Implications for Decisions

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Coastal Sensitivity to Sea Level Rise
U.S. Climate Change Science Program

January 2009

Full Citation

Titus, J.G. and J.E. Neumann, 2009: Implications for decisions. In: *Coastal Sensitivity to Sea-Level Rise: A Focus on the Mid-Atlantic Region*. J.G. Titus, coordinating lead author. K.E. Anderson, D.R. Cahoon, S.K. Gill, B.T. Gutierrez, E.R. Thieler, and S.J. Williams (lead authors). U.S. Environmental Protection Agency, Washington DC, pp. 141-156.

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.

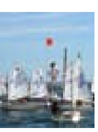
- Sea-level rise does not threaten the financial integrity of the National Flood Insurance Program. Incorporating sea-level rise into the program, however, could allow flood insurance rates to more closely reflect changing risk and enable participating local governments to more effectively manage coastal 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.



Society 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). People 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[1]. 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).

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.

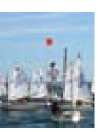
Uncertainty. Because projections of sea-level rise and its precise effects are uncertain, preparing now involves spending today for the sake of uncertain benefits. If sea level rises less than expected, then preparing now may prove, in retrospect, to have been unnecessary. Yet if sea level rises more 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

[1] 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.

Figure 10.1 Homes set back from the shore. Myrtle Beach, South Carolina (April 2004) [Photo source: ©James G. Titus, used with permission].

prepare will still be available[2]. 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.

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 is 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.

[2] There is 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).

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:

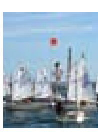
- *Setting a new home back from the sea within a given lot.* Setting a home back from the water can push the eventual damages from sea-level rise farther into the future, lowering their expected present value[3]. Unlike the option of not building, this approach retains almost the entire value of using the property—especially if nearby homes are also set back so that all properties retain the complete panorama 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.

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[4] and avoid some of the noneconomic impacts that can occur after an unexpected relocation (see Section 6.4.1 and Section 12.3 for further discussion).

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[5] (*Matcha versus Mattox*, 1986).



Under a rolling easement, the property owner bears all of the risk of sea-level rise. Without a rolling easement, property

[3] 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).

[4] 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.

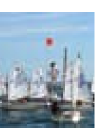
[5] Another mechanism for allowing wetlands and beaches to migrate inland are setbacks, which prohibit development near the shore. Setbacks can often result in successful "takings" claims if a property is deemed undevelopable due to the setback line. By contrast, rolling easements place no restrictions on development and hence are not constitutional takings (see, *e.g.*, Titus, 1998).

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 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).

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

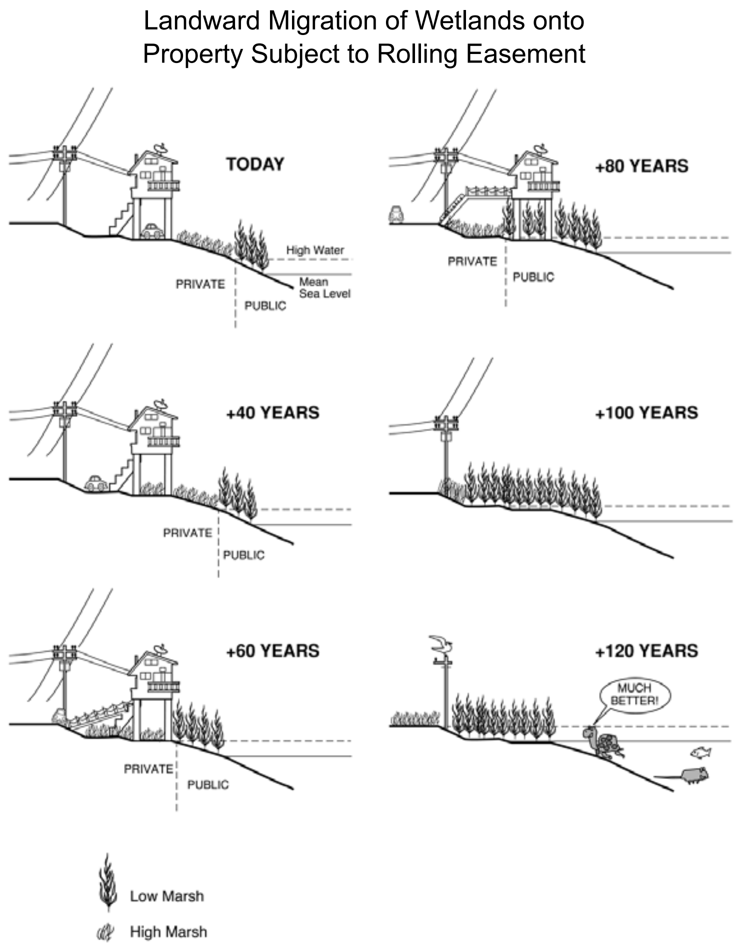


Figure 10.2 A rolling easement allows construction near the shore, but requires the property owner to recognize nature's right-of-way to advance inland as sea level rises. In the case depicted, the high marsh reaches the footprint of the house 40 years later. Because the house is on pilings, it can still 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 reduce the current property value by 1 to 5 percent, which could be compensated or offset by other permit considerations (Titus, 1998).

of wealth, not a cost to society[6].) 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 10.2 shows how a rolling easement might work over time in an area already developed when rolling easements are obtained.

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

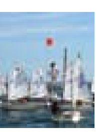
Figure 10.3 Coastal wetlands migrating onto previously dry lowland. Webbs Island, just east of Machipongo, in Northampton County, Virginia (June 2007) [Photo source: ©James G. Titus, used with permission].

[6] 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 10.4 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) [Photo source: ©James G. Titus, used with permission].

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).

Continuing the current practice of protecting almost all developed estuarine shores could reverse the accomplishments of important environmental programs. 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 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)[7]. These permits are generally not issued unless the facility is inherently water-related, such as a marina[8]. Even then, 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

[7] 33 U.S.C. §§ 403, 409, 1344(a)
[8] 40 C.F.R. § 230.10(a)(3)

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[9]. 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.

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).

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

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.

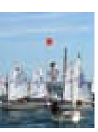
The U.S. Army Corps of Engineers has not evaluated whether sea-level rise will ultimately require fundamental changes in shore protection; such changes do not appear to be urgent. Since the early 1990s, USACE has recommended robust strategies: "Feasibility studies should consider which designs are most 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 deployed on a given project 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 infrastructure 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[10]. 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 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 30 cm above the base flood elevation when the home is built would increase the construction cost by approximately \$500 to \$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 (*e.g*., 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.

[10] *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 twenty-eight years hence (see glossary for definition of discount rate).

Rationale for Incorporating Sea-Level Rise into Floodplain Mapping

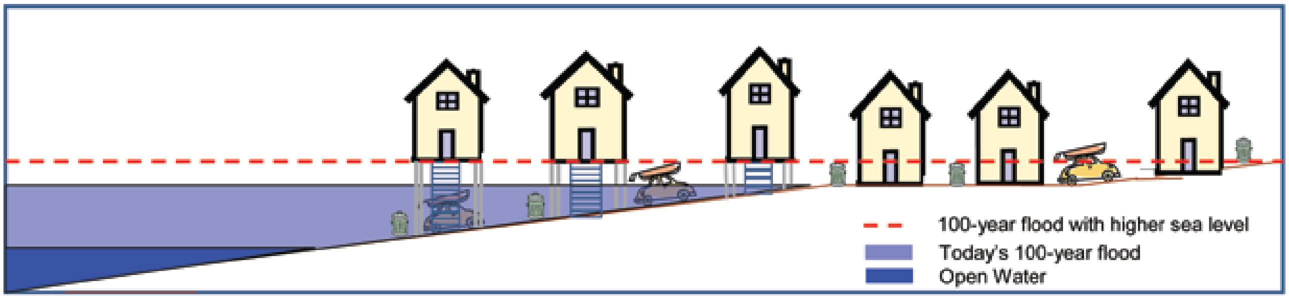


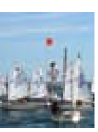
Figure 10.5 The (left) three houses in the existing floodplain have first floor elevations about 80 centimeters (cm) above the level of the 100-year storm, to account for a projected 50-cm rise in sea level and the standard requirement for floors to be 30 cm above the base flood elevation. The (right) 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 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[11]; 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

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"[12] (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[13]. Hypothetically, if sea-level rise were to double flood damage claims in the A Zone, then flood insurance premiums would double (ignoring administrative costs)[14].

[11] 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).

[12] The shaded X Zone was formerly known as the B Zone.

[13] Owners of pre-FIRM homes can also pay the actuarial rate, if it is less than the subsidized rate.

[14] 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

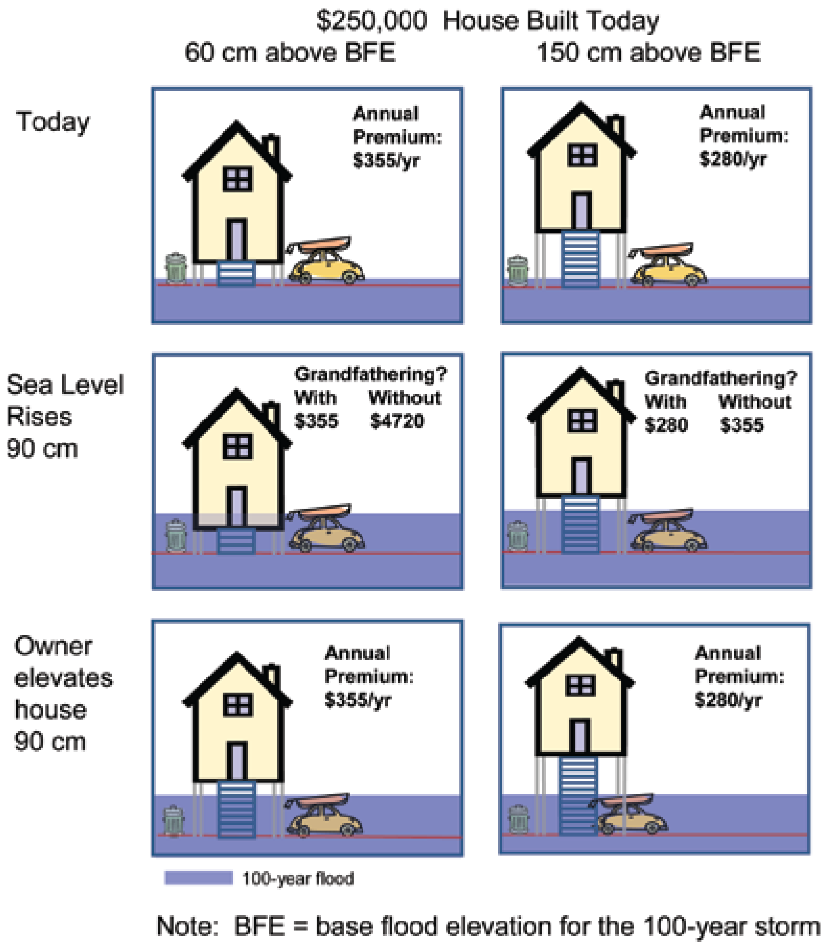


Figure 10.6 Impact of grandfathering and floor elevation on flood insurance rates in the A Zone as sea level rises. Without grandfathering, a 90-centimeter (cm) rise in sea level would increase the flood insurance rate from $355 to $4720, for a home built 60 cm above today's 100-year flood elevation (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.

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[15] 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 damage to 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 changed, its assumed risk is grandfathered[16], that is, FEMA assumes that the risk has not increased when calculating the flood insurance rate (*e.g.*, NFIP, 2007; Heinz Center, 2000)[17]. 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 at the 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,

associated with the historical average loss year.

[15] 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.

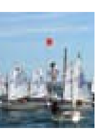
[16] Under the NFIP grandfathering policy, whenever FEMA revises the flood risk maps used to calculate the premium for specific homes, a policy holder can choose between the new map and the old map, whichever results in the lower rate (NFIP, 2007).

[17] 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.

the annual rate would rise to more than $10,000 (NFIP, 2008)[18] 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.* 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 (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).

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)[19]. 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.

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

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

[19] 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.

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 was 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[20]. Therefore, if total damages (which include inland flooding) rise by the same proportion as damages to subsidized policies, the subsidized portion of pre-FIRM policies 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[21].

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).

[20] The year 2005 (Hurricanes Katrina, Rita, and Wilma) is excluded from such calculations.

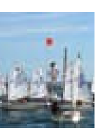
[21] Pre-FIRM owners of homes a few feet *below* the base flood elevation could achieve modest saving by elevating homes a few feet *above* the base flood elevation; but those savings are small compared to the savings available to the owner of a post-FIRM home at the same elevation relative to base flood elevation.

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 would be 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.

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