from erosion (Crowell *et al.*, 2007). FEMA's Severe Repetitive Loss Program is authorized to spend $80 million to purchase or elevate homes that have made either four separate claims or at least two claims totaling more than the value of the structure (FEMA, 2008a). Several other FEMA programs provide grants for reducing flood damages, which states and communities can use for relocating residents out of the flood plain, erecting flood protection structures, or flood-proofing homes (FEMA, 2008b, c, d, e).

**Table 12.1 Selected Beach Nourishment Projects in Florida Authorized by FEMA's Public Assistance Grant Program**

| Year | Location | Hurricane | Authorized Volume of Sand (cubic meters [d]) | Obligated Funds [a] (dollars) |
|---|---|---|---|---|
| 1987 | Jupiter Island | Floyd | 90,000 | 637,670 |
| 1999 | Jupiter Island | Irene | 48,500 | 343,101 |
| | | | 0 | |
| 2001 | Longboat Key | Gabrielle | 48,253 | 596,150 |
| 2001 | Collier County | Gabrielle | 37,800 | 452,881 |
| 2001 | Vanderbilt Beach | Gabrielle | 61,534 | 1,592,582 |
| 2001 | Vanderbilt Beach | Gabrielle | [b] | 738,821 |
| 2004 | Manasota Key/Knights Island | Charley *et al.*[c] | 115,700 | 2,272,521 |
| 2004 | Bonita Beach | Charley *et al.*[c] | 21,652 | 1,678,221 |
| 2004 | Lovers Key | Charley *et al.*[c] | 13,300 | 102,709 |
| 2004 | Lido Key | Charley *et al.*[c] | 67,600 | 2,319,322 |
| 2004 | Boca Raton | Frances | 297,572 | 3,313,688 |
| 2004 | Sabastian Inlet Recreation Area | Frances | 184,755 | 10,097,507 |
| 2004 | Hillsboro Beach | Frances | 83,444 | 1,947,228 |
| 2004 | Jupiter Island | Frances | 871,187 | 8,317,345 |
| 2004 | Pensacola Beach | Ivan | 2,500,000 | 11,069,943 |
| 2004 | Bay County | Ivan | 56,520 | 1,883,850 |
| 2005 | Pensacola Beach | Dennis | 400,000 | 2,338,248 |
| 2005 | Naples Beach | Katrina | 34,988 | 1,221,038 |
| 2005 | Pensacola Beach | Katrina | 482,000 | 4,141,019 |
| 2005 | Naples Beach | Wilma | 44,834 | 3,415,844 |
| 2005 | Longboat Key | Wilma | 66,272 | 1,093,011 |

Source: Federal Emergency Management Agency. 2008. "Project Worksheets Involving 'Beach Nourishment' Obligated Under FEMA's Public Assistance Grant Program: As of June 19, 2008."

a. For some projects, the figure may include costs other than placing sand into the beach system, such as reconstructing dunes and planting dune vegetation, as well as associated planning and engineering costs.

b Supplemental grant. Applicant lost original sand source and had to go 50 kilometers offshore to collect the sand being used. This increased the cost to $30.82 per cubic meter ($23.57 per cubic yard), compared with originally assumed cost of $10.80 per cubic meter ($8.25 per cubic yard).

c. Cumulative impact of the 2004 hurricanes Charley, Frances, Ivan, and Jeanne.

d. Converted from cubic yards, preserving significant digits from the original source, which varies by project.

Flood insurance rates are adjusted downward to reflect the reduced risk of flood damages if a dike or seawall decreases flood risks during a 100-year storm. Because rates are based on risk, this adjustment is not a bias toward shore protection, but rather a neutral reflection of actual risk.

*Wetland Protection.* The combination of federal and state regulatory programs to protect wetlands in the Mid-Atlantic strongly discourages development from advancing into the sea, by prohibiting or strongly discouraging the filling or diking of tidal wetlands for most purposes (see Chapter 9). Within the Mid-Atlantic, New York promotes the landward migration of tidal wetlands in some cases (see Section A1.A.2 in Appendix 1), and Maryland favors shore protection in some cases. The federal wetlands regulatory program has no policy on the question of retreat *versus* shore protection. Because the most compelling argument against estuarine shore protection is often the preservation of tidal ecosystems (*e.g.*, NRC, 2007), a neutral regulatory approach has left the strong demand for shore protection from property owners without an effective countervailing force for allowing wetlands to migrate (Titus 1998, 2000). Wetlands continue to migrate inland in many undeveloped areas (see Figure 12.3) but not in developed areas, which account for an increasing portion of the coast.

Neither federal nor most state regulations encourage developers to create buffers that might enable wetlands to migrate inland, nor do they encourage landward migration in developed areas (Titus, 2000). In fact, USACE has issued a nationwide permit for bulkheads and other erosion-control structures[58]. Titus (2000) concluded that this permit often ensures that wetlands will not be able to migrate inland unless the property owner does not want to control the erosion. For this and other reasons, the State of New York has decided that bulkheads and erosion structures otherwise authorized under the nationwide permit will not be allowed without state concurrence (NYDOS 2006; see Section A1.A.2 in Appendix 1).

Federal statutes appear to discourage regulatory efforts to promote landward migration of wetlands. Section 10 of the Rivers and Harbors Act of 1899 and Section 404 of the Clean Water Act require a permit to dredge or fill any portion of the navigable waters of the United States[59]. Courts have long construed this jurisdiction to include lands within the "ebb and flow of the tides", (*e.g.*, *Gibbons v. Ogden; Zabel v. Tabb*; 40 C.F.R. § 230.3[s][1], 2004), but it does not extend inland to lands that are dry today but would become wet if the sea were to rise one meter (Titus, 2000). The absence of federal jurisdiction over the dry land immediately inland of the wetlands can limit the ability of federal wetlands programs to anticipate sea-level rise.

Although the federal wetlands regulatory program generally has a neutral effect on the ability of wetlands to migrate as sea level rises, along the bay sides of barrier islands, regulatory programs, discourage or prevent wetland migration. Under natural conditions,

[58] See 61 Federal Register 65,873, 65,915 (December 13, 1996) (reissuing Nationwide Wetland Permit 13, Bank Stabilization activities necessary for erosion prevention). *See also* Reissuance of Nationwide Permits, 72 Fed. Reg. 11,1108-09, 11183 (March 12, 2007) (reissuing Nationwide Wetland Permit 13 and explaining that construction of erosion control structures along coastal shores is authorized).
[59] See The Clean Water Act of 1977, § 404, 33 U.S.C. § 1344; The Rivers and Harbors Act of 1899, § 10, 33 U.S.C. §§ 403, 409 (1994).

barrier islands often migrate inland as sea level rises (see Chapter 3). Winds and waves tend to fill the shallow water immediately inland of the islands, allowing bayside beaches and marshes to slowly advance into the bay toward the mainland (Dean and Dalrymple, 2002; Wolf 1989). Human activities on developed islands, however, limit or prevent wetland migration (Wolf, 1989). Artificial dunes limit the overwash (see Section 6.2 in Chapter 6). Moreover, when a storm does wash sand from the beach onto other parts of the island, local governments bulldoze the sand back onto the beach; wetland rules against filling tidal waters prevent people from artificially imitating the overwash process by transporting sand directly to the bay side (see Section 10.3). Although leaving the sand in place would enable some of it to wash or blow into the bay and thereby accrete (build land) toward the mainland, doing so is generally impractical. If regulatory agencies decided to make wetland migration a priority, they would have more authority to encourage migration along the bay sides of barrier islands than elsewhere, because the federal government has jurisidiction over the waters onto which those wetlands would migrate.

In addition to the regulatory programs, the federal government preserves wetlands directly through acquisition and land management. Existing statutes give the U.S. Fish and Wildlife Service and other coastal land management agencies the authority to foster the landward migration of wetlands (Titus, 2000). A 2001 Department of Interior (DOI) order directed the Fish and Wildlife Service and the National Park Service to address climate change[60]. However, resource managers have been unable to implement the order

[60] Department of Interior Secretarial Order 3226

because (1) they have been given no guidance on how to address climate change and (2) preparing for climate change has not been a priority within their agencies (GAO, 2007b).

**Figure 12.3** Tidal Wetland Migration. (a) Marshes taking over land on Hooper Island (Maryland) that had been pine forest until recently, with some dead trees standing in the foreground and a stand of trees on slightly higher ground visible in the rear [October 2004]. (b) Marshes on the mainland opposite Chintoteague Island, Virginia (June 2007).

*Relationship to Coastal Development.* Many policies encourage or discourage coastal development, as discussed in Section 12.2.3. Even policies that subsidize relocation may have the effect of encouraging development, by reducing the risk of an uncompensated loss of one's investment.

### 12.2.2 Shoreline Armoring *versus* Living Shorelines

The combined effect of federal and state wetland protection programs is a general preference for hard shoreline structures over soft engineering approaches to stop erosion along estuarine shores (see Box 12.1). USACE has issued nationwide permits to expedite the ability of property owners to erect bulkheads and revetments[61], but there are no such

[61] Reissuance of Nationwide Permits, 72 Federal Register 11,1108-09, 11183 (March 12, 2007) (reissuing Nationwide Wetland Permit 13 and explaining that construction of erosion control structures along coastal

permits for soft solutions such as rebuilding an eroded marsh or bay beach[62]. The bias in favor of shoreline armoring results indirectly because the statute focuses on filling navigable waterways, not on the environmental impact of the shore protection. Rebuilding a beach or marsh requires more of the land below high water to be filled than building a bulkhead.

Until recently, state regulatory programs shared the preference for hard structures, but Maryland now favors "living shorelines" (see Chapter 11), a soft engineering approach that mitigates coastal erosion while preserving at least some of the features of a natural shoreline (compare Figure 12.4a with 12.4b). Nevertheless, federal rules can be a barrier to these state efforts (see *e.g.*, Section A1.F.2.2 in Appendix 1), because the living shoreline approaches generally include some filling of tidal waters or wetlands, which requires a federal permit (see Section 10.3).

The regulatory barrier to soft solutions appears to result more from institutional inertia than from a conscious bias in favor of hard structures. The nationwide permit program is designed to avoid the administrative burden of issuing a large number of specific but nearly-identical permits (Copeland, 2007). For decades, many people have bulkheaded their shores, so in the 1970s USACE issued Nationwide Permit 13 to cover bulkheads and similar structures. Because few people were rebuilding their eroding tidal wetlands,

shores is authorized). See also Nationwide Permits 3 (Maintenance), 31 (Maintenance of Existing Flood Control Facilities) and 45 (Repair of Uplands Damaged by Discrete Events). 72 Federal Register 11092-11198 (March 12, 2007).

[62] Reissuance of Nationwide Permits, 72 Federal Register 11, 11183, 11185 (March 12, 2007) (explaining that permit 13 requires fill to be minimized and that permit 27 does not allow conversion of open to water to another habitat such as beach or tidal wetlands)

no nationwide permit was issued for this activity. Today, as people become increasingly interested in more environmentally sensitive shore protection, they must obtain permits from institutions that were created to respond to requests for hard shoreline structures. During the last few years however, those institutions have started to investigate policies for soft shore protection measures along estuarine shores.

**Figure 12.4** Hard and Soft Shore Protection. (a) Stone Revetment along Elk River at Port Herman, Maryland, May 2005 (b) Dynamic Revetment along Swan Creek, at Fort Washington, Maryland, September 2008.

**:Box 12.1 The Existing Decision-Making Process for Shoreline Protection on Sheltered Coasts**

- There is an incentive to install seawalls, bulkheads, and revetments on sheltered coastlines because these structures can be built landward of the federal jurisdiction and thus avoid the need for federal permits.
- Existing biases of many decision makers in favor of bulkheads and revetments with limited footprints limit options that may provide more ecological benefits.
- The regulatory framework affects choices and outcomes. Regulatory factors include the length of time required for permit approval, incentives that the regulatory system creates, [and] general knowledge of available options and their consequences.
- Traditional structural erosion control techniques may appear to be the most cost-effective. However, they do not account for the cumulative impacts that result in environmental costs nor the undervaluation of the environmental benefits of the nonstructural approaches.
- There is a general lack of knowledge and experience among decision makers regarding options for shoreline erosion mitigation on sheltered coasts, especially options that retain more of the shorelines' natural features.
- The regulatory response to shoreline erosion on sheltered coasts is generally reactive rather than proactive. Most states have not developed plans for responding to erosion on sheltered shores.

Source: NRC (2007)

### 12.2.3 Coastal Development

Federal, state, local, and private institutions all have a modest bias favoring increased coastal development in developed areas. The federal government usually discourages development in undeveloped areas, while state and local governments have a more neutral effect.

Coastal counties often favor coastal development because expensive homes with seasonal residents can substantially increase property taxes without much demand for government services (GAO, 2007a). Thus, local governments provide services (*e.g.*, police, fire, trash removal) to areas in Delaware and North Carolina that are ineligible for federal funding under the Coastal Barrier Resources Act[63]. The property tax system often encourages coastal development. A small cottage on a lot that has appreciated to $1 million can have an annual property tax bill greater than the annual rental value of the cottage.

Governments at all levels facilitate the continued human occupation of low-lying lands by providing roads, bridges, and other infrastructure. As coastal farms are replaced with development, sewer service is often extended to the new communities—helping to protect water quality but also making it possible to develop these lands at higher densities than would be permitted by septic tank regulations.

Congressional appropriations for shore protection can encourage coastal development along shores that are protected by reducing the risk that the sea will reclaim the land and structures (NRC, 1995; Wiegel, 1992). This reduced risk increases land values and property taxes, which may encourage further development In some cases, the induced development has been a key justification for the shore protection (GAO, 1976; Burby, 2006). Shore protection policies may also encourage increased densities in lightly developed areas. The benefit-cost formulas used to determine eligibility (USACE, 2000) find greater benefits in the most densely developed areas, making increased density a possible path toward federal funding for shore protection. Keeping hazardous areas lightly developed, by contrast, is not a path for federal funding (USACE, 1998; *cf*. Cooper and McKenna, 2008).

[63] 16 U.S.Code. §3501 *et seq*.

Several authors have argued that the National Flood Insurance Program (NFIP) encourages coastal development (*e.g.,* Tibbetts, 2006; Suffin, 1981; Simmons, 1988; USFWS, 1997). Insurance converts a large risk into a modest annual payment that people are willing to pay. Without insurance, some people would be reluctant to risk $250,000[64] on a home that could be destroyed in a storm. However, empirical studies suggest that the NFIP no longer has a substantial impact on the intensity of coastal development (Evatt, 2000; see Chapter 10). The program provided a significant incentive for construction in undeveloped areas during the 1970s, when rates received a substantial subsidy (Cordes and Yezer, 1998; Shilling *et al.*, 1989; Evatt, 1999). During the last few decades, however, premiums on new construction have not been subsidized and hence, the program has had a marginal impact on construction in undeveloped areas (Evatt, 2000; Leatherman, 1997; Cordes and Yezer, 1998; see Chapter 10). Nevertheless, in the aftermath of severe storms, the program provides a source of funds for reconstruction—and subsidized insurance while shore protection structures are being repaired (see Chapter 10). Thus, in developed areas the program helps rebuild communities that might be slower to rebuild (or be abandoned) if flood insurance and federal disaster assistance were unavailable. More broadly, the combination of flood insurance and the various post-disaster and emergency programs providing relocation assistance, mitigation (*e.g.,* home elevation), reconstruction of infrastructure, and emergency beach nourishment provide coastal construction with a federal safety net that makes coastal construction a safe investment.

[64] NFIP only covers the first $250,000 in flood losses (44 CFR 61.6) For homes with a construction cost greater than $250,000, federal insurance reduces a property owner's risk, but to a lesser extent.

Flood ordinances have also played a role in the creation of three-story homes where local ordinances once limited homes to two stories. Flood regulations have induced some people to build their first floor more than 2.5 meters (8 feet) above the ground (FEMA, 1984, 1994, 2000, 2007b). Local governments have continued to allow a second floor no matter the elevation of the first floor. Property owners often enclose the area below the first floor (*e.g.*, FEMA, 2002), creating ground-level (albeit illegal[65] and uninsurable[66]) living space.

The totality of federal programs, in conjunction with sea-level rise, creates moral hazard. Coastal investment is profitable but risky. If government assumes much of this risk, then the investment can be profitable without being risky—an ideal situation for investors (Loucks *et al*., 2006). The "moral hazard" concern is that when investors make risky decisions whose risk is partly borne by someone else, there is a chance that they will create a dangerous situation by taking on too much risk (Pauly, 1974). The government may then be called upon to take on even the risks that the private investors had supposedly assumed because the risk of cascading losses could harm the larger economy (Kunreuther and Michel-Kerjant, 2007). Investors assume that shore protection is cost-effective and governments assume that flood insurance rates reflect the risk in most cases; however, if sea-level rise accelerates, will taxpayers, coastal property owners, or inland flood insurance policyholders have to pay the increased costs?

[65] 44 CFR §60.3(c)(2)
[66] 44 CFR §61.5(a)

The Coastal Barrier Resources Act (16 U.S.C. U.S.C. §3501 *et seq*.) discourages the development of designated undeveloped barrier islands and spits, by denying them shore protection, federal highway funding, mortgage funding, flood insurance on new construction, some forms of federal disaster assistance[67], and most other forms of federal spending. Within the Mid-Atlantic, this statute applies to approximately 90 square kilometers of land, most of which is in New York or North Carolina (USFWS, 2002)[68]. The increased demand for coastal property has led the most developable of these areas to become developed anyway (GAO, 1992; 2007a). "Where the economic incentive for development is extremely high, the Act's funding limitations can become irrelevant" (USFWS, 2002).

## 12.3 INTERDEPENDENCE: A BARRIER OR A SUPPORT NETWORK?

Uncertainty can be a hurdle to preparing for sea-level rise. Uncertainty about sea-level rise and its precise effects is one problem, but uncertainty about how others will react can also be a barrier. For environmental stresses such as air pollution, a single federal agency (U.S. EPA) is charged with developing and coordinating the nation's response. By contrast, the response to sea-level rise would  require coordination among several agencies, including U.S. EPA (protecting the environment), USACE (shore protection), Department of Interior (managing conservation lands), FEMA (flood hazard management), and NOAA (coastal zone management). State and local governments generally have comparable agencies that work with their federal counterparts. No single

[67] Communities are eligible for emergency beach nourishment after a storm, provided that the beach had been previously nourished (GAO, 2007a).
[68] The other mid-Atlantic states each have less than 6 square kilometers within the CBRA system. A small area within the system in Delaware is intensely developed (see Box 9.2).

agency is in charge of developing a response to sea-level rise, which affects the missions of many agencies.

The decisions that these agencies and the private sector make regarding how to respond to sea-level rise are interdependent. From the perspective of one decision maker, the fact that others have not decided on their response can be a barrier to preparing his or her own response. One of the barriers of this type is the uncertainty whether the response to sea-level rise in a particular area will involve shoreline armoring, elevating the land, or retreat (see Chapter 6 for a discussion of specific mechanisms for each of these pathways).

### 12.3.1 Three Fundamental Pathways: Armor, Elevate, or Retreat

Long-term approaches for managing low coastal lands as the sea rises can be broadly divided into three pathways:

- *Protect* the dry land with seawalls, dikes, and other structures, eliminating wetlands and beaches (also known as "*shoreline armoring*") (see Figure 12.4a and Section 6.1.1).
- *Elevate the land*, and perhaps the wetlands and beaches as well, enabling them to survive (see Figures 12.1 and 12.5)
- *Retreat* by allowing the wetlands and beaches to take over land that is dry today (see Figure 12.6).

Combinations of these three approaches are also possible. Each approach will be appropriate in some locations and inappropriate in others. Shore protection costs, property values, the environmental importance of habitat, and the feasibility of protecting shores without harming the habitat all vary by location. Deciding how much of the coast should be protected may require people to consider social priorities not easily included in a cost-benefit analysis of shore protection.

Like land use planning, the purpose of selecting a pathway would be to foster a coordinated response to sea-level rise, not to lock future generations into a particular approach. Shoreline armoring may be appropriate over the next few decades to halt shoreline erosion along neighborhoods that are about one meter above high water; but as sea level continues to rise, the strategy may switch to elevating land surfaces and homes rather than erecting dikes, which eventually leads to land becoming below sea level. Some towns may be protected by dikes at first, but eventually have to retreat as shore protection costs increase beyond the value of the assets protected. In other cases, retreat may be viable up to a point, past which the need to protect critical infrastructure and higher density development may justify shore protection.


**Figure 12.5** Elevating land and house. (a) Initial elevation of house in Brant Beach (New Jersey). (b) Structural beams placed under house, which is lifted approximately 1.5 meters by hydraulic jack in blue truck. (c) Three course of cinder blocks added then house set down onto the blocks. (d) Soil and gravel brought in to elevate land surface. (January through June 2005)

**Figure 12.6** Retreat. (a) Houses along the shore in Kitty Hawk, North Carolina (June 2002). Geotextile sand bags protect the septic tank buried in the dunes. (b) October 2002. (c) June 2003

### 12.3.2 Decisions That Cannot Be Made Until the Pathway Is Chosen

Rising sea level has numerous implications for current activities. In most cases, the appropriate response depends on which of the three pathways a particular community intends to follow. This subsection examines the relationship between the three pathways and six example activities, summarized in Table 12.2.

**Table 12.2 The best way to prepare for sea-level rise depends on whether (and how) a community intends to hold back the sea.**

| Activity | Pathways for responding to sea-level rise | | |
|---|---|---|---|
| | Shoreline armoring (*e.g.*, dike or seawall) | Elevate land | Retreat/wetland migration |
| Rebuild drainage systems | Check valves, holding tanks; room for pumps | No change needed | Install larger pipes, larger rights of way for ditches |
| Replace septics with public sewer | Extending sewer helps improve drainage | Mounds systems; elevate septic system; extending sewer also acceptable | Extending sewer undermines policy; mounds system acceptable |
| Rebuild roads | Keep roads at same elevation; owners will not have to elevate lots | Rebuild road higher; motivates property owners to elevate lots | Elevate roads to facilitate evacuation |
| Location of roads | Shore-parallel road needed for dike maintenance | No change needed | Shore parallel road will be lost; all must have access to shore-perpendicular road |
| Setbacks/subdivisions | Setback from shore to leave room for dike | No change needed | Erosion-based setbacks |
| Easements | Easement or option to purchase land for dike | No change needed | Rolling easements to ensure that wetlands and beaches migrate |

*Coastal Drainage Systems in Urban Areas.* Sea-level rise slows natural drainage and the flow of water through drain pipes that rely on gravity. If an area will not be protected from increased inundation, then larger pipes or wider ditches (see Figure 12.7) may be necessary to increase the speed at which gravity drains the area. If an area will be protected with a dike, then it will be more important to pump the water out and to ensure that seawater does not back up into the streets through the drainage system; so then larger pipes will be less important than underground storage, check valves, and ensuring that the system can be retrofitted to allow for pumping (Titus *et al.,* 1987). If land surfaces will be elevated, then sea-level rise will not impair drainage.

In many newly developed areas, low-impact development attempts to minimize runoff into the drainage system in favor of on-site recharge. In areas where land surfaces will be elevated over time, the potential for recharge would remain roughly constant as land surfaces generally rise as much as the water table (*i.e.*, groundwater level). In areas that will ultimately be protected with dikes, by contrast, centralized drainage would eventually be required because land below sea level can not drain unless artificial measures keep the water table even father below sea level.

**Figure 12.7** Tidal Ditches in the Mid-Atlantic. (a) Hoopers Island, Maryland (October 2004). (b) Poquoson, Virginia (June 2002). (c) Swan Quarter, North Carolina (October 2002). (d) Sea Level, North Carolina. (October 2002). The water rises and falls with the tides in all of these ditches, although the astronomic tide is negligible in (c) Swan Quarter. Wetland vegetation is often found in these ditches. Bulkheads are necessary to prevent the ditch from caving in and blocking the flow of water in (b).

*Septics and Sewer.* Rising sea level can elevate the water table (ground water) to the point where septic systems no longer function properly (U.S. EPA, 2002)[69]. If areas will be protected with a dike, then all of the land protected must eventually be artificially drained and sewer lines further extended to facilitate drainage. On the other hand, extending sewer lines would be entirely incompatible with allowing wetlands to migrate inland, because the high capital investment tends to encourage coastal protection; a mounds-based septic system (see Figure 12.8) is more compatible. If a community's long-term plan is to elevate the area, then either a mounds-based system or extended public sewage will be compatible.

*Road Maintenance.* As the sea rises, roads flood more frequently. If a community expects to elevate the land with the sea, then routine repaving projects would be a cost-effective time to elevate the streets. If a dike is expected, then repaving projects would consciously avoid elevating the street above people's yards, lest the projects cause those yards to flood or prompt people to spend excess resources on elevating them, when doing so is not necessary in the long run.

[69] "Most current onsite wastewater system codes require minimum separation distances of at least 18 inches from the seasonally high water table or saturated zone irrespective of soil characteristics. Generally, 2- to 4-foot separation distances have proven to be adequate in removing most fecal coliforms in septic tank effluent" U.S. EPA (2002).

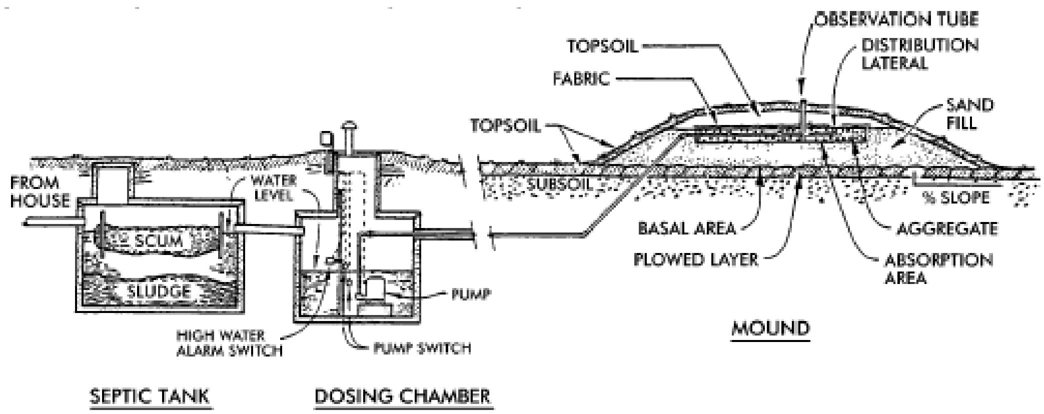


**Figure 12.8** Mounds-based septic system for areas with high water tables. For areas with high water tables, where traditional septic/drainfield systems do not work, sand mounds are often used. In this system, a sand mound is contructed on the order of 50 to 100 cm above the ground level, with perforated drainage pipes in the mound above the level of adjacent ground, on top of a bed of gravel to ensure proper drainage. Effluent is pumped from the septic tank up to the perforated pipe drainage pipe. Source: Converse and Tyler (1998).

The Town of Ocean City, Maryland, currently has policies in place that could be appropriate if the long-term plan was to build a dike and pumping system, but not necessarily cost-effective if land surfaces are elevated as currently expected.the town expects to elevate instead. Currently, the town has an ordinance that requires property owners to maintain a 2 percent grade so that rainwater drains into the street. The town has interpreted this rule as imposing a reciprocal responsibility on the town itself to not elevate roadways above the level where yards can drain, even if the road is low enough to flood during minor tidal surges. Thus, the lowest lot in a given area dictates how high the street can be. As sea level rises, the town will be unable to elevate its streets, unless it changes this rule. Yet public health reasons require drainage to prevent standing water in which mosquitoes breed. Therefore, Ocean City has an interest in ensuring that all property owners gradually elevate their yards so that the streets can be elevated as the sea rises without causing public health problems. The town has developed draft rules that would require that, during any significant construction, yards be elevated enough to drain during a 10-year storm surge for the life of the project, considering projections of future sea-level rise. The draft rules also state that Ocean City's policy is for all lands to gradually be elevated as the sea rises (see Box A1.5 in Appendix 1).

*Locations of Roads.* As the shore erodes, any home that is accessed only by a road seaward of the house could lose access before the home itself is threatened. Homes seaward of the road might also lose access if that road were washed out elsewhere. Therefore, if the shore is expected to erode, it is important to ensure that all homes are accessible by shore-perpendicular roads, a fact that was recognized in the layout of early beach resorts along the New Jersey and other shores. If a dike is expected, then a road along the shore would be useful for dike construction and maintenance. Finally, if all land is likely to be elevated, then sea-level rise may not have a significant impact on the best location for new roads.

*Subdivision and Setbacks.* If a dike is expected, then houses need to be set back enough from the shore to allow room for the dike and associated drainage systems. Setbacks and larger coastal lot sizes are also desirable in areas where a retreat policy is preferred for two reasons. First, the setback provides open lands onto which wetlands and beaches can migrate inland without immediately threatening property. Second, larger lots mean lower density and hence fewer structures that would need to be moved, and less justification for investments in central water and sewer. By contrast, in areas where the plan is to elevate the land, sea-level rise does not alter the property available to the homeowner, and hence would have minor implication for setbacks and lot sizes.

*Covenants and Easements Accompanying Subdivision.* Although setbacks are the most common way to anticipate eventual dike construction and the landward migration of wetlands and beaches, a less expensive method would often be the purchase of (or regulatory conditions requiring) rolling easements, which allow development but prohibit hard structures that stop the landward migration of ecosystems. The primary advantage of a rolling easement is that society makes the decision to allow wetlands to migrate inland long before the property is threatened, so owners can plan around the assumption of migrating wetlands, whether that means leaving an area undeveloped or building structures that can be moved.

Local governments can also obtain easements for future dike construction. This type of easement, as well as rolling easements, would each have very low market prices in most areas, because the fair market value is equal to today's land value discounted by the rate of interest compounded over the many decades that will pass before the easement would have any effect (Titus, 1998). As with setbacks, a large area would have to be covered by the easements if wetlands are going to migrate inland; a narrow area would be required along the shore for a dike; and no easements are needed if the land will be elevated in place.

### 12.3.3 Opportunities for Deciding on the Pathway

At the local level, officials make assumptions about which land will be protected in order to understand which lands will truly become inundated (see Chapter 2) and how shorelines will actually change (see Chapter 3), which existing wetlands will be lost (see Chapter 4), whether wetlands will be able to migrate inland (see Chapter 6), and the potential environmental consequences (see Chapter 5); the population whose homes would be threatened (see Chapter 7) and the implications of sea-level rise for public access (see Chapter 8) and floodplain management (see Chapter 9). Assumptions about which shores will be protected are also necessary in order to estimate the level of resources that would be needed to fulfill property owners' current expectations for shore protection (*e.g.*, Titus, 2004).

Improving the ability to project the impacts of sea-level rise is not the only for such analyses utility of data regarding shore protection. Another use of such studies has been to initiate a dialogue about what *should* be protected, so that state and local governments can decide upon a plan of what will actually be protected. Just as the lack of a plan can be a barrier to preparing for sea-level rise, the adoption of a plan could remove an important barrier and signal to decision makers that it may be possible for them to plan for sea-level rise as well.

## CHAPTER 12 REFERENCES

* Indicates non-peer reviewed literature; available upon request

**Akerlof**, G.A. and W.T. Dickens, 1982: The economic consequences of cognitive dissonance. *American Economic Review*, **72**, 307, 309.

**Arrow**, K.J., 1970: The organization of economic activity: issues pertinent to the choice of market versus nonmarket allocation. In: *Public Expenditures and Policy Analysis* [Margolis, J. (ed.)]. Markham Publishing Company, Chicago, pp. 59-73.

**Bator**, F.M., 1958: The anatomy of market failure. *The Quarterly Journal of Economics*,**72(3)**, 351-79.

**Bradshaw**, G.A. and J.G. Borchers, 2000: Uncertainty as information: narrowing the science-policy gap. *Conservation Ecology*, **4(1)**, 7.

**Burby**, R.J., 2006: Hurricane Katrina and the Paradoxes of Government Disaster Policy: Bringing About Wise Governmental Decisions for Hazardous Areas. *The Annals of the American Academy of Political and Social Science*, **604(1)**, 171-191.

**Converse**, J.C. and E.J. Tyler, 1998: Soil treatment of aerobically treated domestic wastewater with emphasis on modified mounds. In: *On-Site Wastewater Treatment: Proceedings of the Eighth National Symposium on Individual and Small Community Sewage Systems* [Sievers, D.M. (ed.)]. American Society of Agricultural Engineers, St. Joseph, MI.

**Cooper**, J.A.G. and J. McKenna, 2008: Social justice in coastal erosion management: the temporal and spatial dimensions. *Geoforum*, **39(1)**, 294-306.

**Copeland**, C., 2007: *The Army Corps of Engineers' Nationwide Permits Program: Issues and Regulatory Developments*. Congressional Research Service, Washington, DC, [30 pp.]

**Cordes**, J.J. and A.M.J. Yezer, 1998: In harm's way: does federal spending on beach enhancement and protection induce excessive development in coastal areas? *Land Economics,* **74(1)**, 128-145.

**Crowell**, M., E. Hirsch, and T.L. Hayes, 2007: *Marine Technology Society Journal*, **41(1)**, 18-27.

**Dean**, R.G. and R.A. Dalrymple, 2002: *Coastal Processes with Engineering Applications*. Cambridge University Press, Cambridge, UK, and New York, 475 pp.

**Depoorter**, B., 2006: Horizontal political externalities: the supply and demand of disaster management. *Duke Law* Journal, **56(1)**, 101-125.

**Evatt**, D.S., 1999: *National Flood Insurance Program: Issues Assessment*. Federal Emergency Management Agency, Washington, DC, 123 pp.

**Evatt**, D.S., 2000: Does the national flood insurance program drive floodplain development? *Journal of Insurance Regulation*, **18(4)**, 497-523.

**FEMA** (Federal Emergency Management Agency), 1984: *Elevated Residential Structures*. FEMA 54. Federal Emergency Management Agency, Washington, DC, 144 pp.

**FEMA** (Federal Emergency Management Agency), 1994: *Mitigation of Flood and Erosion Damage to Residential Buildings in Coastal Areas*. FEMA 257. Federal Emergency Management Agency, Washington, DC, 40 pp.

**FEMA** (Federal Emergency Management Agency), 2000: *Above the Flood: Elevating Your Floodprone House*. FEMA 347. Federal Emergency Management Agency, Washington, DC, 69 pp.

**FEMA** (Federal Emergency Management Agency), 2002: *FEMA Notifies Monroe County, Florida, of Impending Flood Insurance Probation*. Region IV News Release Number: R4-02-15. <http://www.fema.gov/news/newsrelease.fema?id=4528>

**FEMA** (Federal Emergency Management Agency), 2007a: *Public Assistance Guide*. FEMA 322. Federal Emergency Management Agency, Washington, DC. <http://www.fema.gov/government/grant/pa/policy.shtm>

**FEMA** (Federal Emergency Management Agency), 2007b: *Coastal Construction Manual*. Federal Emergency Management Agency, Washington, DC. <http://www.fema.gov/rebuild/mat/fema55.shtm>

**FEMA** (Federal Emergency Management Agency), 2008a: *Severe Repetitive Loss Program*. [Web site] Federal Emergency Management Agency, Washington, DC. <http://www.fema.gov/government/grant/srl/index.shtm>

**FEMA** (Federal Emergency Management Agency), 2008b: *Repetitive Flood Claims Program: Program Overview*. [Web site] Federal Emergency Management Agency, Washington, DC. <http://www.fema.gov/government/grant/rfc/index.shtm>

**FEMA** (Federal Emergency Management Agency), 2008c: *Hazard Mitigation Grant Program*. [Web site] Federal Emergency Management Agency, Washington, DC. <http://www.fema.gov/government/grant/hmgp/>

**FEMA** (Federal Emergency Management Agency), 2008d: *Flood Mitigation Assistance Program* [Web site] Federal Emergency Management Agency, Washington, DC. <http://www.fema.gov/government/grant/fma/index.shtm>

**FEMA** (Federal Emergency Management Agency), 2008e: *Pre-Disaster Mitigation Program*. [Web site] Federal Emergency Management Agency, Washington, DC. <http://www.fema.gov/government/grant/pdm/index.shtm>

**Festinger**, L., 1957: *A Theory of Cognitive Dissonance*. Stanford University Press, Stanford, CA, 291 pp.

**GAO** (General Accounting Office), 1976: *Cost, Schedule, and Performance Problems of the Lake Pontchartrain and Vicinity, Louisiana, Hurricane Protection Project*. PSAD-76-161. General Accounting Office, Washington, DC, 25 pp.

**GAO** (General Accounting Office), 1992: *Coastal Barriers: Development Occurring Despite Prohibitions Against Federal Assistance*. GAO/RCED-92-115. General Accounting Office, Washington, DC, 71 pp.

**GAO** (Government Accountability Office), 2007a: *Coastal Barriers Resources System: Status of Development that Has Occurred and Financial Assistance Provided by Federal Agencies: Development Occurring Despite Prohibitions Against Federal Assistance*. GAO/07-356. Government Accountability Office, Washington, DC, 66 pp.

**GAO** (Government Accountability Office), 2007b. *Climate Change: Agencies Should Develop Guidance for Addressing the Effects on Federal Land and Water Resources.* GAO-07-863. Government Accountability Office, Washington, DC, 179 pp.

**Gibbons v. Ogden**, 22 U.S. 1, 217-18 (9 Wheat. 1824)

**Harmon-Jones**, E. and J. Mills, 1999: *Cognitive Dissonance: Progress on a Pivotal Theory in Social Psychology*. American Psychological Association, Washington, DC, 411 pp.

**Kunreuther**, H.C. and E.O. Michel-Kerjant, 2007: Climate change, insurability of large-scale disasters, and the emerging liability challenge. *University of Pennsylvania Law Review*, **155(6)**, 1795-1842.

**Kunreuther**, H., R. Ginsberg, L. Miller, P. Sagi, P. Slovic, B. Borkan, and N. Katz, 1978: *Disaster Insurance Protection*. John Wiley and Sons, New York, 400 pp.

**Kunreuther,** H., R. Meyer, and C. Van den Bulte, 2004: *Risk Analysis for Extreme Events: Economic Incentives for Reducing Future Losses*. National Institute of Standards and Technology, Gaithersburg, MD, 93 pp.

**Lead**, D. and R.E. Meiners, 2002: *Government vs. Environment*. Rowan and Littlefield, Lanham, MD, 207 pp.

**Leatherman**, S.P., 1997: *Flood Insurance Availability in Coastal Areas: The Role It Plays in Encouraging Development Decisions*. Federal Emergency Management Agency,Washington, DC.

**Lockhart**, J. and A. Morang, 2002: History of coastal engineering. In: *Coastal Engineering Manual, Part I* [Morang, A. (ed.)]. Engineer manual 1110-2-1100. U.S. Army Corps of Engineers, Washington, DC, [39 pp.] <http://chl.erdc.usace.army.mil/cemtoc>

**Loucks**, D.P., J.R. Stedinger, and E.Z. Stakhiv, 2006: Individual and societal responses to natural hazards. *Journal of Water Resources Planning & Management*, **132(5)**, 315-319.

**MD DNR** (Maryland Department of Natural Resources), 2006: *Shore Erosion Control Guidelines for Waterfront Property Owners*. Maryland Department of Natural Resources, Annapolis, 30 pp. <http://www.dnr.state.md.us/ccws/sec/download/waterfrontpropertyownersguide.pdf >

**MD DNR** (Maryland Department of Natural Resources), 2008: *Grants and Loans: Shore Erosion Control*. [web site] Maryland Department of Natural Resources, Annapolis. <http://www.dnr.state.md.us/land/sec/>

**Mileti**, D.S., 1999: *Disasters by Design: A Reassessment of Natural Hazards in the United States*. Joseph Henry Press, Washington, DC, 351 pp.

**NRC** (National Research Council), 1995: *Beach Nourishment and Protection.* National Academy Press, Washington, DC, 334 pp.

**NRC** (National Research Council), 2004: *River Basins and Coastal Systems Planning Within the U.S. Army Corps of Engineers*. National Academies Press, Washington, DC, 167 pp.

**NRC** (National Research Council), 2007: *Mitigating Shore Erosion along Sheltered Coasts.* National Academies Press, Washington, DC, 174 pp.

**NYDOS** (New York Department of State), 2006: Department of State review of US Army Corps of Engineers consistency determination for reissuance, modification, and issuance of new nationwide permits and conditions. Letter to USACE Buffalo and New New York districts, December 8, 2006. New York Division of Coastal Resources, Albany, 5 pp.

**Pauly**, M.V., 1974: Overinsurance and public provision of insurance: the roles of moral hazard and adverse selection. *Quarterly Journal of Economics*, **88(1)**, 44-62.

**Scodari**, P., 1997: *Measuring the Benefits of Federal Wetland Protection Programs*. Environmental Law Institute, Washington, DC, 103 pp.

**Simmons**, M., 1988: *The Evolving National Flood Insurance Program*. 86-641 ENR. Congressional Research Service Washington, DC.

**Shilling**, J.D., C.E. Sirmans, and J.D. Benjamin, 1989: Flood insurance, wealth redistribution, and urban property values. *Journal of Urban Economics*, **26(1)**, 43-53.

**Suffin**, W.J., 1981: Bureaucracy, entrepreneurship, and natural resources: witless policy and barrier islands. *Cato Journal,* **1(1)**, 293-311.

**Tibbetts**, J.H., 2006: After the storm. *Coastal Heritage*, **20(4)**, 3-11.

**Titus**, J.G., 1998: Rising seas, coastal erosion and the taking clause: how to save wetlands and beaches without hurting property owners. *Maryland Law Review,* **57(4)**, 1277-1399.

**Titus**, J.G., 2000: Does the U.S. government realize that the sea is rising? How to restructure federal programs so that wetlands and beaches survive. *Golden Gate University Law Review*, **30(4)**, 717-778.

* **Titus**, J.G., 2004: Maps that depict the business-as-usual response to sea level rise in the decentralized United States of America. Presented at: *Global Forum on*

*Sustainable Development*, Paris, 11-12, November 2004. Organization of Economic Cooperation and Development, Paris.

**Titus**, J.G., C.Y. Kuo, M.J. Gibbs, T.B. LaRoche, M.K. Webb, and J.O. Waddell, 1987: Greenhouse effect, sea level rise, and coastal drainage systems. *Journal of Water Resources Planning and Management*, **113(2)**, 216-227.

**TRB** (Transportation Research Board), 2008: *Potential Impacts of Climate Change on U.S. Transportation*. National Academies Press, Washington, DC, 234 pp.

**USACE** (U.S. Army Corps of Engineers), 1998: *Atlantic Coast of Long Island, Fire Island Inlet to Montauk Point: Alternative Screening Report*. Draft report. U.S. Army Corps of Engineers New York District, New York, 118 pp. <http://www.nan.usace.army.mil/fimp/pdf/montauk/screening.pdf>

**USACE** (U.S. Army Corps of Engineers), 2000: *Planning Guidance Notebook*. Document ER 1105-2-100. U.S. Army Corps of Engineers, Washington, DC. <http://www.usace.army.mil/publications/eng-regs/er1105-2-100/>

**U.S. EPA** (Environmental Protection Agency), 2002: *Onsite Wastewater Treatment Systems Manual*. EPA/625/R-00/008. EPA Office of Water and Office of Research and Development, Washington, DC, [367 pp.] <http://purl.access.gpo.gov/GPO/LPS21380>

**USFWS** (U.S. Fish and Wildlife Service), 1997: *Biological Opinion: Administration of the National Flood Insurance Program in Monroe County, Florida, by the Federal Emergency Management Agency*. U.S. Fish and Wildlife Service, Atlanta, GA.

**USFWS** (U.S. Fish and Wildlife Service), 2002: *The Coastal Barrier Resources Act: Harnessing the Power of Market Forces to Conserve America's Coasts and Save Taxpayers' Money*. U.S. Fish and Wildlife Service, Arlington, VA, 34 pp. <http://www.fws.gov/habitatconservation/TaxpayerSavingsfromCBRA.pdf>

**Viscusi**, W.K. and R.J. Zeckhauser, 2006: National survey evidence on disasters and relief: risk beliefs, self-interest, and compassion. *Journal of Risk & Uncertainty*, **33(1/2)**, 13-36.

**Wolff**, F., 1989: Environmental assessment of human interference on the natural processes affecting the barrier beaches of Long Island, New York. *Northeastern Environmental Science*, **8(2)**, 119-134.

**Wiegel**, R.L., 1992: Dade County, Florida **b**each nourishment and hurricane surge protection. *Shore and Beach,* **60(4)**, 2-28.

**Zabel v. Tabb,** 430 F.2d 199, 215 (5th Cir. 1970)