Greenhouse Effect and Coastal Wetland Policy: How Americans Could Abandon an Area the Size of Massachusetts at Minimum Cost*

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ABSTRACT / Climatologists generally expect an anthropogenic global warming that could raise sea level 30–150 cm in the next century and more thereafter. One of the impacts would be the loss of coastal wetlands. Although the inundation of adjacent dryland would enable new wetlands to form, much of this land is or will soon be developed. If developed areas are protected, wetlands will be squeezed between an advancing sea and the land being protected, which has already happened in China and the Netherlands, where people have built dikes for centuries.

Unlike those countries, the United States has enough land to accommodate the landward migration of wetlands; but governments lack the funds to purchase all the coastal lowlands that might be inundated and the legal authority to prohibit their development.

We propose a third approach: allowing property owners to use coastal lowlands today as they choose, but setting up a legal mechanism to ensure that the land is abandoned if and when sea level rises enough to inundate it. Although compensation may be required, this approach would cost less than 1% as much as purchasing the land, and would be (1) economically efficient by enabling real estate markets to incorporate expectations of future sea level rise; (2) constitutional by compensating property owners; and (3) politically feasible by pleasing people who care about the long-term fate of the coastal environment without disturbing people who either are unconcerned about the distant future or do not believe sea level will rise.

This article demonstrates that it would be irrational to delay policy formulation until sea level rise projections are more precise. The cost will be small if we act now but great if we wait, and sea level is already rising along most coasts. The US government should develop a strategy in the next three years.

Along most of the world's coasts, just beyond the reach of the ocean waves, lie nearly unbroken chains of marshes and swamps. Part land and part water, these coastal "wetlands" provide nursing grounds for many types of fish and shellfish, a resting place for migratory birds, and natural cleansing of ground and surface waters. In many developing nations, they also provide the only effective barrier to surges from tropical storms.

The importance of coastal wetlands was not always appreciated. For two thousand years, people have diked and drained them for agriculture and urban development. More recently, hydroelectric dams, navigation channels, and flood control levees have blocked the flow of sediment, nutrients, and freshwater to river deltas, converting wetlands to open water.

In the last twenty years, the world has begun to recognize the importance of environmental quality in general and these ecosystems in particular. In the United States, the Clean Water Act discourages people from dredging or filling wetlands; and several states have effectively prohibited these activities. These restrictions have substantially reduced the conversion of wetlands to dryland (Redelfs 1983; Tiner 1984; Hardisky and Klemas 1983).

Unfortunately, conversion to open water is increasing. Wetlands in the Nile, Niger, and many other deltas are eroding rapidly. In the United States, the majority of coastal wetland loss is taking place in coastal Louisiana, where relative sea level rises 1 cm, and 100 km^2 (40 mi^2) of wetlands erode each year (Gagliano and others 1981, LWPP 1987).[1]

Although conversion to open water is mostly confined to river deltas today, it may become widespread in the coming decades. Increasing concentrations of carbon dioxide and other gases released by human activities are expected to warm our planet a few degrees centigrade in the next century by a mechanism commonly known as the "greenhouse effect" (NAS 1979, 1982). Such a warming would expand ocean waters, melt mountain glaciers, and perhaps eventually cause polar ice sheets to disintegrate, thereby raising the sea

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to levels above the current elevations of virtually all coastal wetlands. While the timing and magnitude are uncertain, recent studies suggest that the sea could rise 30 cm (1 ft) by 2050 (Meier 1990), 30–200 cm (1–7 ft) in the next century (NRC 1987, 1985, Hoffman and others 1983, Revelle 1983) and perhaps 6 m (20 ft) in the next few centuries (Hughes 1983, Bentley 1983) (Figure 1).

Offsetting this potential threat are two compensating factors: (1) A rise in sea level would flood adjacent lowlands,[2] creating new wetlands; and (2) wetlands can grow upward by accumulating sediment and organic material. However, in the long run, the ability of these factors to avert a major loss of coastal wetlands may be limited. There is no evidence that wetlands could keep pace with the accelerated rise expected in the next century (Kearney and Stevenson 1985, NRC 1987), with the possible exception of a few deltas; thus existing wetlands will probably convert to open water. More important, much of the land adjacent to coastal wetlands is continuing to be developed, and new wetlands will not be able to form inland unless these areas are abandoned to the sea.

Considering economics alone, such an abandonment seems unlikely. A recent study concluded that a one-meter rise in sea level would inundate 20,000 km^2 (7000 mi^2) of dryland in the United States—an area the size of Massachusetts. Most of these areas could be protected from rising water levels with dikes and pumping systems at a cost of about $400–1200 per hectare ($150–500 per acre) each year, suggesting that even lightly developed areas could be economically protected (EPA 1989).

Nevertheless, we may have to consider abandoning many coastal lowlands because it is the only known way to enable coastal ecosystems to survive a rapidly rising sea. Although the abandonment would not have to take place for at least several decades, it seems prudent to consider it now because (1) it may be easier to channel development away from lowlands today than to abandon them later; and (2) many of the difficulties of abandoning currently developed areas could be averted if the abandonment were planned 50–100 years in advance.

Perhaps the greatest challenge is overcoming the fact that most people are unconcerned about events that might occur 100 years hence; a procedure known as "discounting" analytically legitimizes this tendency. Although many economists believe that a lower discount rate is necessary for long-term issues, the solution to this problem may lie not in a low social discount rate but in taking advantage of a principle of financial

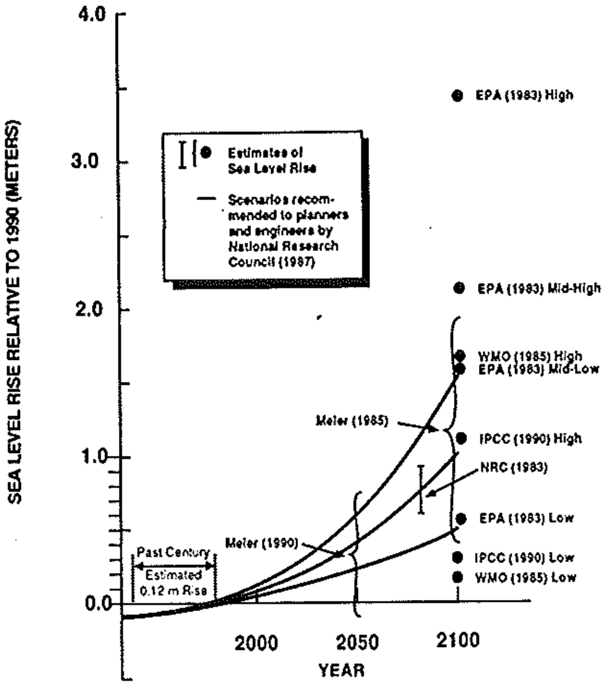


Figure 1. Published estimates of future sea level rise. Although the original EPA (Hoffman and others 1983) estimates were higher, the central estimate since then has been about one meter by 2100. Note in particular that in spite of the article's title ("Reduced rise in sea level"), Meier (1990) was generally consistent with Meier (1985). Note also that NRC 1983 refers to Revelle 1983, and that EPA 1983 refers to Hoffman and others 1983.

theory: arbitrage, which emphasizes the advantages of recognizing that people value the future returns of an investment differently. If environmentalists discount the future less and expect sea level to rise more than developers and coastal property owners, policies that take effect (1) 100 years hence and (2) only if sea level rises to a particular level will satisfy the former group while being of little concern to the latter.

This article examines options for abandoning coastal lowlands in order to enable wetlands to migrate inland. After summarizing the impacts of sea level rise on wetlands, it describes seven options and discusses the extent to which each satisfies desirable criteria, such as economic feasibility, success under uncertainty, equity, constitutionality, institutional feasibility, the risk of backsliding, and overall likelihood of protecting ecosystems.

The author notes at the outset that the planning options examined here are only part of the solution. In Louisiana, the restoration of natural deltaic processes is far more important.[3] Elsewhere, low-cost technologies may emerge to artificially enhance the ability of wetlands to accrete vertically[4]; and it may be possible to maintain wetlands by diking them and artificially maintaining low water levels.[5] Although there are reasons to doubt the general feasibility and environmental acceptability of those options, they will probably be appropriate in some cases.

Although this article focuses on the sheltered waters of the United States, most of the options would apply to wetlands in Australia and other nations with strong property rights, a coast largely in private hands, and enough available land to accommodate resettlement. Many of the principles would also apply to sandy ocean beaches (c.f. Titus 1990a).

Finally, the article does not attempt to evaluate *whether* coastal wetlands will be worth protecting. Our more limited objective is to lay out how it might be done, in hopes of accelerating the studies and political decisions that must ultimately resolve this issue.

Impact of Sea Level Rise on Coastal Wetlands

Sea level rise can disrupt wetlands by inundation, erosion, or saltwater intrusion. In some cases, wetlands will be converted to open water; in other cases, the type of vegetation will change, but a particular area will still be wetland. In explaining the potential impacts of sea level rise, the following discussion focuses on what the impacts would be if the wetlands did not accrete vertically and leaves it to the reader to remember that accretion can offset these impacts.

Tidal Flooding

Because periodic flooding is the essential characteristic of wetlands, increasing the frequency and duration of floods can substantially alter these ecosystems. The natural impact of a rising sea would be to cause the entire ecosystem to shift landward, with dryland converting to the transitional wetland vegetation flooded a few times per year, transition wetlands converting to high marsh, high marsh converting to low marsh, and low marsh converting to mudflats and eventually open water.

The net change in wetland acreage would depend on the slopes of the marsh and lowlands. If the land has a constant slope throughout the wetlands and adjacent dryland, the area of wetlands lost to the sea will equal the area gained. *In most areas, however, the slope above the wetlands is steeper than that of the wetlands; so a rise in sea level causes a net loss of wetland acreage.* Two extreme examples are noteworthy: marshes immediately below cliffs in New England and along the Pacific coast, and those in Louisiana, where thousands of square kilometers of wetlands are within one meter of sea level with very narrow ridges in between.

Figures 2A and 2B illustrate why there is so much

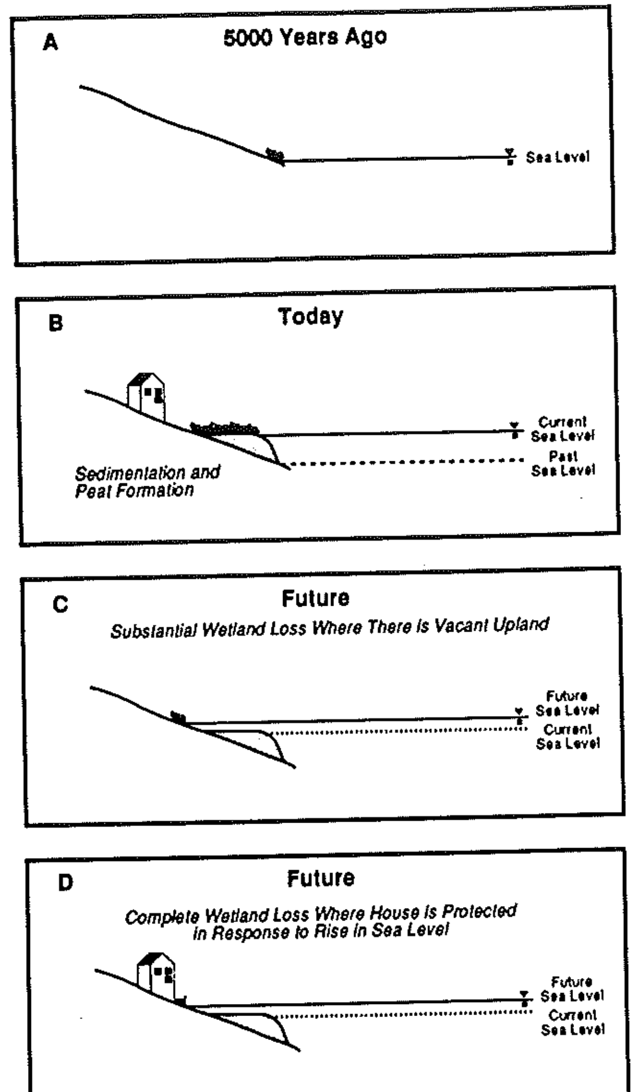


Figure 2. Coastal wetlands have kept pace with the slow rate of sea level rise that has characterized the last several thousand years. Thus, the area of wetlands increased as new lands were inundated. If in the future sea level rises faster than the ability of the wetlands to keep pace, the wetland area will decline. Construction of bulkheads or dikes to protect developed areas would prevent new wetlands from forming inland, resulting in a total loss in some areas. Source: Titus (1986).

Table 1. Impact of sea level rise on the United States (billions of 1988 dollars)[a]

	Sea level scenario		
	50 cm	100 cm	200 cm
If no shores are protected			
Land lost			
Wetlands lost (%)	17–43	26–66	29–76
Dry land lost (sq mi)	3,300–7,300	5,100–10,300	8,200–15,400
Value of lost property	78–188	165–451	411–1,407
Cost of coastal defense	0	0	0
If densely developed dryland is protected			
Land lost			
Wetlands lost (%)	20–45	29–69	33–80
Dry land lost (sq mi)	2,200–6,100	4,100–9,200	6,400–13,500
Value of lost property	?	?	?
Cost of coastal defense	32–43	73–111	194–285
Open coast	25–32	54–92	145–203
Sheltered waters	5–13	11–33	30–101
If all dryland is protected			
Land lost			
Wetlands lost (%)	38–61	50–82	66–90
Dry land lost	0	0	0
Value of lost property	0	0	0
Cost of coastal defense	?	?	?

[a]Sources: value of lost property: Yohe (1990); all other figures are from EPA (1989). Wetlands lost, dry land lost, and cost of protecting sheltered waters show 95% confidence intervals. Value of lost property shows 75% confidence interval. Cost of defending the open coast is based on alternative formulas with no associated probabilities.

more land at wetland elevation than just above it. Wetlands have been able to keep pace with the slow rise in sea level that most areas have experienced during the last few thousand years (Kaye and Barghoom 1964, Coleman and Smith 1964, Redfield 1967). Thus, areas that might have been covered with two to ten meters of water have wetlands instead. But if sea level rises more rapidly than the ability of wetlands to keep pace, the increase in wetland acreage of the last few thousand years will be negated (Figure 2C). Moreover, if the adjacent development is not removed, all the wetlands could be squeezed between the rising sea and the dikes or bulkheads used to protect the development (Figure 2D).

The vulnerability of coastal wetlands to inundation depends largely on their tidal range. Coastal wetlands are generally less than one tidal range above mean sea level; if the sea rose one tidal range overnight, all the existing wetlands would drown. Along the open coast, the tidal range is over 4 m in Maine, about 1.5 m along the mid-Atlantic, and 50 cm in the Gulf of Mexico. The shape of an embayment, however, can amplify or dampen the tidal range. Estuaries behind Atlantic coast barrier islands, for example, often have tidal ranges of 30–50 cm (NOAA 1985).

Kana and others (1988) surveyed transects over the wetlands and adjacent lowlands around Charleston, South Carolina, where the tidal range is about 2 m. Figure 3A shows how the concave profile would narrow the zones of low, high, and transitional marsh vegetation, while at least temporarily expanding the area of tidal flats, given the assumptions of a 90-cm rise by the year 2075 and current accretion rates. Figure 3B illustrates the loss of vegetated wet lands by the year 2100 for alternative estimates of sea level rise and vertical accretion. The net loss would be roughly proportional to sea level rise for the first 90 cm (plus accretion), but level off at 80% if developed areas are abandoned,[6] while eventually reaching 100% if these areas are protected.

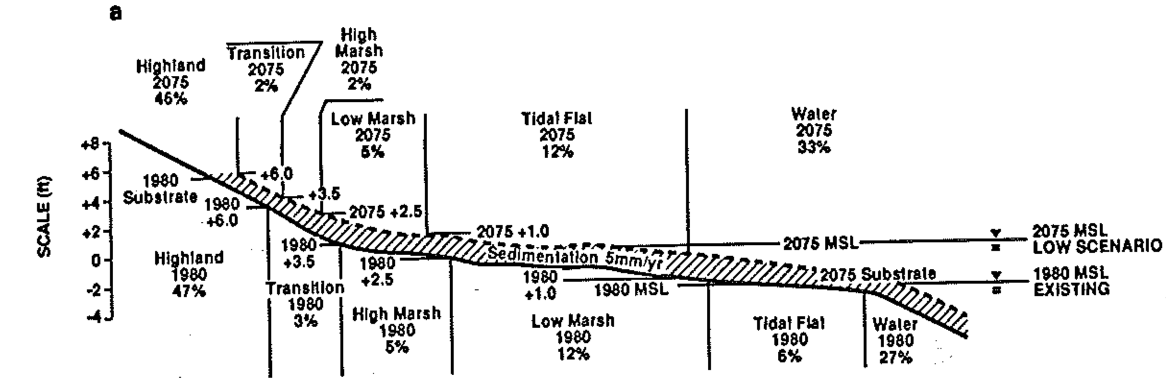
Table 1 shows the US Environmental Protection Agency's estimates of the likely loss of wetlands and dryland, as well as the cost of coastal defense, for a 50-, 100-, or 200-cm rise in sea level (EPA 1989, Titus and others 1990). If no shores are protected, a 1-m rise would result in a 26%–66% loss of wetlands, while a 2-m rise would increase the loss only slightly, to 29%–76% (Park and others 1989). If all coastal lowlands are protected with dikes, a 1-m rise would result in a 50%–82% loss and a 2-m rise, 66%–90%. The table also shows that the dryland at risk would be 14,000, 20,000, and 30,000 km² for rises of 50, 100, and 200 cm; this is the area that would eventually have to be abandoned if America intends to keep its coastal ecosystems in the natural condition.

In both studies, the additional wetlands lost from protecting developed shores would be a small fraction of the total wetland loss from sea level rise. But comparing the loss of wetland acreage understates the difference between protecting and abandoning developed areas: in the former case, many areas would lose all their wetlands; in the latter case, the band of wetlands would narrow, but persist. The ability of wetlands to provide habitat for fisheries appears to depend more on the length of wetland shorelines than on total area (Browder and others 1985). As Figure 4 illustrates, sea level rise would not necessarily reduce the length of wetland shores if developed areas are abandoned.

Deltas, Barrier Islands, and Saltwater Intrusion

For completeness, this section describes a number of other processes by which sea level rise could affect wetlands; for these processes, abandonment is unlikely to be a major part of the solution.

River and tidal deltas receive much more sediment than wetlands elsewhere; hence they may be able to keep pace with a more rapid rise in sea level. For example, the sediment washing down the Mississippi



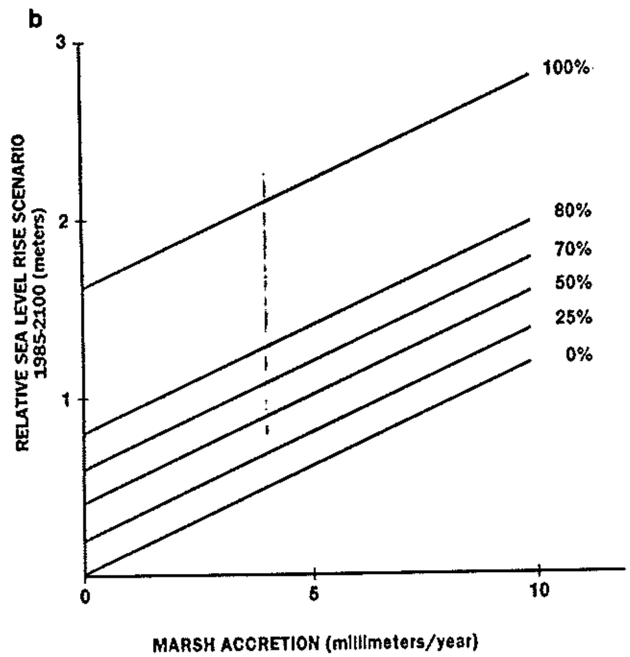


Figure 3. Impact of sea level rise on wetlands around Charleston, South Carolina, as reported by Kana and others (1988). (a) Shift in wetlands zonation along a shoreline profile. Assuming an accretion of 5 mm/yr, the various zones of vegetated wetlands would be squeezed, while the area of tidal flats would expand. (b) Percent marsh loss in the Charleston area by 2100 for combinations of sea level rise and marsh accretion. For a given rate of accretion, wetland loss would be roughly proportional to sea level rise until 80% of the wetlands are lost. After that point, there would be no net wetland loss if shores are not protected; if they are protected, the steeper slopes being inundated implies that less acreage would be lost per centimeter of sea level rise. Sources: Kana and others (1988), Titus (1988).

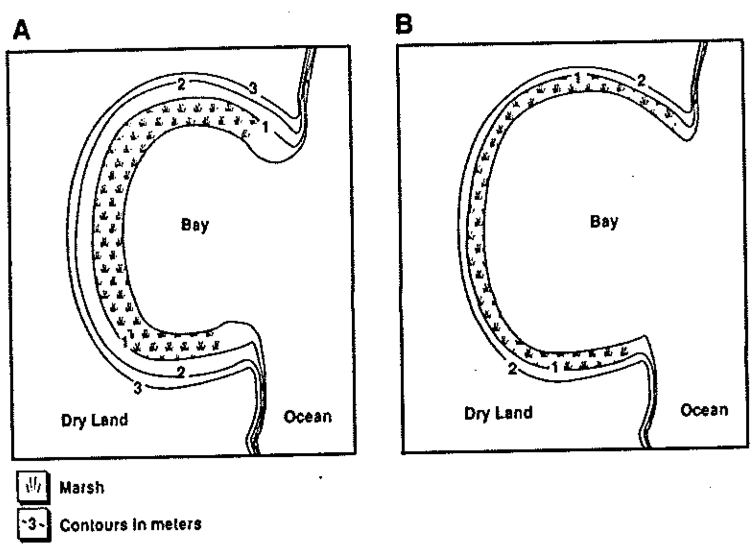


Figure 4. Although a one meter rise would generally reduce area of wetlands, it would not necessarily reduce the shoreline length or wetland–open water interface. **A:** Original condition. **B:** With 1 meter sea level rise.

River was long sufficient to sustain the delta and enable it to advance into the Gulf of Mexico, even though the delta was subsiding about 1 m per century (Gagliano and others 1981). Nevertheless, the current wetland area of river and tidal deltas is predicated on the current rate of sea level rise; for a given supply of sediment, a doubling in the rate of relative sea level rise would roughly halve the sustainable area of wetlands.[7]

Human activities seem likely to thwart the ability of deltas to keep pace with sea level rise. Dams along the Nile, Niger, Colorado, and others rivers throughout the world prevent water and sediment from reaching the deltas, many of which are eroding rapidly (Milliman and Meade 1983). In the United States, flood protection levees and channels for navigation, as well as dams, are preventing sediment from reaching most of Louisiana's coastal wetlands, leading to an annual loss of 100 km^2/yr (LWPP 1987). Officials in other countries are currently considering dams and flood control levees, with little thought about the resulting impacts on deltaic wetlands as sea level rises.[8]

Barrier islands tend to respond to sea level rise by migrating landward, as storms wash sand from the ocean to the bay side (Leatherman 1982). This "overwash" process may enable undeveloped barrier islands and their adjacent wetlands to keep pace with an accelerated rise in sea level. However, sea level rise might also cause these islands to disintegrate, which has already happened in Louisiana (Penland and others 1988). Although additional inlets would create new tidal deltas, the long-term impact of barrier-island disintegration would be to reduce total wetland acreage, as larger waves could enter the estuary and erode them (LWPP 1987). The deepening of estuaries associated with rising sea level would also allow larger waves to strike wetland shores.

Development on barrier islands could have an ambiguous impact. Structures and other human activities thwart the ability of storms to wash sand landward to nourish the bayside wetlands. On the other hand, the value of the development virtually guarantees that substantial efforts will be taken to ensure that these islands do not break up; barrier islands will continue to prevent ocean waves from striking wetlands in the back bays.

Finally, sea level rise could increase the salinity of estuaries (Hull and Titus 1986, Williams 1989). In many areas, the zonation of wetlands depends as much on proximity to the sea—which determines salinity—as on elevation. The most seaward wetlands are salt marshes, or their tropical equivalent, mangrove swamps. As one moves inland, the fresh water flowing to the sea reduces salinity, and brackish wetlands are found. Still farther inland, fresh water completely repels all salt water and fresh marshes and cypress swamps are found. Although they may be tens (even hundreds) of kilometers inland, they are often no higher than the saltwater wetlands.

If salt water invades them, freshwater species would often be replaced with those that are salt-tolerant. However, cypress swamps in the southeast, as well as some fresh "floating marshes" lack a suitable base for salt marshes to form. Saltwater intrusion could convert these wetlands to open water, which is already occurring in Louisiana (Wicker and others 1980).

Alternative Approaches for Allowing Wetlands to Migrate

Table 2 lists seven strategies for abandoning coastal lowlands as sea level rises. These strategies fit broadly into three categories:

- Preventing development of areas likely to be inundated
- Doing nothing today—allowing areas to be developed and abandoning them later
- Presumed mobility—allowing development today but only on the condition that the property will not be protected from rising water levels.

Figure 5 illustrates the three approaches.

Governments can prevent development either by (#1) prohibiting it through regulation and legislation, or (#2) purchasing the property. Because these options apply only to areas that are still undeveloped, most states would also have to consider mechanisms for abandoning developed areas, even if preventing development becomes their primary strategy for protecting wetlands.

Developed lowlands can be abandoned either by doing nothing now and reacting to the problem later, or by anticipating it now. Table 2 lists three ways for eventually solving the problem if no action is taken today: (#3) laws requiring people to abandon property, (#4) public purchase of land and structures, and (#5) ending governmental subsidies of coastal protection but otherwise relying on economics and the sea itself to remove structures.[9]

The final category of strategies, "presumed mobility," shifts the risk of sea level rise from the environ-

Table 2. Options for allowing wetlands to migrate landward

Policy	Description
I. Prevent areas from being developed (undeveloped areas only)	
1. Prohibit development	Statutes or regulations prevent construction in particular areas.
2. Buy coastal land	Government agencies or conservancies purchase land onto which wetlands could migrate.
II. Allow development	
A. Defer action	
3. Order people out later	Ignore sea level rise on the assumption that the government will require people to remove structures when sea level rises enough for them to interfere with landward migration of ecosystems.
4. Buy people out later	Ignore sea level rise now on the assumption that government will buy out properties when sea level rises enough for them to interfere with ecosystem.
5. Rely on economics	End subsidies to coastal development but otherwise ignore sea level rise on the assumption that governmental action will never be necessary because people will voluntarily abandon their properties, provided that the government does not subsidize the protection or construction of such property.
B. Presumed mobility	
6. Prohibit bulkheads	Do not interfere with private activities today, but explicitly notify property owners that as sea level rises they will not be allowed to construct bulkheads to protect their properties.
7. Leases	Do not interfere with private activities today but convert (with compensation if necessary) property rights of current owners to long-term leases which expire after 99 years, or conditional leases, which expire whenever the sea rises enough to inundate the property. Underlying ownership could belong to the public or a private conservancy group.

ment to private property owners by institutionalizing the presumption that development will have to make way for migrating ecosystems. These options allow market forces to decide whether, when, and how people will develop coastal areas, based on investors' assessments of the risk of sea level rise and the profits from erecting structures with limited lifetimes. With the likely abandonment 100 years in the future, the constraint of an eventual abandonment would probably do little to change near-term development decisions. But over time, developers would have an increasing incentive to design houses that can be easily moved. In the final decade or so before abandonment, owners would stop improving property and would gradually allow it to depreciate, perhaps converting homes to rental property.

The State of Maine has explicitly adopted presumed mobility for protecting wetlands in areas developed after 1987, implementing it with (#6) prohibitions of future bulkhead construction; although no other states have explicitly adopted this approach for protecting wetlands along sheltered waters, most coastal states restrict bulkheads and seawalls along the open ocean coast, in order to protect beaches.

Finally, the article examines (#7) incorporating presumed mobility into the deeds of coastal property, effectively converting land ownership into long-term and/or conditional leases that expire when the sea rises enough to inundate the property. Such a conversion might be accomplished by changing laws on property ownership[10]; by purchasing property through eminent domain and leasing it back to the current owners; or, in the case of newly developed areas, as part of the negotiating process by which builders get permits to develop coastal lowlands. In effect, society would be buying an option to take over coastal property should it be necessary to protect ecosystems.

Aside from a few passing references in the author's previous publications (Titus 1984, 1986, 1990b), this is a new approach for protecting natural shorelines and hence warrants considerable skepticism. Nevertheless, conditional leases have often been used by the National Park Service; rather than buying homes outright, it pays a substantially reduced price to take over the property when the current owner dies. Moreover the concept is taught to beginning real estate agents (Galaty and others 1985).

All of the seven options, in theory, could be implemented by governments at one or more levels. In addition, private conservancies could purchase (#2) land

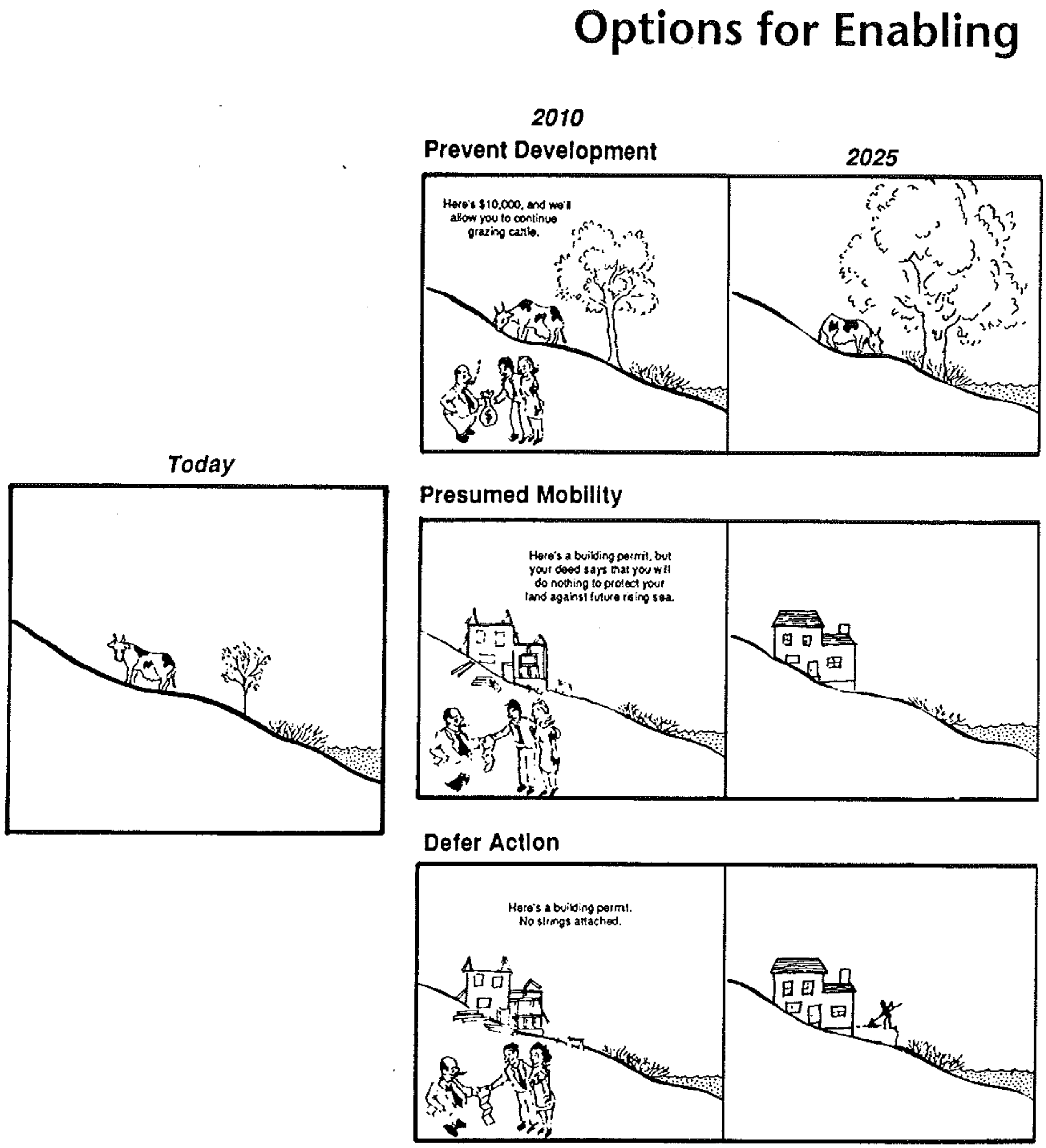


Figure 5. Conceptual description of three policies for allowing wetlands to migrate inland as sea level rises: preventing development, doing nothing today, and presumed mobility.

or (#7) the right to take it over when sea level rises. Although they would lack the resources to solve the nationwide problem, they could target and protect some of the most "critical" ecosystems, and taking some actions could help motivate governmental action.

If local governments decide to oppose development that would prevent wetlands from migrating inland, it may be administratively convenient for developers to come to terms with a conservancy group before applying for building permits or zoning changes.

Wetlands to Migrate Inland

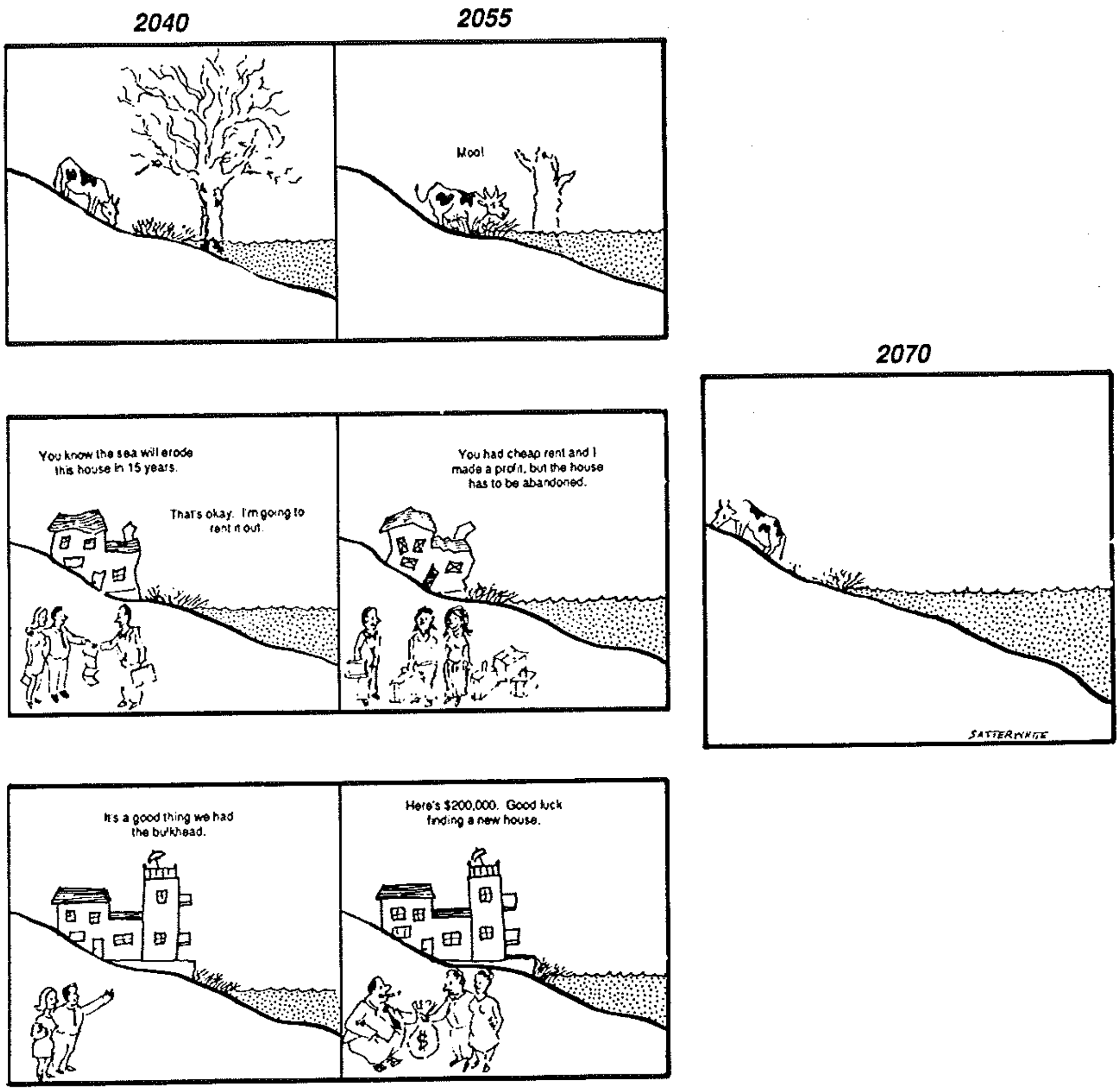


Figure 5. *Continued*

Ability of Various Strategies to Satisfy Desirable Criteria

The decision whether and how to abandon a particular coastal area will depend on the interplay of economic, environmental, and social factors, a process that will vary from place to place and hence cannot be reliably generalized. Nevertheless, so that the strategies can be viewed by a common framework, the following discussion examines each of them in terms of their abilities to satisfy various desirable criteria, as summarized in Table 3.

Table 3. Ability of alternative strategies to satisfy desirable criterim

Policy for protecting natural shorelines as sea level rises	Cost to public	Social cost (vs no sea level rise)		Economic efficiency	Performance under uncertainty	
		Present value	Cumulative		Sea level	Economics
Prevent development*						
1. Prohibit development	None	Speculative premium + <1% of base value	Land	Poor	No	Yes
2. Buy coastal land	Speculative premium	Speculative premium + <1% of base value	Land	Poor	No	Yes
Defer action						
3. Order people out later	None	<1% of land and structures	Land and structures	Fair	Yes	Perhaps
4. Buy out later	Land and structures	<1% of land and structures	Land and structures	Fair	Yes	No
5. Rely on elements/ economics	None	<1% of land and structures	Land and structures	Fair (if it works)	Yes	Useless
Presumed mobility						
6. No bulkheads	None	<1% of land value	Land + residual value of structures	Optimal	Yes	Yes
7. Leases	<1% of land and residual value of structures	<1% of land value	Land + residual value of structures	Optimal	Yes	Yes

*Only applicable for areas that have not yet been developed.

Cumulative Cost

If two strategies would be equally successful in protecting the environment, the first question most policy makers ask would be: "What are the relative costs?" However, different people mean different things by "cost." As representatives of the taxpayers, legislators would logically want to know the cost to the public; but as representatives of all citizens, they must consider the social cost, which also includes the cost to people who must yield their property to the sea.

Cost to the public. There would be no direct cost to taxpayers from telling property owners that they cannot build (#1) or, if they already have built, that they will have to vacate the property (#3, #6).[11] Relying on economics to induce an abandonment (#5) would even save taxpayers money, as subsidies for flood insurance and coastal protection were eliminated.

Buying land likely to be inundated (#2) would be more expensive. If applied to all 20,000 km^2 of coastal lowlands likely to be inundated, such a policy would imply buying out entire cities and hence the cost would be prohibitive; even if densely developed areas were exempt, the cost of buying undeveloped land and moderate-density areas would amount to tens and perhaps hundreds of billions of dollars.[12]

If limited to undeveloped land, the net cost to taxpayers of this strategy might be reduced to the *speculative premium* associated with the potential for future development. The first column of Table 4 compares costs to the public for a parcel of forest likely to be flooded in 100 years. Suppose that the parcel would be worth $10,000 for the timber alone, but worth $100,000 given the potential to build houses with views of the bay and only a short commute to the ocean. If the government bought the land, logging could continue, recovering the $10,000 logging value, thereby reducing the net cost to the $90,000 speculative premium. Where premiums are high, the proceeds from maintaining alternative uses such as logging, farming, parks, or recreation areas would not substantially reduce the net cost to taxpayers; but in remote areas premiums are lower.

The cost of converting ownership to long-term and conditional leases (#7) would depend on how they were implemented. If enacted legislatively or as part of the permit process for coastal development, they might have no cost to the taxpayer; if compensated,

Table 3. *Continued*

Constitutional	Equitable	Political feasibility	Risk of backsliding	New institutional requirements	Likelihood of success
No	No	None	Possible	Regulatory	Almost certain at first, unlikely in long run
Yes	Yes	None	Possible	Park Service aquisition	Almost certain at first, unlikely in long run
Maybe	Doubtul	Low	Very likely	Police	Unlikely
Yes	Yes	Low	Very likely	Park Service aquisition	Unlikely
Yes	Yes	Good	Low	Hazard mitigation	Unlikely
Probably	Usually	Good	Likely	Regulatory	Very likely
Yes	Yes	Fair	Very unlikely	Change in titles of real property	Almost certain

the costs would be significant, but probably less than 1% of the cost of purchasing coastal lowlands. For example, if owners do not relinquish the property for 100 years, the fair market value of the property would generally be calculated by "discounting" the current value over a period of 100 years. Assuming the private-sector discount rate to be 5% implies that the costs would be about $1400—0.7% of the cost of buying the land and the house. Moreover, the price might be further discounted according to the probability that the sea will rise enough to inundate the property. For example, if the land is 2 m above high water, and there is only a 1% chance of such a rise by 2100, the market value of the right to take over the property when it is inundated would be reduced to $14.[13]

An unusual aspect of this approach is that because most of the costs are in the distant future, using a high discount rate makes presumed mobility more economically feasible, in stark contrast to the many environmental policies where a near-term action produces benefits over future decades and economic viability rests on the assumption of a low discount rate. For example, a 10% discount rate would lower the $1400 to $15 for the hypothetical parcel of land. Another novel feature is that in negotiating the assumed abandonment year for calculating compensation, the "regulated party" has an incentive to argue that the problem is more severe than the government claims; if the sea is rising faster than assumed, the property will be abandoned sooner and hence the cost of abandonment and resulting compensation will be greater. This feature may prove useful in negotiating with developers who will not want to scare off potential homebuyers by understating the expected lifetime of the property.

Social cost. Some policies that seem to be a bargain when one considers only the cost to the taxpayer turn out to be quite expensive when the costs to private parties are considered as well. The social cost of prohibiting development (#1), for example, is as great as the cost of buying the land (#2), because both policies involve the same physical action. The only difference is that the property owner takes the loss in the former case, while taxpayers bear the burden in the latter case. Similarly, taking no action until areas must be abandoned implies that land will be developed and that perfectly good structures will be lost; the only difference between strategies is that in one case (#4) the government compensates property owners, while in two cases (#3 and #5), it does not. The two options for presumed mobility each imply that investors will only build structures that they are prepared to move or write off as sea level rises, and that they will gradually allow property to depreciate in the decade before abandonment. The only difference is that the conversion to conditional/long-term leases would involve compensation and a change in the legal status of property.

Table 4. Costs (profits) of alternative abandonment policies for hypothetical coastal property[a]

Option	Cumulative cost			Discounted present value		
	Public	Private	Social	Public	Private	Social
1. Prohibit development	0	90[b]	40[c]	0	90[b]	40[c]
2. Buy land	90[b]	0	40[c]	90	0	40[c]
3. Order people out later	0	190[d]	140[c]	0	1.44[d]	1.06[c]
4. Buy people out later	190[d]	0	140[c]	1.44[d]	0	1.06[c]
5. Rely on economics and elements	0	190[d]	140[c]	0	1.44[d]	1.06[c]
6. Prohibit bulkheads	0	110[e]	60[c]	0	0.84[e]	0.46[c]
7. Leases						
1990[g]	1.44[f]	0	0	1.44[f]	(1.44[f])	0
2090[g]	0	110[e]	60[c]	0	0.84[e]	0.46[c]
Total	1.44[f]	110	60[c]	1.44[f]	(0.6[f])	0.46[c]

[a]Assumptions: Land is worth $10,000 for logging over next century. By building a $100,000 house, the total property value will be $200,000. If sea level rise is not anticipated, the $100,000 structure can be depreciated by 1% per year the last ten years before inundation. If sea level rise is anticipated, property can be 90% depreciated or moved for $10,000. If property is not developed, the next available lot would be only worth $150,000 with a $100,000 house. Social and private discount rate of 5%.

[b]Loss of speculative premium (100–90).

[c]Nets out $50,000 gain to owner of inland property.

[d]Reflects loss of land and structures.

[e]Assumes depreciation or ability to move house for $10,000.

[f]Although property could be depreciated with 100 years' notice, these calculations assume that consumption would not make an allowance for depreciation; as a result, private parties would make a profit on the transaction.

[g]For the lease option, we display costs incurred today and 100 years hence separately.

From the standpoint of cumulative cost, buying land or prohibiting development is least expensive, since only the land will be lost to the sea. The cost of presumed mobility would be somewhat greater because either structures will have to be moved or their undepreciated value will be lost. The cost of deferring action would be greatest because structures will not have been designed to be easily moved, and property owners will not have strategically run their houses into the ground.

The second and third columns of Table 4 illustrate the cumulative private and social costs for each of the seven options. Note that the social cost would be less than the sum of private and public costs: If the particular parcel at issue is not developed or is abandoned, another—albeit less desirable—property would be developed instead.

Economic Efficiency

Classical microeconomic theory defines economic efficiency as a condition in which (1) costs are minimized for a given level of output, (2) spending any more on a particular sector would increase the benefits by less than the additional expenditure,[14] but (3) spending any less would decrease benefits by more than the reduction in spending. Cost-benefit analysis (the application of microeconomic theory) focuses exclusively on achieving economic efficiency. For private corporations, financial theory shows that the most efficient investment should maximize the value of common stock.[15] (Policy makers, however, face other constraints, discussed below.)

Let us now examine two criteria related to economic efficiency: the present value of the social cost, and performance under uncertainty. For both of these criteria, presumed mobility appears to be most efficient.

Present value of future costs. Ultimately, society would have to weigh the costs and benefits of environmental protection, but because this article examines how (not whether) to protect wetlands, it focuses on the first condition of efficiency—minimizing cost for a given level of environmental protection—which is sometimes called "cost-effectiveness."

Economic efficiency includes an allowance for the fact that a dollar in the future is worth less than a dollar today. In principal, any time society invests resources today for future environmental protection, it would also be possible to invest the resources elsewhere and earn a return. Hence, cost-benefit analysis determines efficiency by "discounting" future monetary flows by the rate of return on investment.

Financial theory shows that the appropriate discount rate is equal to the rate on risk-free investments (e.g., US Treasury bonds) plus a risk premium. If markets are efficient, this risk premium depends not on the riskiness of the investment (total risk) but on the extent to which it increases the riskiness of the investor's portfolio, which depends on the correlation between the project's success and the success of other investments (Van Horne 1977). Thus, real estate whose value is highly related to society's wealth would have a high risk premium and hence a high required return; by contrast, purchasing insurance is generally viewed as rational, even though on average it loses money. The risks associated with policies that anticipate sea level rise depend primarily on uncertainty surrounding global warming and sea level rise, not the performance of the economy. Hence, these policies can be viewed as insurance and the appropriate social discount rate for evaluating their benefits would be less than the risk-free bond rate (although compensation might be calculated using the higher required return on real estate).

The final three columns of Table 4 illustrate the present value of costs associated with the various options, assuming a 5% discount rate. Policies that prevent development (#1, #2) are by far the most expensive; because they are implemented today, the costs are not discounted, and society loses whatever value could be obtained by developing the property and using it between now and whenever it had to be abandoned. By contrast, all of the options involving a subsequent abandonment allow the property to be used in the intervening years. The cost of presumed mobility is somewhat lower than deferring action for the same reasons its cumulative cost is lower.

Performance under uncertainty. This article has discussed costs as if we knew how rapidly sea level will rise; in reality, it is very uncertain. Although sea level has been rising along most of the world's coasts for at least the last century, Meier (1990) suggests that it is possible that sea level will drop between now and 2050. Thus, policies whose success depends on accurately predicting sea level rise have a good chance of failing. Policies that do not require an accurate forecast are known as "robust".[16]

Prohibiting development and purchasing land require officials to draw a line on a map and focus only on the seaward side. Once the sea has risen above that line, the wetlands will be lost; but if the sea never reaches this line, society will have wasted resources by unnecessarily redirecting development farther inland. Doing nothing eliminates the risk of doing too much, but the risk of doing too little is even greater. By contrast, presumed mobility is totally robust: if sea level does not rise, it costs nothing; and no matter how much it does rise, natural shorelines will be protected.

Efforts to predict the fate of the US coastal zone are also confounded by our uncertainty regarding future coastal development. No policy can avoid the fact that abandoning the coast will cost more if coastal property becomes more valuable. Nevertheless, both presumed mobility and prohibiting coastal development are robust as far as costs to the taxpayer are concerned, because the compensation is fixed today.

Equity

Economic efficiency assumes that one cares about the total cost but is unconcerned about who pays. Economists have long been aware of this limitation, but point out that (1) individual investors are concerned solely with their own profit and loss and (2) public policy makers can, in principle, ensure that everyone benefits by compensating would-be losers with the proceeds of a windfall-profits tax or, in the case of intergenerational issues, by establishing trust funds (Baumol 1965). The Italian economist Vilfredo Pareto (1897) proposed as an equity criteria the condition in which it is not possible to make anyone better off without making someone worse off, a criteria that is now known as "Pareto optimality" (Samuelson and Nordhaus 1989).

Unfortunately, governments usually do not have the option of coupling policy initiatives with windfall-profit taxes to compensate losers, nor can they reliably create trust funds whose proceeds would be guaranteed to solve a particular problem several decades later. For this reason, policy makers must consider whether policies are "fair," a condition that philosophers have debated for centuries.

One solution would be to only consider Pareto improvements—that is, policies with no losers. However, for new issues such as sea level rise, defining a Pareto improvement may be difficult because there is no agreement among the various parties on what would happen without the proposed policy; even winners may perceive themselves as losers. Property owners assume they have the right to protect their property, and would find prohibition (#1) or eviction (#3) as inequitable. Environmentalists could point to public ownership of the intertidal zone and the "polluter pays principal" and conclude that people have no inherent right to bulkhead property at the expense of the environment, and would thus question the equity of compensating property owners (#2, #4).

To completely avoid the equity problem, one would have to ensure that there would be no losers, even given the initial allocation of rights most favorable to the potential losers, which is impossible if one group insists on compensation while another group refuses to pay. Nevertheless, prohibiting bulkheads (#6) helps minimize the conflict by laying out the "rules of the game" a generation or so before they become effective. People's idea of fairness depends mostly on the expectations with which they grew up; a policy is easier to accept if people never expected anything else. Moreover, if future conditions necessitate policy changes, a common baseline will make it easier to agree on how much the policy changes cost particular individuals (even if people continue to disagree on how much other people deserve to pay).

A final reason why establishing the rules of the game in advance helps to ensure equity is that, as the philosopher John Rawls (1971) pointed out, it is easiest to agree on what is fair when the judges of fairness are disinterested parties. Rawls defined an equitable system of distributing wealth as one that a person would choose if he did not yet know whether he would be born rich or poor. This mechanism for ensuring fairness is also embodied in our judicial system, which excludes from juries anyone associated with the victim, a witness, the defense, or the prosecutor.

The leasing approach to presumed mobility seems most likely to be a Pareto improvement from the perspective of all parties concerned. To homeowners, it is an improvement as long as compensation is greater than their estimate of the present value of using their property after the sea has risen enough to inundate it; to taxpayers, it is a Pareto improvement as long as the compensation is less than the present value of eventually losing the wetlands (adjusted by the subjective probability that property owners would eventually abandon their homes anyway).

Under the buy-out later approach (#4), a Pareto improvement would be possible only if society viewed a hectare of wetlands as more valuable than the market price of the property and was willing to pay the owner such a sum. Under the leasing option, however, policy makers can engage in arbitrage with respect to both the discount rate and the likelihood of sea level rise: Many people view protecting the environment for future generations as equally important to protecting it for the current generation, implying little if any discounting of the future; by contrast, real estate investors have a short time horizon. In addition, people who invest in property likely to be flooded by rising seas tend to be more skeptical about future sea level rise than environmentalists and the public at large.

Consider once again the $100,000 lot on which an investor intends to build a $100,000 home. If inundation 100 years hence is certain and there is a 5% real return on investment after taxes, the owner would require compensation of $1400. However, a property owner that viewed inundation as 10% probable would require only $140. Suppose that the wetlands are worth $20,000. If no action is taken today, the value of the wetlands will not subsequently justify abandoning the $200,000 property. However, if environmentalists believe that the existence of coastal wetlands 100 years hence is at least 50% as important having wetlands today, and if they believe that inundation is 50% probable, then from their perspective the value of presumed mobility would be $5000. Thus the writer suspects that even the least-sympathetic environmentalists would be willing to let the government pay a few hundred dollars. If environmental quality were traded on Wall Street, there is little doubt the arbitrageurs could reap substantial profits by protecting coastal wetlands. Politicians, who are equally adept at mediating different perspectives should be able to take advantage of this situation.

Constitutionality

Efficiency and equity are embodied in our legal system. People would not create wealth if they could not expect to retain some of it. When the founding fathers concluded that a Bill of Rights would be necessary to convince reluctant states to join the Union, the right to property was one of their most fundamental concerns. The 5th Amendment of the US Constitution provides that no one will be "deprived of life, liberty, or property without due process of law nor shall private property be taken for public use without just compensation," a provision commonly known as the "takings clause."

When the Bill of Rights was ratified, the primary concern was literal confiscation of property. Judges and legal scholars have long agreed, for example, that the prohibition was never meant to apply to indirect impacts of government projects on investment values.[18] No one seriously challenged the constitutionality of federal subsidies to the railroads, even though they hurt shipping and the Pony Express; nor was the impact of the interstate highway system on railroads considered to be a taking. The 5th Amendment ensures that government is sensitive to equity, but not that every action is a Pareto improvement. Nevertheless, because the same Congress that initiates actions also has the authority to tax windfall profits and compensate losers if appropriate, the political process has often been able to circumvent this problem.

The ascendancy of regulatory bureaucracies, however, has made this balance more difficult to achieve because their authority to impose costs on private parties is not matched by an ability to compensate losers. As a result, the courts have had to specify more clearly what is and what is not a taking, by mediating the conflicts between the 5th Amendment and other constitutional responsibilities of government.

The definition of a taking is still evolving, and sea level rise may precipitate further evolution. State courts have allowed zoning and other restrictions on development if they either abate nuisances, do not arbitrarily or suddenly reduce property values, enable alternative profitable uses to continue, have negligible impacts on property values, do not take away use that the owner reasonably anticipated when buying, or exercise governmental prerogatives that the owner should have reasonably anticipated (Travis 1980).

Along the coast, the rights of government have been somewhat greater (MacRae 1984). The "public trust doctrine" from English common law, as well as numerous state constitutions, places tidal waters in the hands of the public. The US Supreme Court has ruled that the interstate commerce clause of the Constitution gives the federal government a property right in the navigable waters of the United States, commonly known as "navigational servitude" (*United States v Chandler-Dunbar Water Power Co.* 1913; *United States v Rands* 1967). This clause has enabled the government to reroute rivers without compensating people who are left "high and dry" (*Gibson v United States* 1897) and to build bridges that cut people off from access to navigational waters (*Gilman v Philadelphia* 1865). When water levels are unusually low in the Great Lakes, the federal government can prevent people from erecting bulkheads in areas that are currently above the high-water mark but that have been under water during previous higher levels, largely on the grounds that the bulkheads can reasonably be anticipated to eventually impede the waterway (since that is the major reason for building them). Courts have also interpreted this clause as allowing the federal government to build navigational works that cause property to erode, without compensating the victims (MacRae 1984).

Because the framers of the Constitution did not know about sea level rise, and did not explicitly mention tidal waters, one can only speculate whether they intended to include only the navigational waterways that existed in 1789 or all waterways that would occur under natural conditions. Even if they would have included the latter, it is unclear whether interpretations based on the commerce clause would outweigh the more explicit wording of the 5th Amendment. Nevertheless, under the public trust doctrine and navigational servitude, governments have been able to prevent people from filling intertidal wetlands. Although this does not mean that the government can prevent someone from developing an area on the grounds that it may become a waterway in the future, the logic might permit the federal government to prohibit bulkheads that block landward penetration of navigational waterways.

Another way to frame the question is to ask whether changes in shorelines resulting from civil engineering alter land ownership. In many states, naturally accreting land belongs to waterfront owners while land artificially created belongs to the public. Even if a shore retreats and the owner refills the land several years later, many state laws imply that the new land belongs to the public. In *Kaiser Aetna v United States* (1979) case, the court ruled that if a private lake is connected to the sea, the artificial creation of tidal waters does not abolish private rights to the shore. The question is whether one can preempt public rights to intertidal waters by erecting a structure before the sea rises, and if so, whether governments can, in turn, preempt that possibility by regulating structures that currently do not interfere with public rights but eventually will.

Prohibiting all development (#1) would probably not be constitutional if uncompensated. Granted: regulation requiring homes to be set back from the shore have withstood court challenges; however, lots have usually been deep enough and erosion slow enough to permit development on the properties to which they apply. Prohibiting all development on thousands of square kilometers of land would effectively confiscate people's property. By contrast, because the 5th Amendment only prohibits takings without compensation, strategies that involve buying property outright (#2, #4) or buying the right to take it over at a future date (#7) would clearly be allowed under the US Constitution (although the powers of particular units of government to do so would depend on state constitutions and local charter restrictions on the use of eminent domain).

Less certain is the constitutionality of prohibiting construction of bulkheads or otherwise evicting people from their property when they have the resources to protect it (#3, #6). A better case can be made for their constitutionality if they take effect decades after they are implemented than if they take effect immediately: Courts generally have found that an action must have a substantial impact on property values to be a taking; our example where having to abandon a property 100 years hence would decrease property values 0.007%–

0.7% assuming a 5%–10% rate of return suggests that an effective date of 2090 would have a negligible impact. However, judges are not economists and the fact that there would eventually be a large impact may be more persuasive than the relatively small impact on current values. Moreover, there is always the risk that courts in the future will interpret the 5th Amendment more conservatively than today and invalidate these regulations just when they are about to take effect.

Political and Institutional Feasibility and the Risk of Backsliding

Political feasibility is another compelling reason to avoid policies that create a class of losers. Most politicians realize that if they are not careful, actions that help the community while penalizing a few property owners can motivate the losers to actively seek their removal from office, without creating a countervailing effort from the larger group that benefits. Most coastal property owners have grudgingly accepted setback regulations, which still enable them to build on their property. However, any policy that prohibited development of large expanses of land would have a high risk of motivating coalitions of small and large investors to support political challengers. On the other hand, purchasing all the coastal lowlands would require substantial increases in taxes, which has also been known to end politicians' careers.

If a class of losers must be created, the most politically feasible approach is to ensure that the losers (1) do not vote and (2) are wealthy enough to attract little sympathy from the press. Maine has found it easier to implement presumed mobility, in part, because the majority of coastal property owners are second-home owners and live in another state. Another group of nonvoters that might be "left with the bill" would be the generations of people who will own coastal property after the middle of the next century. Although that may seen unfair, these generations are, after all, the beneficiaries of the policies for which they would be paying. Thus, presumed mobility and deferring action are politically feasible, at least for now.

Deferring action, however, simply implies that future politicians would have to choose between more stringent versions of options that are politically infeasible today. Land purchases would be even more expensive than today because more areas would have been developed; and the outcry that would result if people were evicted from their homes would be far worse than the reaction to prohibiting additional development. Even if bulkhead provisions had been implemented decades in advance, it would be difficult for local officials to withstand the pressures to continually delay the effective dates of the regulations.

Implementing presumed mobility through leases would have the best chance of withstanding challenges. If conservancy groups own the underlying land once the leases expire, abandonment of particular parcels of land will be out of the politicians' hands; and because courts rarely interfere with deed provisions, abandonment would be largely immune to court challenges as well. Even if state or federal governments own the underlying property, the expiration of a lease is generally taken more seriously by leaseholders than regulations because it is part of a contract that they or their benefactors have signed. Hence, leaseholders would be more likely to hedge their challenges by preparing for the eventual abandonment, which would diminish both the credibility and emotional fervor of any political or legal challenges.

Nevertheless, there would be substantial legal and administrative costs in initiating a program based on conditional leases. Unlike the other strategies, this approach would require a fundamental change in one of our institutions, real property titles. Moreover, because it has never been applied on the broad scale necessary to protect coastal wetlands, unanticipated problems would undoubtedly emerge. On the other hand, deferring action and subsequently purchasing or requiring people to abandon an area the size of Massachusetts would keep the lawyers busy as well.

Likelihood of Success

The likelihood that a strategy will protect coastal wetlands depends on the likelihood that it will ensure the availability of vacant land and on the likelihood that coastal wetlands will be able to migrate onto that land.

Securing vacant land. In the short run, strategies based on preventing development would probably be successful. States have been able to require buffer zones between new construction and wetlands. Moreover, there are already many parks and wildlife refuges along the coast that could be extended inland. Preventing development can have social benefits other than long-term wetland migration: Extending refuges inland helps to protect terrestrial wildlife that commutes to estuaries for feeding. The typical setback of 20–30 meters helps to minimize current human interference with ecosystems, decreases vulnerability of houses to flooding, and requires developers to leave property owners with slightly larger lots, which is not altogether undesirable. The long-term success of this approach is limited, however, by the impracticality of applying it to more than isolated refuges and the first 100 or so meters from the shore.

Deferring action seems unlikely to protect wetlands because property owners will be able to afford bulkheads; it will be politically impossible to evict people from their property; and the costs of buying developed coastal lowlands later will be even more prohibitive than buying undeveloped land today.

Strategies based on presumed mobility seem most likely to accomplish the necessary abandonment in the long run. Conditional or long-term leases would be almost immune to court challenges and, if implemented by the private sector, to political challenges as well. Bulkhead restrictions are more likely to fail in the short run than setbacks or land purchases, since the latter, once implemented, virtually ensure the availability of land while bulkhead restrictions are vulnerable to political pressures and court challenges. Nevertheless, because they are as likely to work for a 5-m rise as a 50-cm rise, bulkhead restrictions are more likely to succeed in the long run.

Likelihood wetlands will take root. In spite of the many difficulties with prohibiting development or purchasing all the undeveloped land, these options are superior in one feature: the vacant land is unspoiled. By contrast, the other policies require wetlands to migrate onto land that had been developed. This difference suggests that for certain critical areas where resources are available to purchase land up to the 6-m (20-ft) contour, the safest course of action is to do so.

Nevertheless, the ability of coastal plants and animals to take root on old tires, sunken ships, and abandoned streets suggests that coastal ecosystems will survive even if structures are not removed. In the case of long-term or conditional leases, homeowners and the conservancy group or government agencies with underlying title to the land might find it mutually beneficial if leases were extended a few years in return for a rent sufficient to cover the cost of enhancing the habitat that replaces the house.

Next Steps

If current activities continue, sea level rise will eventually threaten most coastal ecosystems in the United States. Although many of them could be saved through a gradual abandonment of coastal lowlands, a complete abandonment seems unrealistic.

A first step would be to decide the level of wetland protection that is desirable. In the case of estuaries largely enclosed by one state, such as Narragansett Bay, San Francisco Bay, Puget Sound, and numerous bays behind barrier islands, such decisions might be made by state governments. In other cases, such as Chesapeake and Delaware bays, new interstate compacts may suffice.

Although state and local governments often serve as proving grounds for the new strategies, national legislation may eventually be necessary. It is unclear whether such legislation would be more like the Coastal Zone Management Act (which encourages sound planning) or the Clean Air Act (which sets absolute limits to environmental degradation). But regardless of the ultimate nature of federal involvement, there should be a national goal.

As an initial target, the author suggests that we start with President Bush's stated goal of "no net loss" in wetlands. However, because sea level rise would cause a major loss of wetland acreage even without human interference, wetlands should be measured by the proportion of natural to armored shores instead of area. Even then, while the target of no net loss of natural shorelines is conceptually appealing, it may not be obtainable everywhere; on the other hand, in some areas, the loss of wetland acreage due to sea-level rise may require a reduction in armored shorelines to make up for the loss.

Our analysis suggests that in the long run, the least expensive way to protect coastal wetlands would be to allow people to use property today as they choose but on the condition that it will be abandoned if and when the sea rises enough to inundate it. Nevertheless, regulations and land purchases that prevent coastal development could also be important, particularly in the short run. In either case, it is urgent to implement a policy, not because there is an impending catastrophic loss of wetlands but because we may miss the opportunities to inexpensively prevent an eventual catastrophic loss if we do not act soon. To be effective, presumed mobility needs to be implemented 50–100 years before the physical abandonment, while setbacks and land purchases must be enacted before an area is developed.

To accelerate the process by which various levels of government protect coastal ecosystems from sea level rise, the author proposes that an interagency panel of the US government undertake a national study of the costs, benefits, and probability of success for various options for protecting the nation's natural shorelines. Such a study should be conducted on a state-by-state basis with sufficient detail for state decision making. It should also include case studies in cooperation with state and local governments to test the viability of the various options, and conclude with recommendations to both the US Congress and state governments.

Such an effort would probably take three years. It usually takes almost a year set up such a study, pick the panel, and transfer the funds to the participating states. The analysis itself would take about a year or so. Finally, close to a year would be required for technical and policy review and developing recommendations. Because it could take the better part of a decade (or more) to implement any recommendations, such a study should not be delayed.

It is difficult for Americans to imagine an area the size of Massachusetts or larger gradually being abandoned to allow coastal ecosystems to migrate inland. But is it any easier to accept a world in which these ecosystems are lost as we invest ever-increasing sums to hold back a rising sea?

Notes

1. In Louisiana, marsh buggies, canals, and boat traffic have also converted wetlands to open water.

2. By "lowland" we mean dry land within a few meters of high tide.

3. However, the change in the course of the Mississippi River advocated by many might necessitate an abandonment of the delta along the current main channel.

4. However, by preventing today's wetlands from converting to shallow waters, such a procedure would necessitate raising the elevation of shallow waters as well or risk the loss of some types of submerged aquatic vegetation.

5. However, no means has been devised to enable fish to travel freely from one side of a dike to the other.

6. The transects by Kana and others indicate that the average slope between zero and 90 cm above sea level is only one fifth that of the slope above the 90-cm contour. Therefore, the area of new wetlands created by a 90-cm rise would be only one fifth the area lost—an 80% loss. After that point, the area of new wetlands balances the area that it inundated.

7. Simple geometry suggests that for a delta with an equilibrium area, the annual volume of sediment added to the wetlands equals the area of wetlands times the annual rise in sea level, that is, the area of wetlands equals the volume of sediment divided by the rate of sea level rise.

8. Personal communications with S. Hug, Bangladesh Center for Advanced Studies, Dakka; M. El-Raey, Cairo University; and V. Asthana, Jawarhal Nehru University in Delhi.

9. Although the premise of this paper is that market economics alone would not lead people to abandon most coastal areas, it would probably be appropriate in some areas. Moreover, an end to government subsidies might discourage people from even developing some areas.

10. In some cases, this would require amending state constitutions.

11. There would be indirect costs, such as a decline in tax revenues. On the other hand, required expenditures would be less.

12. An average cost of $20,000 per acre would imply $100 billion. Although farmland in many areas would be less expensive, the average would also include the residential developments that are often found along estuarine shorelines, even in areas that are otherwise undeveloped.

13. There might be a good chance that the property will be inundated by 2200, but discounting $200,000 over 210 years gives an even smaller figure.

14. Technically, efficiency requires that the increased benefits in a particular sector must be less than the reduced benefits from whatever sector would be cut back to accommodate the increase; assuming that "costs" reflect the true opportunity cost, this is the same as requiring that incremental benefits be less than incremental costs.

15. Provided that taxes do not distort the picture.

16. Besides being more efficient, robust policies will also be more politically feasible, since they do not provide people with incentives to argue about whether sea level is going to rise.

17. However, some of these premiums will simply be transferred from the original shorefront owner to whoever has shorefront property after the abandonment.

18. In *Eldridge v Trezevant*, 160 U.S. 452 (1896), Justice Strong stated: "Acts done in the proper exercise of governmental powers, and not directly encroaching upon private property, though their consequences may impair its use, are universally held not to be a taking within the meaning of the constitutional provision."

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