RESPONDING TO GLOBAL WARMING ALONG THE U.S. COAST

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INTRODUCTION

The process of responding to accelerated sea level rise in the United States is well underway, at least for a phenomenon that is not expected for several decades. Over the last seven years, almost all of the coastal states have held at least one major conference on the subject, and a few of them have altered coastal development policies to accommodate a future rise. Public officials are generally familiar with the issue, as are representatives of the press, nongovernmental organizations, and coastal investors. The federal government has conducted assessments of possible nationwide responses, as well as implications for specific types of decisions such as the design of coastal drainage systems, maintaining recreational beaches, and protecting coastal wetlands.

This paper examines possible responses to sea level rise in the United States. Because the most important question is what we should actually do in response to rising sea level, we focus primarily on the planning and engineering strategies that will determine how activities on the coast eventually change. Nevertheless, because the process by which society comes to understand the need for action is also important, we close with a brief summary of the evolution of U.S. sea level rise studies in the 1980s.

FUTURE RESPONSES: SHORELINE RETREAT AND FLOODING

The most important responses to sea level rise in the United States can be broadly classified as responses to shoreline retreat increased flooding, and saltwater intrusion. In each case, the fundamental question is whether to retreat or hold back the sea.

Shoreline retreat has received by far the greatest attention; nevertheless, because flooding involves the same strategic questions, we combine the discussion. Because there is a general consensus in the United States to "let nature take its course" in national parks and other undeveloped areas, we examine only developed areas. We divide our discussion of this impact into two parts: barrier islands and the open coast, and sheltered areas. We conclude the section by discussing when action is likely to be necessary.

Barrier Islands and the Open Coast

Oceanfront communities could respond to sea level rise protecting developed areas with dikes, pumping sand onto the beach and other low areas, or retreating from the shore. Along mainland beaches, the latter option generally implies no coastal protection; in barrier islands, however, it would also be possible to engineer a landward retreat of the entire island, creating new land on the bayside to offset that lost to oceanside erosion. The four options are illustrated in Figure 2.

To get a rough understanding of the relative costs of these options, we examined Long Beach Island, a long, narrow barrier island developed with single-family homes and one and two-story businesses (See Figure 2). Table 1 illustrates the costs of the four options for a rise in sea level between 30 and 240 cm. For a rise greater than 50 cm, any of the protection options would be less expensive than allowing the sea to reclaim the valuable resort property. Although surrounding the entire island with a dike would be less expensive than raising the island, it would be culturally unacceptable because it would interfere with access to the beach and people would lose views of the bay.

Engineering a retreat would also be much less expensive than raising the island in place, because the latter option would require more (and higher quality) sand. However, this option would be vigorously opposed by the oceanfront owners who would have to move their houses to the bay side, as well as bayfront owners who might lose their access to the water. Moreover, filling new bayside land would disrupt back-bay ecosystems unless the estuary were also allowed to migrate landward onto the mainland (which we discuss below). As Table 2 shows, island raising would cost less than $600 per house per year until after sea level had risen more than 60 cm, which would be less than the rent for one week. Thus, we suspect that the more expensive but less disruptive approach of pumping sand onto beaches and the low bay sides of barrier islands would be the most commonplace, at least in the beginning.

Table 3 compares the ability of the four options to satisfy various desireable criteria. (Most of the rationale for this table is found in Titus 1990). An important lesson from the Long Beach Island study is that the least expensive solutions are not always the most likely; dikes are culturally unacceptable and an engineered retreat is administratively difficult. Nevertheless, the noneconomic criteria should not always outweigh economics.

Leatherman (1989) estimated the quantity of sand necessary to hold back the sea for every coastal state but Alaska, and estimated the cost assuming that sand does not become more expensive. Titus et al. (1990) adjusted those cost estimates on the assumption that as least-cost supplies are exhausted, it will be necessary to go farther out to sea for suitable sand. Table 4 illustrates the resulting estimates of dredging costs for current trends and rises in sea level of 50, 100, and 200 cm. Titus et al. also estimated the cost of elevating buildings and utilities as sea level rises.

These calculations are only rough estimates. leatherman probably underestimated total sand requirements by assuming that beaches would only be designed for a one-year storm; designing them for a 100-year storm would increase the cost by 50-100 percent. Moreover, Titus et al. ignored the cost of elevating multifamily buildings and sea level rise would be factored into routine reconstruction of water and sewer lines at no incremental cost. On the other hand, our calculations assume that all developed areas will be protected. Although this is a reasonable assumption for Long Beach Island and similar areas, it would be less expensive to abandon more lightly developed islands. Moreover, a number of states have already required construction to be set back from the shore a few hundred meters, suggesting that no protection would be required for the first 50 cm of sea level rise.

<u>Sheltered Waters</u>

Americans` affinity for beaches and concern for the environment has created a strong constituency against holding back the sea with dikes and seawalls, counterbalancing the natural tendency of all landowners to protect their property. Along the open coast, both interests can be accommodated, because beach nourishment protects property by maintaining the natural shoreline. Along sheltered waters, however, the prospects for avoiding a conflict are not as great. As Figure 3 shows, the protecting property with dikes and bulkheads, would prevent wetlands from migrating inland and could eventually result in their complete loss in some places.

In a recent EPA report to Congress on the implications of global warming, Park et al. (1989) examined the potential loss of wetlands and dry land for a sample of 46 sites comprising 10 percent of the U.S. coastal zone, for three alternative responses: no protection, protecting areas that are densely developed today with dikes and bulkheads, and protecting all shores. For each site, Weggel et al. (1989) estimated the cost of protecting developed areas from a 2-meter rise. Titus et al. (1990) used cost functions suggested by Weggel et al. and estimates of inundated land from Park et al. to interpolate the cost estimates, and developed confidence intervals for the estimates of lost land.

Table 4 illustrates the nationwide results (the source studies provide regional detail). For a one meter rise, the cost of protecting the most densely developed one thousand square miles of coastal lowlands would work out to $3,000 per acre per year, which would generally warrant protection. However, such protection would increase the loss of wetlands by 300-500 square miles, and reduce the area of shallow water for submerged vegetation by another 500-700 square miles. Moreover, many vacant areas are being rapidly developed. If all areas much be protected, the additional loss of wetlands would be 1800-2700 square miles, and another 3000-7000 square miles of shallow waters would be lost.

The political process will have to decide whether to abandon coastal lowlands to protect the environment. To help the necessary discussions get underway we are circulating a draft that investigates seven options for enabling coastal wetlands to migrate landward (Titus 1989). The first two apply only to undeveloped areas: prohibiting development and purchasing coastal lowlands. The next three involve doing nothing today and purchasing land and structures when inundation is imminent; forcing people to move out when inundation is imminent; or hoping that protection will prove to be uneconomic. The final two options, which we call "presumed mobility", allow people to use their property as they choose, but on the condition that they will eventually abandon it if and when sea level rise threatens it with inundation; presumed mobility could be implemented wither by prohibiting construction of bulkheads and dikes, or by converting property ownership to long-term or conditional leases that expire when sea level rises a particular amount.

Table 5 summarizes our assessment of each option to satisfy various desireable criteria, including low social cost, low cost to taxpayers, performance under uncertainty, equity, constitutionality, political feasibility and the risk of backsliding. Unlike the table for barrier islands, we omit environmental criteria because these options are each designed to achieve roughly the same level of environmental protection.

Our overall assessment is that presumed mobility would be the best general approach. A general prohibition of development would probably violate the takings clause of the Bill of Rights; buying 20,000 km^2 of land would be expensive, and in any event, these options only apply to areas that have not yet been developed. Doing nothing today seems unlikely to protect wetlands because (a) purchasing property in the future would be even more expensive if it is developed; (b) forcing people to move out of their homes would be politically impossible if they are willing to tax themselves to pay for the necessary protection; and (c) economics alone is unlikely to motivate people to abandon developed areas.

One of the most overlooked but important criteria is performance under uncertainty. No one knows how much sea level will rise in the future; only rough estimates are available. Thus policies likely to succeed for a rise anywhere between 0 and 3 m should be preferred over those that might be superior for a particular scenario but fail should other scenarios unfold. For this criteria, the approach of presumed mobility is clearly superior: ecosystems will be protected no matter how much sea level rises; real estate markets will be able to efficiently incorporate new information on sea level trends; and if the sea does not rise significantly, the policy costs nothing. By contrast, buying coastal lowlands or prohibiting development requires policy makers to draw a (disputable) line on a map above which the policy does not apply. If sea level rise more than assumed, ecosystems will eventually be lost; if it rises less, society will have unnecessarily forfeited the use of valuable coastal land.

When Will A Response Be Necessary?

A recent study by the National Research Council (Dean et al. 1987) concluded that because dikes can be erected in a relatively short period of time, no action is necessary today. This argument also applies for beach nourishment on the open coast. However, our analysis of wetland-protection options suggests that these measures are likely to be effective only if they are implemented several decades in advance: people would need several decades to depreciate structures and become accustomed to the idea that property must be abandoned to the sea to protect the environment.

A number of planning mechanisms are in place along the ocean coast to foster a retreat. North Carolina and a number of other states require houses to be set a few hundred meters back from the beach, and prohibit hard engineering structures along the beach. South Carolina prohibits reconstruction of storm-damaged property if they are too close to the shore.

Along wetland shores, however, only Maine has implemented planning measures to allow ecosystems to migrate inland. That state has explicitly incorporated presumed mobility into its development regulations, which state that structures are presumed to be moveable; in the case of apartments that are clearly not moveable, the regulations state that if the buildings would block the landward migration of wetlands and dunes resulting from a one meter rise in sea level, the developer must supply the state with a demolition plan. Although other states require construction to be set back somewhat from the wetlands, the setbacks are small compared with the inland migration of wetlands that would accompany a one meter rise in sea level.

FUTURE RESPONSES: Mississippi Delta

Louisiana is currently losing over 100 square kilometers of land per year because human activities are thwarting the processes that once enabled the Mississippi Delta to expand into the Gulf of Mexico. For thousands of years, the annual river flooding would deposit enough sediment to enable the delta to more than keep pace with sea level rise and its own tendency to subside. In the last century, however, the federal government has built dikes along the river and sealed off "distributaries", to prevent flooding and maintain a sufficiently rapid river flow to prevent sedimentation in the shipping lanes. As a result, sediment and nutrients from the river no longer reaches most of the wetlands, and they are being rapidly submerged. Moreover, with flows in distributaries cut off, saltwater is penetrating inland, converting cypress swamps to open water lakes and otherwise disrupting wetlands. If sea level rise accelerates, the already-rapid disintegration of coastal Louisiana would follow suit.

As with other coastal areas, dikes and abandonment are both possible. However, there is a general consensus that these options should be avoided if possible because in either event, most of the deltas wetlands would be lost, and those wetlands support 50 percent of the nation's shellfish and 25 percent of its fish catch. Thus, federal and state officials are focussing primarily on options to restore natural processes which would enable at least a large fraction of the delta to survive even an accelerated rise in sea level. The U.S. Congress has authorized a number of projects to divert freshwater and sediment to wetlands by effectively cutting holes in the dikes. Under current policies, however, only a small fraction of the river water is likely to be diverted by such projects, to avoid siltation of shipping lanes.

In the long run, protecting Louisiana's wetlands would require people to allow the vast majority of the river's discharge to reach the wetlands. This would be possible if navigation was separated from the streamflow of the river. One way to do this would be to construct a series of canals with locks between New Orleans and the Gulf of Mexico, and completely restore the natural flow of water to the delta below the canal. Unfortunately, requiring ships to pass through locks would hurt the economic viability of the Port of New Orleans. Another option would be to build a new deep-water port 10-20 miles to the east.

Perhaps the far-reaching response, one that has been advocated by the State's Secretary for Environmental Protection, would be to allow the river to change course and flow down the Atchafalaya River. Without a $1 billion river control structure, the river would already have done so. Although from the purely environmental perspective, this option is most appealing, it would further accelerate the loss of wetlands in the eastern part of the state, and enable saltwater to back up to New Orleans, requiring the city to find a new water supply.

It is somewhat ironic that human activities designed to prevent flooding may leave the entire area permanently below sea level in the long run. There may be a lesson for Bangladesh and other nations who are considering flood-protection dikes to protect land from surges in river levels: build dikes around a few cities, but make sure the river is still able to flood enough areas for the flow of water to slow sufficiently to deposit sediment onto farmland and wetlands, rather than being washed out to sea, where it will benefit no one.

FUTURE RESPONSE: SALTWATER INTRUSION

Responses to saltwater intrusion, like shoreline retreat and flooding, can either involve holding back the sea or adapting to a landward encroachment.

Preventing Salinity Increases

Figures 4 and 5 illustrate why sea level rise increases the salinity of estuaries and aquifers, respectively. In the former case, a rise in sea level increases the cross-sectional area of the estuary, slowing the average flow of water to the sea, the major process that keeps the estuary from having the same salinity as the ocean. Assuming that the tides continue to carry the same amount of water and that mixing stays constant, salinity will increase because the force of freshwater is reduced while the saltwater force is increased. Moreover, if the bay becomes wider, the tidal exchange of water will increase, further increasing the freshwater force. (Because it is difficult to graphically represent the previous explanation, figure 4 expresses it in a different fashion, by comparing the amount of freshwater entering the estuary with the amount of seawater from the tides.)

Salinity increases can be prevented either by impeding the ability of saltwater to migrate upstream or by increasing the amount of freshwater entering the estuary. During the drought of 1988, the New Orleans District of the Corps of Engineers designed a barrier across the bottom of the Mississippi River which blocked saltwater on the bottom while allowing the ships and freshwater to pass on the top. In many cases where human withdrawals of freshwater have increased estuarine salinity enough to have adverse environmental consequences, water resource agencies have constructed projects to divert freshwater into estuaries. Elsewhere in Louisiana, the Corps has designed projects to divert water from the Mississippi River to wetlands that are suffering adverse effects of saltwater intrusion; and Everglades National Park has long has a similar arrangement with the Corps of Engineers and the South FLorida Water Management District.

The Delaware River Basin Commission releases water from its system of reservoirs whenever salinity reaches undesirable levels, to protect Philadelphia's freshwater intake and aquifers in New Jersey that are recharged by the (usually) fresh part of the river. Hull and Tortoriello (1979) estimated that a 13 cm rise in sea level would require an increase in reservoir capacity of 57 million cubic meters (46,000 acre feet), while Hull and Titus (1986) suggested that a 30 cm rise would require about 140 million cubic meters, about one fourth the capacity that would be provided by the proposed Tocks Island reservoir, and noted that the DRBC has identified reservoir sites sufficient to offset salinity increases from sea level rise and economic growth well into the 21st century. Williams (1989) conducted a similar analysis of the impacts and responses to sea level rise in the Sacramento Delta in California.

Although dams can be useful, one must understand their limitations. Most importantly, there is a finite amount of water flowing in the typical river; dams can increase the freshwater flow during the dry season because they reduce the flow during the wet season. Because droughts are generally the only time when high salinity is a concern, the impact on salinity during the wet season is generally not a problem. Dams also reduce flooding, which (as we discussed above) can be viewed as a benefit by people who might otherwise lose property (or drown) in a flood; but it is a liability to the extent that flood prevention keeps sediment from reaching wetlands and enabling them from keeping pace with sea level. A final problem is that if climate change makes droughts more severe in the future, if may be difficult to find sufficient reservoir capacity to offset the resulting reductions in river flow, let alone increasing river flow enough to offset sea level rise. Salinity increases in aquifers can also be prevented either by increasing the force of freshwater or decreasing the force of saltwater. The most notable application of the former approach is in southern Florida, where water managers maintain a series of freshwater canals whose primary purpose is to recharge the Biscayne aquifer with fresh water. Various types of barriers have also been identified for blocking saltwater intruding into the estuary (Sorensen et al. 1984).

Decreasing depletive uses of water can help to offset salinity increases. For example, during droughts the Delaware River Basin Commission has the power to curtail diversions of water to New York City. Reducing water consumption within the basin is a critical component of water management strategies in this and many other regions.

Adapting to Salinity Increases

If measures are not undertaken to prevent salinity increases, people will have to adapt to it. Some cities could respond by moving their intakes upstream. Note that this appears to be the only response to increased salinity that would work with sea level rise but (at least in many cases) not with decreased river flow: In the case of sea level rise, moving the uptake upstream the same distance as salinity advanced would leave the public (and if ecosystems were able to migrate upstream and inland, the environment) in roughly the same condition as before sea level rose. By contrast, if less freshwater is flowing into an estuary, there may no longer be enough freshwater to supply the previous level of consumption.

Another response is to shift to alternative supplies. For example, if flows in the Mississippi River decline, or if wetland loss motivates a policy makers to allow the river to change course, New Orleans would have to abandon the river as a supply of freshwater. Many argue that the river is polluted enough to view such a situation as a "blessing in disguise," and have suggested that the groundwater under Lake Ponchartraine would be a suitable source (Louisiana Wetland Protection Panel 1987). Nevertheless, alternative supplies are finite, and may become increasingly scarce as the economy grows, especially in areas where the greenhouse effect fails to increase precipitation enough to offset the increased evaporation that warmer temperatures invariably imply.

Water conservation is likely to play an increasingly important role in efforts to adapt to reduced availability of freshwater. Many jurisdictions already place restrictions on depletive uses such as watering lawns and washing cars. Officials in New Jersey are planning to ration the water that farmers withdraw from the Potomac-Raritan-Magothy aquifer, which is recharged by the Delaware River. Nevertheless, regulations of water use are difficult to enforce and generally apply only to a limited number of visible activities.

In our view, the best long-term response would be to treat water like any other scarce commodity: charge water a market- clearing price rather than a price based on cost. There is an emerging trend in this direction among large water users in the western United States, but the principle is likely to face severe cultural and institutional barriers. First, Americans generally believe that water should be as free as the air we breathe. Secondly, public utilities are generally not allowed to make a profit. Nevertheless, with increasing government deficits and a gradual acceptance of the scarcity of water, the public would probably learn to accept water markets.

The Need for Near Term Action

As with dikes to prevent inundation, there is no need to build dams or canals to counteract future saltwater intrusion. Nevertheless, setting aside sufficient land for future dam sites is similar to allowing wetlands to migrate landward: It will be less expensive to prevent people from developing the land today than to buy people out later. Accordingly, to the extent that regions will rely on dams in the future, it would be best to identify those sites today and implement policies that will keep options open for future reservoir construction.

The matter of reserving land for dams or wetlands illustrates a principal that may apply to other commodities: even when a particular action will not be necessary for a few decades, it is best to establish the "rules of the game" in advance so that people can gradually take whatever measures are necessary based on how they perceive the probability and eventuality of the particular situation that is anticipated. If we want to use water efficiently, its price will eventually have to rise. Political realities prevent a substantial rise today, but if the government put everyone on notice that it would charge a fair-market price beginning in the year 2030, the public would probably accept such a policy. It is easier to agree on what is fair when no one is immediately threatened, and honorable people do not object to fulfilling the conditions of treaties, contracts, and other arrangements made by a previous generation.

EVOLUTION OF THE U.S. RESPONSE: 1982-89

For most practical purposes, the United States began to seriously examine potential responses to accelerated sea level rise in the summer of 1982. Two officials of the Environmental Protection Agency, John Hoffman and the head of his office, Joseph Cannon, were troubled by an apparent failure in information transfer. For several years, climatologists had warned that a global warming due to the greenhouse effect was likely (NAS 1979; 1982); yet federal, state, and local officials responsible for coastal decision making were generally either unaware of this prospect or viewed it as mere speculation.

No one had estimated the likely rise in sea level for specific years, and even if they had, the EPA officials were not sufficiently familiar with coastal activities to know whether consideration of a possible rise would warrant changes in current decision making. But Hoffman had a hunch that sea level rise would justify changes in at least some decisions, and convinced Cannon to initiate a small program to begin the process by which the United States prepared to live with a rising sea on a warmer planet, hiring the author to direct the project.

In retrospect, it may seem strange that EPA, a regulatory agency responsible for controlling air (and other types of) pollution, first addressed the greenhouse effect issue by initiating a program to adapt to a global warming, rather than a program to reduce emissions of greenhouse gases into the atmosphere; even then, a number of environmental groups were initially suspicious that the Agency was effectively "throwing in the towel." But in the context of what could actually be accomplished at the time, the strategic decision Cannon made was perfectly rational: (1) The nation has just elected a new president who had promised to relax environmental regulations; nonregulatory approaches to protecting the environment seemed to have more promise. The planned sea level rise project would encourage state and local officials to anticipate sea level rise, with the hope of averting situations that would otherwise eventually necessitate regulations. Moreover, (2) there was no public consensus to reduce global warming; a project aimed a increasing awareness would help create the political conditions necessary for policy makers to consider reducing emissions of CO_2 and other greenhouse gases.

The first major activity of the Sea Level Rise Project was an interdisciplinary study in which Hoffman et al. (1983) estimated the range of future sea level rise; Leatherman (1984) and Kana et al. (1984) used those scenarios to estimate the physical effects on Galveston, Texas and Charleston, South Carolina; Sorensen et al. (1984) provided rough cost estimates for engineering responses to sea level rise; and Gibbs (1984) and the Titus (1984) performed economic analyses using the information provided by the other researchers. The results were presented at a conference in Washington in 1983 and published the following year (Barth and Titus 1984).

The initial effort was only partially successful. On the positive side, Hoffman's study estimating sea level rise prompted the National Academy of Sciences to prepare their own estimate (Revelle 1983), so that by the end of the first year, there were two available studies, both of which suggested that a substantial rise in the next century was likely. We were also successful in making officials and coastal scientists aware of the potential for a significant rise: (1) Our reports were written for the layman; no matter how technical the subject matter of a study, there was always an overview chapter that explained the contents. (2) We sent out form letters telling people how to obtain our reports to most people in the country working on coastal issues, and about one-third responded by requesting at least one document. (3) We gave about fifty speeches and briefing per year on the subject to government offices and public meetings.

However, we failed to obtain our most important objectives. By 1984, we had identified only a handful of issues where we could make a case that sea level rise required changes in current practices. Moreover, while we continued to study the issue, were generally unable to convince federal and state agencies with a stake in sea level rise to undertake efforts themselves to address the issue. There were four notable exceptions: (1) The National Academy of Sciences formed panels to (a) estimate the future contributions of glaciers to sea level rise (Meier et al. 1985) and (b) assess the engineering implications of a possible rise (Dean et al. 1987). (2) Orrin Pilkey, the most prominent environmental activist on coastal matters began to incorporate global warming into his many speeches to civic groups on the need for coastal development to be more sensitive to environmental processes. (3) The Army Corps of Engineers agreed to cofund with EPA a $25,000 study on the implications of sea level rise for coastal protection works (Kyper and Sorenson 1985). Finally, (4) The legislature of Terrebonne Parish, a local government in Louisiana, passed a resolution calling on Congress to improve estimates of future sea level rise and initiated a $100,000 study on response strategies for their community, which was already facing substantial erosion due to subsidence.

It was clear we were doing something wrong, so in the middle of 1984 we changed the focus of our studies. From then on, we decided to only fund studies only after we had internally developed a specific hypothesis demonstrating that a consideration of sea level rise would alter decisions people make today. In the ensuing two years, we commenced studies to investigate the following hypotheses: (1) sea level rise would destroy a large fraction of our coastal wetlands unless planning solutions were implemented soon to require development to be abandoned to allow wetlands to migrate inland; (2) because groins help to control erosion due to alongshore transport but not the offshore erosion from sea level rise, a consideration of the issue would prompt the State of Maryland to drop its plans to build more groins at Ocean City, Maryland and instead employ beach nourishment; (3) because it is much easier to put slightly larger pipes in a coastal drainage system during construction than to subsequently add new pipes, it would be rational to design new coastal drainage systems with an allowance for sea level rise; (4) sea level rise would accelerate the already- alarming rate of land loss in Louisiana, and hence, implies that action is much more urgent than currently assumed; (5) increased salinity in the Delaware Estuary might eventually necessitate additional reservoirs to protect Philadelphia's water supplies and although they need not be built today, the risk of this eventually happening warrants land-use planning to ensure that all the suitable sites are not developed.

Because we had conducted "back of the envelope" assessments that demonstrated the need to consider sea level rise before funding them, all of the studies turned out to demonstrate that even a 50-50 chance of accelerated sea level rise would warrant changes in current decisionmaking. Although sea level rise was probably not the only reason, within a month of the Ocean City study's (Titus et al. 1985) release, Maryland announced that it would shift its erosion-control strategy from groins to beach nourishment (Associated Press 1985). (The wetland study (Titus 1988) was not released until much later, but even while it was still in draft, the State of Maine responded by issuing regulations requiring structures to be removed if necessary to enable wetlands and dune ecosystems to migrate landward.)

Although the other studies did not precipitate specific actions, they provided additional examples to buttress our claim that people should begin preparing for sea level rise even though it is uncertain. We continued to give about 30 speeches a year on the subject to various communities and professional organizations, trying where possible to talk to enough people beforehand to develop a hypothetical example relevant to their own activities where planning for sea level rise today would be warranted. The fact that we could cite studies demonstrating the rationality of planning today increased the credibility of our assertion that the particular audience should consider it as well; and the fact that Maryland and later Maine had made a decision based on sea level rise helped convince people that policy makers are capable of planning for the long-term future.

Although many scientists, reporters, low-level officials, and members of the public continued to request our reports, in the beginning of 1986 we knew that we had failed to achieve our primary goal of motivating people to prepare for sea level rise. We had the sense that we were fulfilling a need to have someone thinking and telling people about the long-term implications of current activities, but that for most people, our activities were little more than a curiosity; practical people could safely ignore the issue of sea level rise.

But then the British Antarctic Survey discovered an emerging hole in the ozone over the South Pole. This seemingly-unrelated event attracted the attention of several U.S. Senators, who held hearings on the subject and decided to include that related issue of global warming. Suddenly, there was widespread public attention to the greenhouse effect and its impact on sea level. The unusually hot year of 1988 further increased public awareness. For the first five years of our project, we were able to motivate only a few agencies to undertake any substantive efforts; in the last two years, the momentum of the issue has motivated dozens of initiatives, as Hershman (this volume) discusses.

We would like to think that our initial efforts laid the groundwork for the emerging response to sea level rise, even though at the time our efforts seemed futile. By this line of reasoning, our initial reports explaining the issue convinced low- level officials, low-level environmental spokesmen, and coastal scientists that sea level rise is important, but failed to convince high-level officials, heads of nongovernmental organizations, or prominent scientists that the time was ripe for addressing the issue. When the ozone hole and hot year of 1988 convinced leaders that global warming is a serious issue, their lower-level counterparts were already informed and ready to recommend action.

We will never know whether our efforts made much of a difference in the final analysis. Nevertheless, on the assumption that they did, we briefly offer a few lessons that may be useful for nations beginning to prepare for future sea level rise. First, it is important to designate an individual to work full-time on the issue. A key to the success of the EPA project is that Hoffman was able to find a (then) young individual who was sufficiently interested in the issue to stay with it for the better part of a decade. It takes time to develop expertise when a new issue emerges: Much of the relevant information is unpublished, and disciplines ranging from law and economics to biology and engineering must be synthesized.

Secondly, because responding to sea level rise is likely to be decentralized, public information is sufficiently important to warrant 10-20 percent of the total budget and 25 percent of the project manager's time. Thousands of one-hour conversations with reporters and professionals working on related issues will be necessary, as well as many shorter conversations with curious citizens. Anyone who views their time as too valuable to completely satisfy all inquiries is doomed to failure: College students and low-level assistants that have the initiative to question the project manager about the implications of future sea level rise often surface later as influential researchers or directors of organizations. Although the typical conversation on the subject may accomplish little, the totality of thousands of conversations over the course of several years produces a critical mass by which people begin to talk to eachother about the issue and spend their own time investigating its implications.

If the need to satisfy all inquiries is recognized, the project manager will find that he or she can save time by preparing summary reports that explain the issue to someone with no background in the issue. Managers of government projects often commission numerous studies, and in their own minds, develop a broad vision of the issue; but while they make the studies available, they rarely prepare reports summarizing their perspective. This is unfortunate both because preparing such reports disciplines one to examine the weaknesses in their opinions, and because their overviews of the issue would correspond more closely to what the public needs to know than the reports prepared by specialists in particular disciplines.

Finally, studies should begin with a socially relevant hypothesis before being funded. In our case, the hypothesis was that a particular change in current activities was warranted even if one allows for the possibility that sea level might not rise. In some cases, it is worth examining an issue just to make sure that no action is yet necessary. However, any project manager unable to present a cost-benefit argument in favor of action today in at least a few cases should be criticized for at best a lack of imagination and at worst for directing resources to the wrong issues and thereby forfeiting any savings that might be realized from preparing for sea level rise in other ares. Such criticism may not always be fair, but the fear of receiving it will be a powerful incentive to ensure that "no stones go unturned."

CONCLUSION

No one would accuse the United States of overreacting to the prospect of a rise in sea level from the greenhouse effect; the process has been slow, but steady. After seven years, we have reached the point where the relevant disciplines and the relevant government agencies are considering the issue and looking for opportunities to respond. Every one realizes that it is difficult to convince politicians to make short-term sacrifices for the long-term good, but we have a public that is concerned about environmental quality in general and the greenhouse effect in particular.

We understand that many of the assumptions American researchers take for granted would not apply in other nations. Nevertheless, we believe that two recommendations are universally appropriate for any foreign colleague who decides to dedicate a number of years helping a nation prepare for rising seas: Focus your efforts on identifying actions that need to be taken today and make sure that no one ever considers you an expert on the issue: what you learn will be important only if its knowledge becomes commonplace.

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TABLE 1
COST OF SEA LEVEL RISE FOR FOUR ALTERNATIVE OPTIONS
(millions of $US)

Sea Level Rise (cm)	Total Cost			
	Dike with Beach	Raise Island	Island Retreat	No Protection
30	52	105	41	55
60	434	285	109	462
90	509	522	178	843
120	584	786	247	1548
150	659	1048	308	1740
180	734	1310	371	1932
210	809	1574	431	total loss
240	884	1835	492	total loss

Incremental Cost

Sea
Level Dike With Raise Island No Protection
Rise Beach: Island Retreat
(cm) Dike Sand
30 0 52 105 41 55
60 330 52 180 68 407
90 0 75 237 69 381
120 0 75 264 69 705
150 0 103 262 61 190
180 0 103 262 61 total loss
210 0 110 262 61 total loss
240 0 110 258 61 total loss

Source: Weggel et al. (1989): Dike Cost
Yohe (1989): No Protection

Source: Titus (1990)

TABLE 2

EVOLUTION OVER TIME OF THE RELATIVE COSTS OF RETREAT ISLAND RAISING

Sea level Year* Years it Cost (millions) Cost ($/yr/house)
above 1986 will take Retreat Raise Retreat Raise
(cm) sea to rise island Island 15 centimters

15 2013 18 20 57 77 219
30 2031 14 34 85 168 420
45 2045 12 34 95 196 548
60 2057 11 34 110 214 692
75 2068 10 34 127 235 879
90 2078 9 34 132 261 1015
105 2087 9 34 132 261 1015
120 2096 8 34 132 294 1142
135 2112 7 30 132 296 1305
150 2126 6.5 30 132 319 1406
165 2139 6 30 132 346 1523

* Assuming global sea level rises one meter by the year 2100.

NOTE: All costs assume that until the particular year, the community has responded to sea level rise by raising the island in place.

Source: Titus (1990)

TABLE 3
ABILITY OF ALTERNATIVE RESPONSES TO SATISFY DESIREABLE CRITERIA
LONG BEACH ISLAND, NEW JERSEY
(assuming 1 m rise by 2100)

Policy: Dikes Raise Engineered Abandonment
Islands Retreat Forced Unplanned

Criteria

Social Cost
Cumulative 584 786 247 1548 1548
($millions)
Present Value
($millions, 3%) 115 130 46 170 170

Environmentally No Usually Usually Yes Yes
Acceptable

Culturally No Yes Yes No Maybe
Acceptable

Legal Yes Yes Maybe Maybe Yes

Constitutional Yes Yes Yes Probably Yes
Institutionally Yes Yes Maybe Maybe Yes
Feasible

Performs Under Poor Good Good Good Good
Uncertainty

Immmune to Yes Mostly Somewhat No Mostly
Backsliding

Source: Titus (1990).

Table 4--See Cost of Holding Back the Sea summary results
Table 5--See Maryland Law Review--ability of various options to satisfy deireable criteria

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