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Changing Climate and the Coast

Volume 1: Adaptive Responses and their Economic, Environmental, and Institutional Implications

Report to the Intergovernmental Panel on Climate Change
from the Miami Conference on Adaptive Reponses
to Sea Level Rise and Other Impacts
of Global Climate Change

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CHANGING CLIMATE AND THE COAST

VOLUME 1: ADAPTIVE RESPONSES AND THEIR ECONOMIC, ENVIRONMENTAL, AND INSTITUTIONAL IMPLICATIONS

REPORT OF THE INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE
FROM THE MIAMI CONFERENCE ON ADAPTIVE RESPONSES TO
SEA LEVEL RISE AND OTHER IMPACTS OF
GLOBAL CLIMATE CHANGE

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PREFACE

Increasing concentrations of carbon dioxide and other gases released by human activities are expected to warm the Earth by a mechanism commonly known as the "greenhouse effect." Such a warming could raise the level of the oceans and thereby inundate low-lying areas, erode beaches, exacerbate coastal flooding, and increase the salinity of estuaries and aquifers. Changes in temperatures, precipitation patterns, and storm severity could also have important impacts on the coastal environment.

In November 1988, the United Nations Environment Programme and the World Meteorological Organization created the Intergovernmental Panel on Climate Change (IPCC), and directed it to assess the science, impacts, and possible responses to global climate change. This report presents the findings of a conference held in Miami from November 27 to December 1 on the under the auspices of the Coastal Management Subgroup of the IPCC's Response Strategies Working Group. The Miami conference focused on the implications of sea level rise for Western Africa, the Americas, the Mediterranean Basin, and the rest of Europe; a second conference held in Perth, Australia addressed the other half of the world.

Many people helped in the compilation of this report. Roberta Wedge coordinated the production. Norbert Psuty provided overall guidance to the authors of eleven country-specific papers. Jack Fancher rewrote one of the papers. Sheila Blum, Lou Butler, Karen Clemens, Marcella Jansen, Susan MacMillan, Joan O'Callahan, Karen Swetlow, and Lim Valianos copyedited the manuscripts.

John Carey chaired the conference, assisted by session chairpersons Job Dronkers, Asgar Kej, Randy Hanchey, Ahmad Ibrahim, John Campbell, Ines Schusdziarra, Thomas Clingan, Chidi Ibe, C.A. Liburd, and Jim Broadus. Tom Ballentine made conference arrangements; Muriel Cole, Joan Pope, Steve Leatherman, Fatimah Taylor, Charles Chesnutt, and Melanie Jenard also assisted with the conference organization. V. Asthana, J.R. Spradley, Cate McKenzie, Peter Shroeder, Katie Ries, and Morgan Rees worked several nights attempting to ensure that the summary conference report adequately reflected the views expressed at the meeting. But most importantly, over one hundred researchers and officials from all six inhabited continents and several island states -- on short notice -- prepared papers, came to Miami, and initiated a dialogue on how the nations of the world can work together to meet the challenges of rising seas and changing climate.

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INTRODUCTION

Since the beginning of human history, a large portion of the Earth's population has inhabited the coastal zones of the world. Proximity to fertile coastal lowlands, the richness of the seas, and water transportation have long been, and still are, the primary motivations for coastal habitation.

Population growth and increasing exploitation of coastal resources are threatening the integrity of the coastal environment. Moreover, there is a growing consensus among scientists that the atmospheric buildup of greenhouse gases could change global climate and accelerate the rate of sea level rise, which would place further stress on coastal zones. Loss of lives, deterioration of the environment, and undesirable social and economic dislocation may become unavoidable.

These circumstances demand political, scientific, legal, and economic action at international and national levels. It is imperative that such actions focus on sustainable approaches to the management of coastal resources.

To provide the basis for an internationally accepted strategy to address climate change, the World Meteorological Organization and the United Nations Environment Programme established the Intergovernmental Panel on Climate Change (IPCC) in November 1988, creating working groups to (I) conduct a <u>scientific assessment</u> of the magnitude and timing of climate change; (II) assess the resulting socioeconomic and environmental <u>impacts</u>; and (III) develop <u>response strategies</u> to limit and/or adapt to climate change.

This report presents the findings of a workshop held in Miami (U.S.A.) from November 27 to December 1, 1989, under the auspices of the Coastal Zone Management Subgroup of the IPCC Working Group III. More than 100 scientists and government officials from 37 nations met to discuss potential strategies to adapt to sea level rise and other impacts of global climate change, and to consider the social, economic, legal, environmental, financial, and cultural implications of such strategies. This workshop focused on the Americas, Europe, the Mediterranean, and Western Africa. A second workshop in February 1990 at Perth (Australia) will examine the concerns of other continents and island nations.

The sections of this report were drafted by the participants in each of the corresponding workshop sessions during the third and fourth days, with the final day devoted to a plenary review of the entire report. The following sections summarize the findings on problem identification; adaptive options; the environmental, social and cultural, legal and institutional, and economic and financial (including funding) implications of the adaptive strategies; regional findings for Western Africa, the Northern Mediterranean and Black Seas, the Southern Mediterranean, Non-Mediterranean Europe, Central and South America, and North America. The final section presents general conclusions and recommendations.

The workshop examined numerous structural and planning approaches. Although human ingenuity can reduce the effects of sea level rise, the participants concluded that even the most concerted actions could not eliminate all of the adverse consequences. Thus, even though the focus of the workshop was on adaptive options, the participants felt that limiting the buildup of atmospheric greenhouse gases must be a global priority. Moreover, the burden of coping with accelerated sea level rise and other consequences of a greenhouse warming would fall disproportionately on those nations least able to cope with them. Many participants believe that the industrialized nations have a special responsibility to assist developing nations in adapting to these consequences.

The participants were unanimous in their conviction that the world urgently needs to begin the process of identifying, analyzing, evaluating, and planning adaptive responses and their timely implementation. Even though sea level rise is predicted to be a relatively gradual phenomenon, strategies appropriate to unique social, economic, environmental, and cultural considerations require long lead times. Nature has provided us with some time; the nations of the world -- collectively and individually -- should use it wisely.

PROBLEM IDENTIFICATION

Coastal zones have high economic values and are rich in natural resources and amenities, but their environments are often physically hostile. Life on the coast is already vulnerable to natural forces whose effects could be exacerbated by an accelerated rise in local sea level. Most shorelines experience significant and almost constant change, with enormous commercial, recreational, and environmental values at risk. Each year, throughout the world, lives are lost, people are injured and left homeless, and tens of billions of dollars' (or equivalent denominations) worth of property are damaged by storms and other natural coastal hazards. Flooding, beach erosion, habitat modification and loss, structural damage, silting, shoaling, and subsidence resulting from natural factors continue to pose major public safety and economic consequences and impair many of the intangible benefits derived from the coastal zone.

Yet while the risks are substantial, the benefits of coastal resources significantly outweigh their costs, and thus continue to attract human activity (Figure 1). If an accelerated rise in global sea level is added to the equation, however, the risks to life and property become significantly worse.

Tidal gauge records show that global sea level has been rising 1 to 2 millimeters per year over the last century. However, according to IPCC Working Group I, models of the climate, oceans, and cryosphere suggest that sea level could rise 4 to 6 millimeters per year on average through the year 2050 for a total rise of 25 to 40 centimeters. The accelerated rise would be due principally to thermal expansion of the oceans and melting of small mountain glaciers. Although Working Group I has concluded that the melting of the Greenland ice sheet could contribute up to 0.37 millimeters per year for every degree (C) of warming, it estimates that this contribution would be largely offset by an accumulation of ice in Antarctica sufficient to lower sea level 0.3 millimeters per year per degree of warming. Working Group I believes that there is so much inertia in global warming that some acceleration of sea level rise is inevitable.

A rise in sea level would (1) inundate wetlands and lowlands; (2) erode shorelines; (3) exacerbate coastal flooding; (4) increase the salinity of estuaries and aquifers and otherwise impair water quality; (5) alter tidal ranges in rivers and bays; (6) change the locations where rivers deposit sediment; (7) change the heights, frequencies, and other characteristics of waves; and (8) decrease the amount of light reaching the sea floor. Local subsidence can exacerbate all of these effects.

Nature requires coastal wetlands, and the dryland found on coral atolls, barrier islands, and river deltas, to be just above sea level. If sea level rises slowly, as it has for the last several thousand years, these systems can keep pace. Wetlands collect sediment and produce peat, which enable them to stay just above sea level; atoll islands are sustained by sand produced by nearby coral reefs; barrier islands migrate landward; and the sediment washing down major rivers enables deltas to keep pace with sea level. If sea level rise accelerates, however, at least some of these environments will be lost. Riverside lands tens of kilometers inland could be as vulnerable as land along the open coast. The loss of productive wetlands, which act as protective buffers from the sea and provide crucial habitats for many animal species important to human society, could be particularly important.

A one-meter rise in sea level could inundate a major part of Bangladesh, for example; a two-meter rise could inundate Dhaka, its capital, and over one-half of the populated islands of several atoll nations, including the Maldives (Figure 2), Kiribas, and the Marshall Islands. Shanghai (Figure 3) and Lagos -- the largest cities of China and Nigeria, respectively -- are less than two meters above sea level, as is 20 percent of the population and farmland of Egypt. In many areas, the total shoreline retreat from a one-meter rise would be much greater than suggested by the amount of land below the one-meter contour on a map, because shorelines would also erode (Figures 4 and 5).

Sea level rise would also increase the risk of flooding (Figure 6). The higher base for storm surges would be particularly important in areas where

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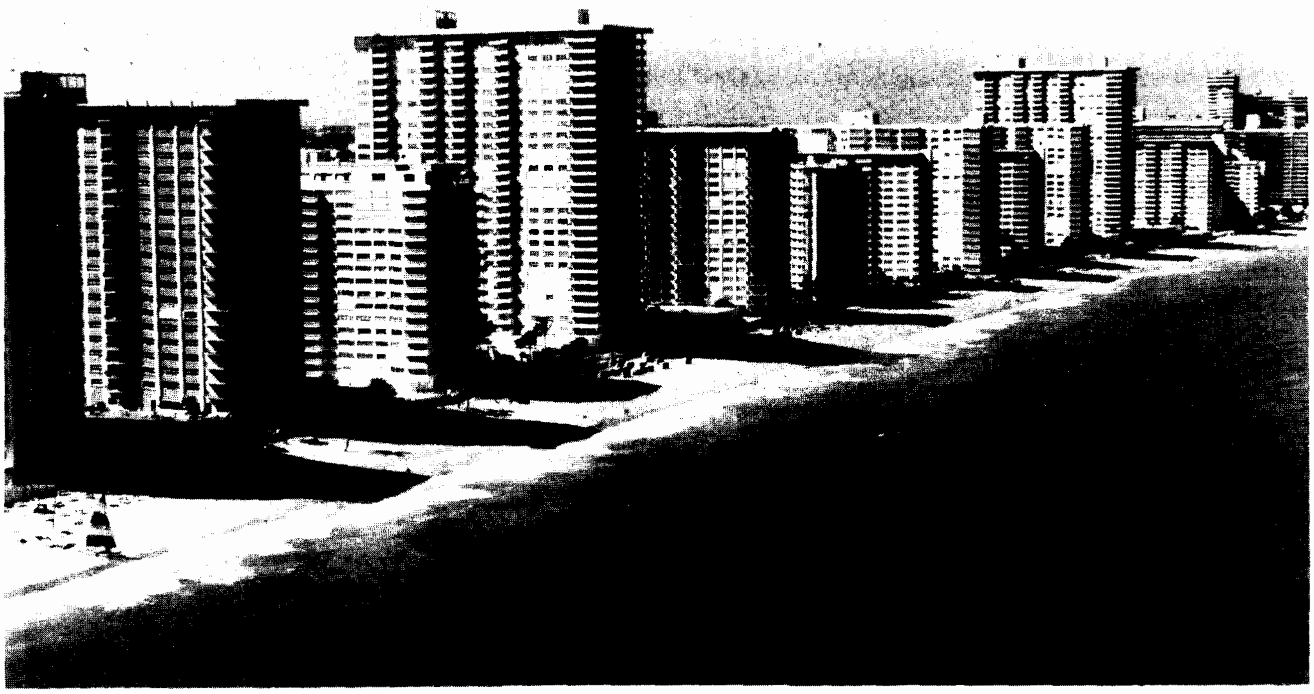

Figure 1. Activity along the coast is increasing in both developing and industrial nations, as shown in (A) Bombay and (B) Miami.

A

B

Figure 2. Low vulnerable areas: (A) Tulhadoo, Republic of Maldives (note that the high-water mark is just below the land elevation); (B) in crowded areas such as Bombay, it is often necessary to build up to the water's edge.

Figure 3. Much of Shanghai is below sea level.

Figure 4. The Great Wall of China is already eroding.

A

B

Figure 5. (A) Cliff and (B) beach erosion in Massachusetts.

hurricanes and typhoons are frequent, such as islands in the Caribbean Sea, the southeastern United States, and the Indian subcontinent. Had flood defenses not already been erected, London and the Netherlands would also be at risk from winter storms.

Rising sea level could also degrade water quality. Saltwater would advance inland in both aquifers and estuaries; and wetlands could become saltier even if the salinity of adjacent bays did not increase. Moreover, by deepening shallow bodies of water, sea level rise could cause them to stagnate. Fish ponds in Malaysia, the Philippines, and China have been designed so that the tides provide sufficient mixing; deeper ponds would require more flushing to avoid stagnation.

In atolls, coral reefs supply the sand necessary to keep the islands from being eroded and inundated. In the long run, any limitation of coral productivity could increase the risk that these islands will suffer from erosion or inundation.

In addition to sea level rise, global warming could alter the frequency and severity of storms; change ocean currents and the resulting local climates; change the amount of rainfall and hence, the flow of freshwater in rivers; and alter the wave climatology along shores.

These physical changes could pose a threat to ecological balances and to the coastal infrastructure, including roads, ports, industrial facilities, and residential and commercial structures. Populations and land-based activities could be forced to abandon the inundated areas. The productivity of agricultural lands adjacent to the coast could be threatened, and the economic and social culture of small communities dependent upon fishing and related activities could be severely damaged. As the resources and uses of the coastal area are affected, secondary social and economic impacts may be felt both locally and nationally. Delicate ecosystem balances could be upset, threatening fisheries, wildlife, and other resources important to mankind.

Finally, there is the question of "winners" and "losers." Changes in rainfall and temperature would affect the ability of particular regions to exploit natural resources. Some would win and some would lose, and additional analysis of this issue is necessary. In the case of sea level rise, however, it is difficult to see how there could be any winners at the national level.

ADAPTIVE OPTIONS

In light of these problems, nations should immediately assess the implications of sea level rise and develop site-specific strategies for adapting to them. Possible strategies include: (1) defending a site to maintain its existing uses; (2) adapting in place by modifying structures and various activities to accommodate rising seas; (3) retreating landward, spending resources on relocation rather than on coastal defenses; and (4) employing temporary solutions until escalating economic, social, and resource costs require a different approach, at which time one of the three previous options can be implemented. (The "preventive option" of controlling greenhouse gas

Figure 6. Urban flooding, such as the 1954 surge in Providence, Rhode Island (USA), would become more frequent is the sea level rises.

emissions is outside the scope of this report but is the primary focus of two of the other subgroups of Working Group III.) Although national policies may encourage one of these approaches, the actual response and its implementation will often be a local decision.

Types of Adaptive Options

The potential responses to sea level rise fall into three basic categories: (1) technical, engineering, and structural responses to keep the sea back; (2)

natural or ecological responses to replace lost or damaged resources; and (3) nonstructural options, which focus on modifying the human uses of coastal lands and resources. In most situations, the actual response would be a combination of these three categories.

Technical, Engineering, and Structural Responses

These responses include construction of seawalls, breakwaters, dikes, levees, tidal barriers, floodgates, and bulkheads; beach nourishment; raising of coastal land by filling; and stimulation of siltation in deltaic areas. Some of these responses could be very costly and could result in significant environmental impacts. However, they can be extremely effective at protecting existing land and structures (Figures 7 through 16). These measures are well established, have evolved over several centuries, and are continuously refined and improved.

In addition to primary protective works, ancillary engineering works may be needed to reduce adverse effects. For example, lands currently drained by gravity may require pumping; and channels may need additional dredging to remove silt in order to maintain the preexisting flow of freshwater. To counteract saltwater intrusion, reservoirs may be necessary to augment low flows.

Natural, Biological, and Ecological Options

These options can mitigate the impacts of rising sea level by replacing lost resources or by developing alternative habitat areas that could serve similar ecological functions. Options include creating wetlands and dunes, stabilizing dunes by planting vegetation, and planting mangroves. Finally, the productivity associated with coastal habitat losses could be replaced through aquaculture to compensate for losses in particular fisheries, or to maintain biodiversity through preservation of endangered species and genetic resources.

Nonstructural Options

The simplest approach is to allow coastal resources and land uses to naturally respond to the changing conditions. If complete inaction is unacceptable, nonstructural options can help reduce the risk to property and the environment by removing structures and directing populations away from vulnerable areas (Figure 17). Resettlement can be encouraged by regulatory and legal measures that (1) require structures to be removed, (2) prohibit rebuilding of structures under special circumstances (e.g., after significant storm damage), (3) prohibit private construction of bulkheads, or (4) establish restrictions on new development through zoning or other means to reduce population concentrations. The fourth approach may be particularly useful; in many coastal regions it can be justified by existing erosion problems alone.

The process of a gradual retreat from areas threatened by sea level rise may require new institutional arrangements to coordinate various levels of governmental decision making. It will also require public education to increase awareness for all sectors of society about both the impacts of sea level rise and the implications of various adaptive responses. Additional research is necessary to develop more effective options.

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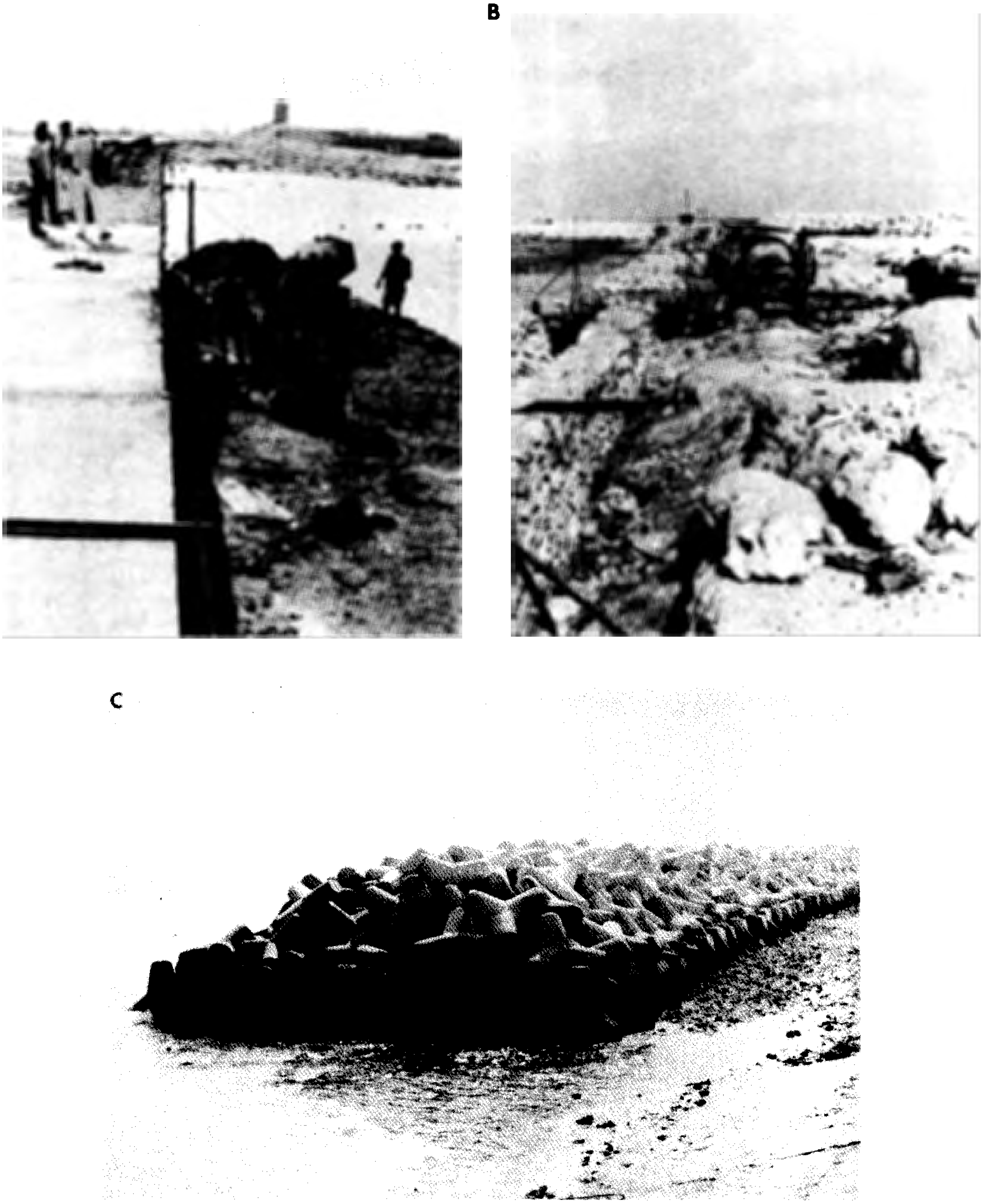


C

Figure 7. (A,B) Manual construction of seawalls to protect Male, capital of the Maldives. In the background of (B), a Japanese engineering firm manufactures tetrapods and builds a new breakwater (C).

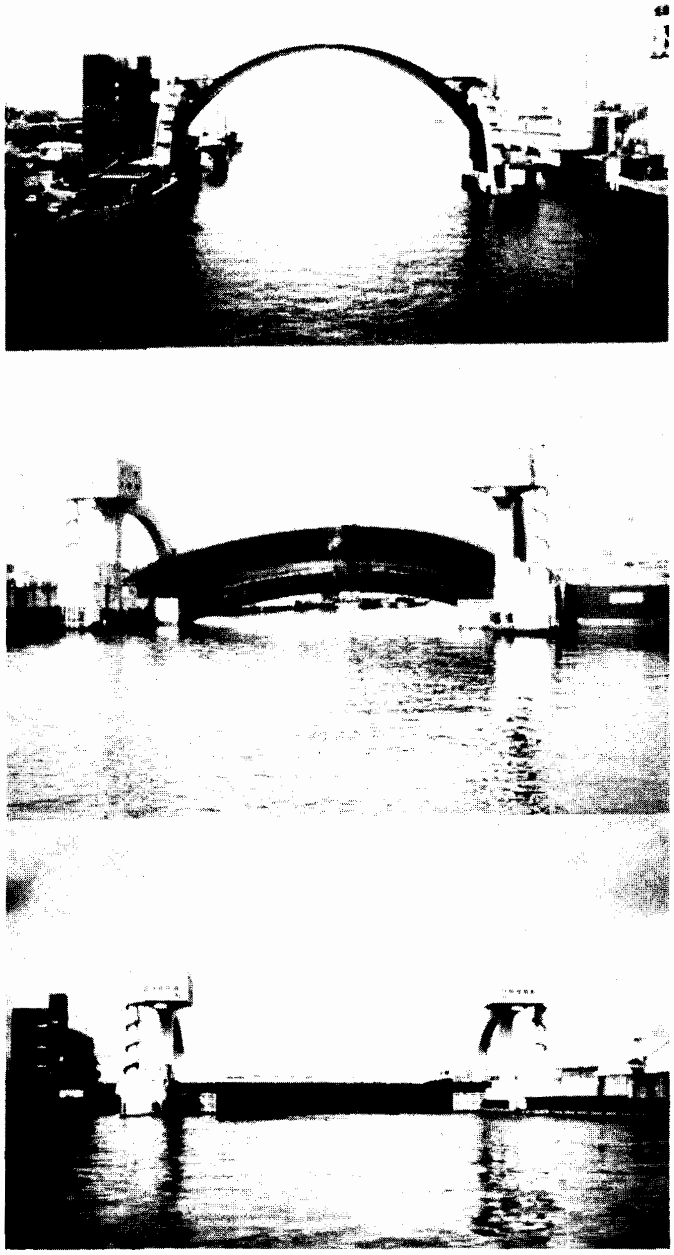


Figure 8. Tidal barrier in Japan.

Factors Influencing the Choice of Adaptive Options

While general analyses of response options for various scenarios can be helpful, the actual choices will be site-specific. The following factors must be considered for any given coastal area: the physiography of the area and its known response to tectonic and isostatic processes; the population density and its social and economic characteristics; the type and quality of development -- e.g., industrial, residential, or agricultural; other ecological attributes and the value of the affected area; the ability of existing institutional arrangements to plan and implement an appropriate response; the financial ability and technological resources required to implement the chosen response;

Figure 9. Shanghai has adapted to flooding by installing sliding gates in front of doorways and other openings to buildings.

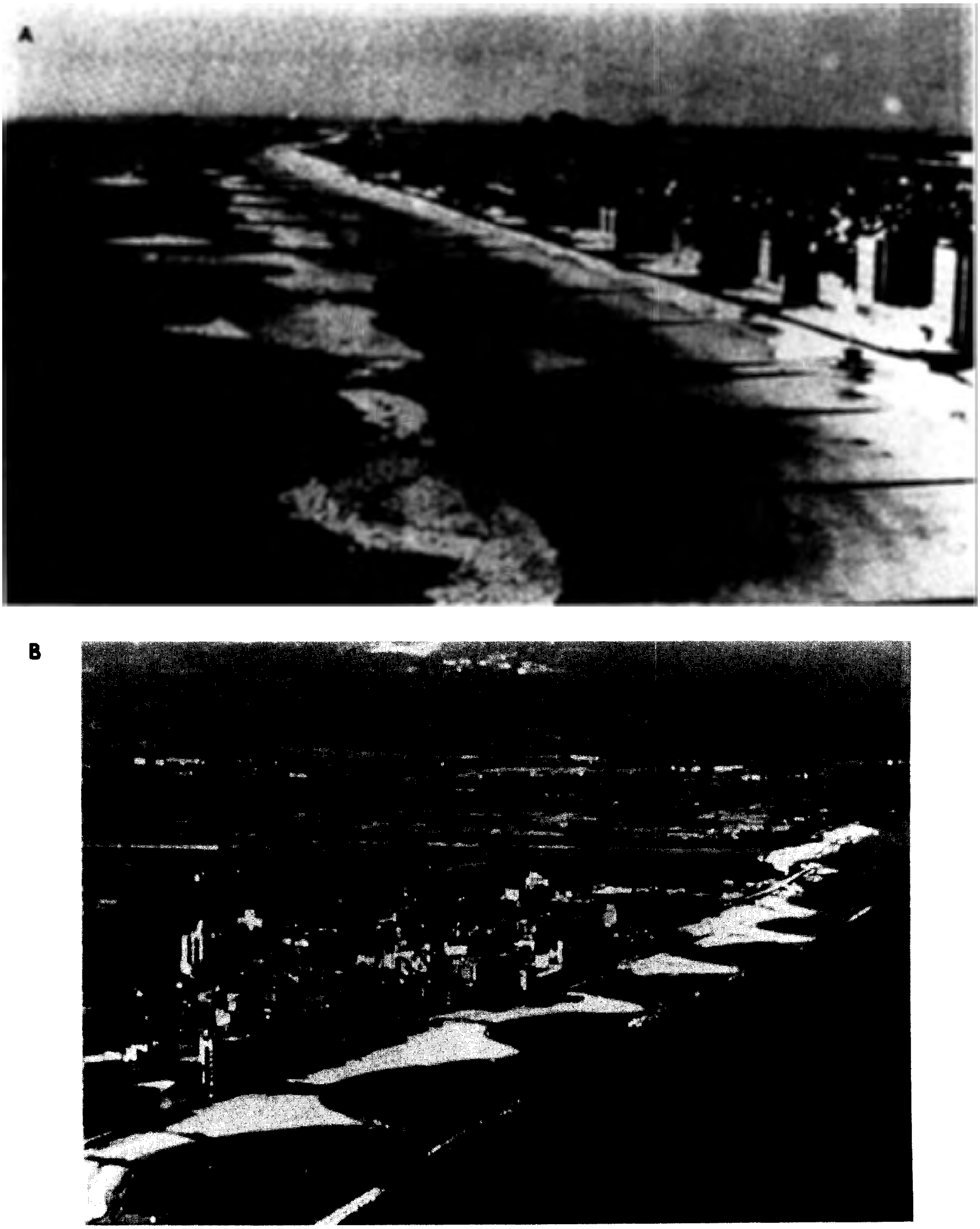


Figure 10. (A) Groins trap sand moving along the shore. (B) Breakwaters limit the erosive power of waves.

Figure 11.
Timber bulkhead.

Figure 12. Fencing to stabilize dunes.

Figure 13. Along the Dutch coast, seasonal buildings that are dismantled at the end of summer are common.

Figure 14. Rubble consisting of stone, demolished building and highways, and even junked cars, are often used to stop erosion, though the aesthetics vary.

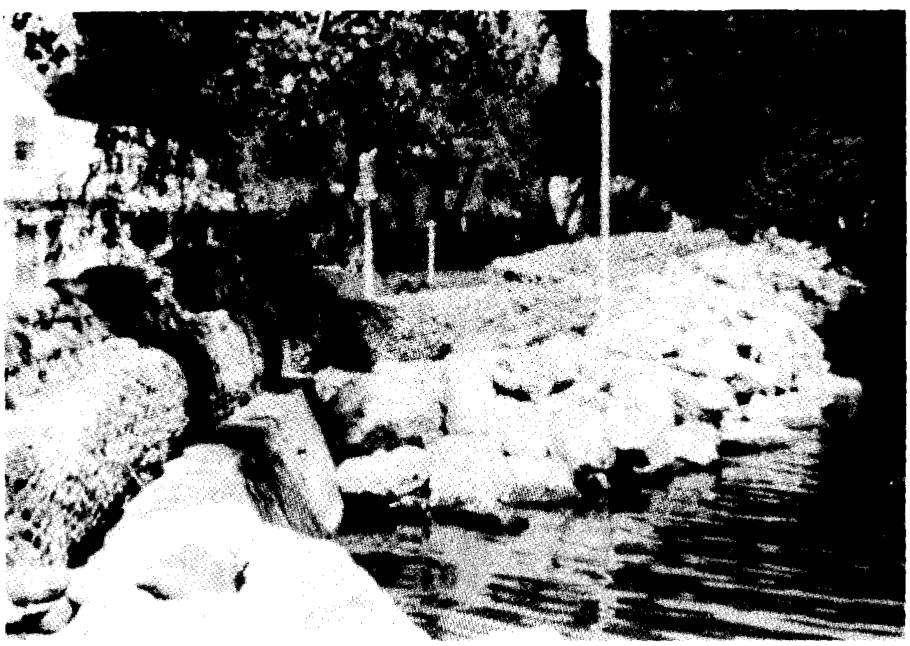
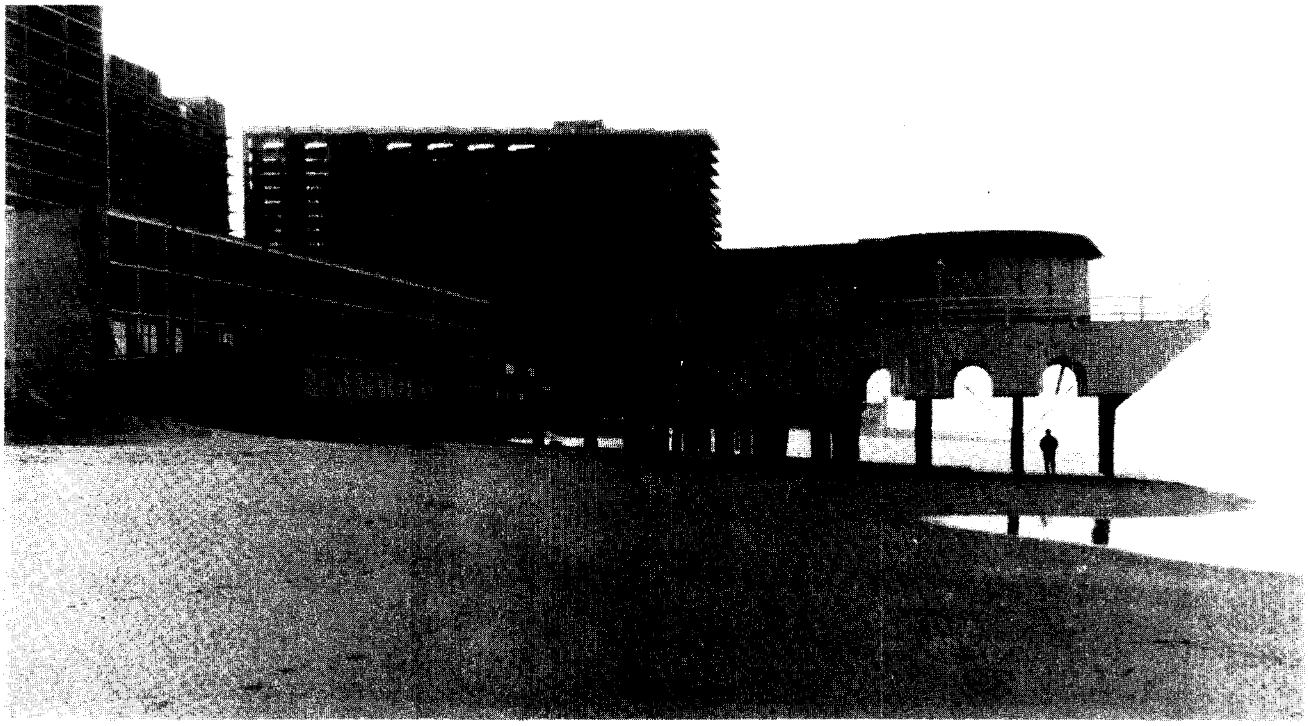


Figure 15. This home is protected by a stone revetment, wire baskets filled with stones, and sandbags.

A



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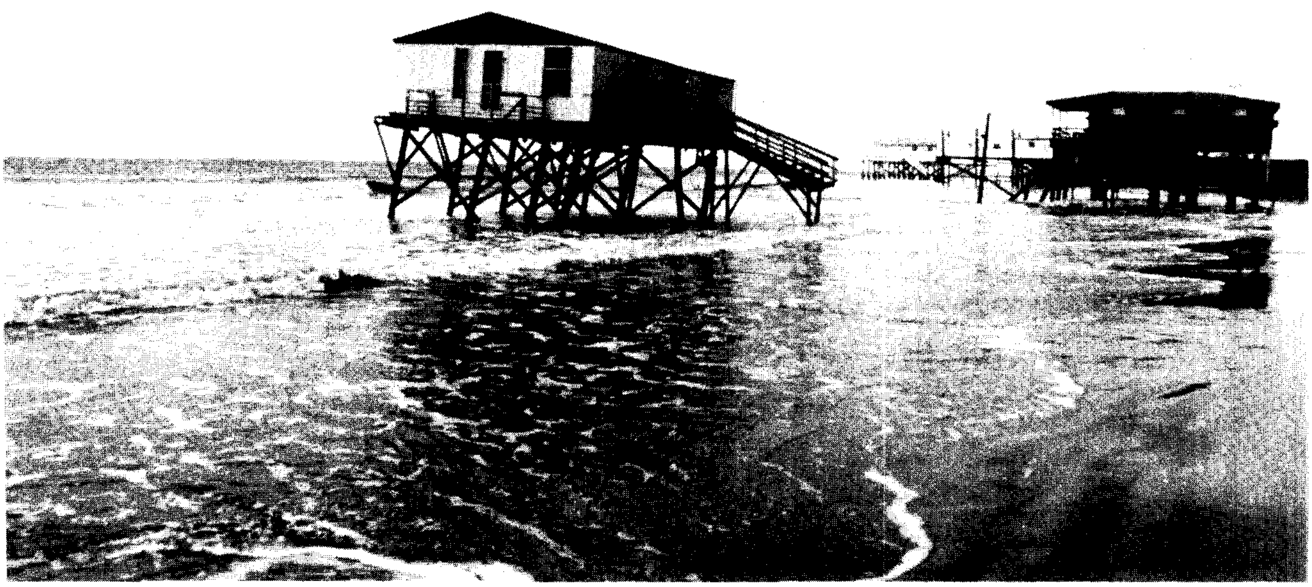

Figure 16. Although elevating structures on stilts diminishes flood damages, it can have adverse aesthetic impacts on a recreational beach as seen in (A) Ocean City, Maryland, and (B) Grand Isle, Louisiana (USA).

A

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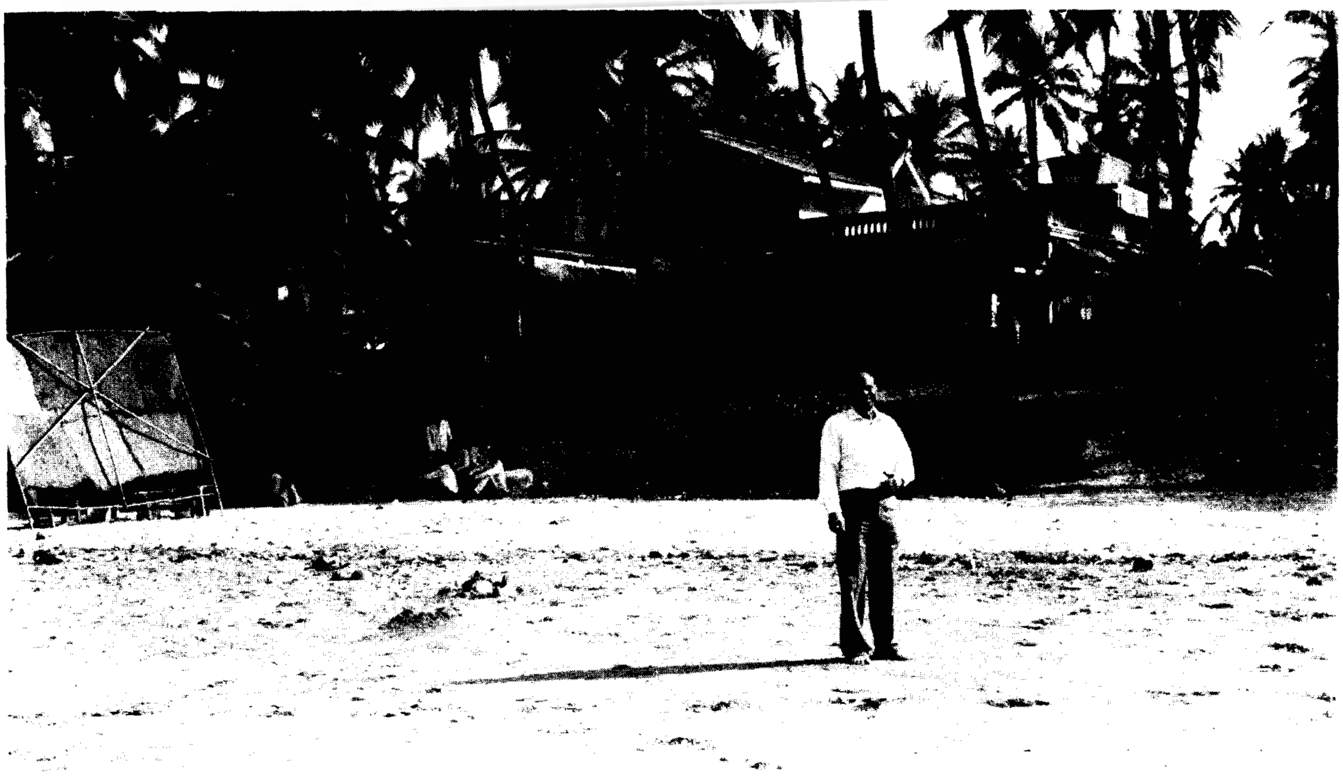

Figure 17. Houses are set back from the shore along the coasts of (A) Estonia, and (B) much of India.

and the secondary social, economic, and environmental impacts of the chosen response. All of these factors, which can be quantified or qualitatively described, must also be viewed in the context of the existing financial and political situation.

Constraints on Response Capabilities

Implementation of any response will require support from both the policymaking level of the government and the affected populations. Lack of support by decisionmakers can result from a lack of understanding of the impacts of sea level rise and the costs of various types of options. Decisionmakers may also rank other national or regional problems as having a greater priority. The effective implementation of a chosen option will also require the coordinated efforts of a variety of public and private institutions.

Responses will face a number of constraints. Financing may be a critical problem, particularly where structural options are chosen. Even for nonstructural options, such as limited retreat, the economic dislocations may sometimes be unacceptable to policymakers. Finally, many responses will face legal, environmental, and cultural constraints.

Recommendations for Short-Term Actions

1. The first course of action must be to heighten awareness of sea level rise and its potential impacts for governments and citizens alike. While many uncertainties exist, a long-term vision of potential problems should be incorporated into public and private decision making. Planning efforts must be flexible to allow future accommodation to changing conditions and to avoid aggravating existing problems.

2. Governments should support continued research into the causes of climate change and the likely effect and timing of sea level rise and its impacts. Establishment of a comprehensive data base, including data and information on tides, coastal currents, waves, storm surges, areas vulnerable to erosion and flooding, and other resources at risk, will provide the knowledge necessary for selecting the most cost-effective response for any given situation.

3. Because of the global implications of climate change, effective mechanisms for information exchange and technology transfer among all nations should be developed. Both between and within countries, special technical assistance should be offered to all levels of government.

4. International funding mechanisms to support response activities should be developed.

5. Governments should implement education and public awareness programs to prepare the population at large to accept the necessary controls and associated trade-offs, including reducing population density in the coastal zone.

ENVIRONMENTAL IMPLICATIONS

Most of the fish, shellfish, and sea turtles of the world depend on sandy beaches, fertile coastal wetlands, marshes, swamps, submerged aquatic vegetation or unpolluted estuaries for parts of their lifetimes, as do many types of birds and mammals found in the coastal zone. These areas have high recreational, cultural, and aesthetic values for many people. Protecting dryland from sea level rise, however, could have adverse impacts on many of these resources. This section divides those impacts into three categories: the open coast, wetlands, and water quality.

Open Coast

Responses along the open coast can, in turn, be broadly divided into three types: hard structures, soft responses, and allowing shores to retreat. The last option (no action) has been addressed by IPCC Working Group II and is outside the scope of this report.

Hard structural approaches can be divided into (1) seawalls and other measures that physically hold back the sea, and (2) groins, which alter the deposition of sand. The primary purpose of seawalls is to protect inland areas from storm damage and inundation without regard to the beach itself. If a seawall is placed between development and an eroding shore, eventually the beach will erode up to the seawall; some scientists also believe that such structures can accelerate erosion. Consequently, a major impact of seawalls is that beach is eventually lost (Figure 18), removing important habitat for shorebirds, sea turtles, and other species. By contrast, groins trap sediment moving along the shore. However, protection of one area is generally at the expense of increased erosion downdrift from the area protected. Because these structures do not increase the total sand available to beaches and barrier islands, their long-term impact is primarily to geographically shift the erosion, not to eliminate it.

The most common soft engineering approach is beach nourishment, which involves dredging sand from back bays, navigation channels, or offshore -- or excavating material from a land-based source -- and placing it on the beach (Figure 19). Because beach ecosystems are already adapted to annual erosion/accretion cycles, the placement of sand onto the beach generally has negligible impacts on beach ecosystems. By contrast, dredging bays can seriously disrupt shallow-water ecosystems and wetland habitats, a problem that has already led some nations to effectively stop this practice, except as part of navigation projects. Although the environmental impacts of dredging offshore deposits are generally less severe, care must be taken to avoid interference with coral reefs and life in the nearshore zone or altering wave refraction, which can cause previously stable shores to erode.

Wetlands (swamps, marshes, sea grasses, and shallow waters)

The impacts of adaptive strategies on wetlands can be broadly divided into deltaic and other wetland ecosystems. In deltaic areas, people might build dikes along rivers in response to increased river flooding due to sea level rise. Unfortunately, the resulting "channelization" of rivers would prevent annual river floods from providing the sediment and nutrients needed to keep agricultural lands fertile and to enable deltas to keep pace with sea level rise

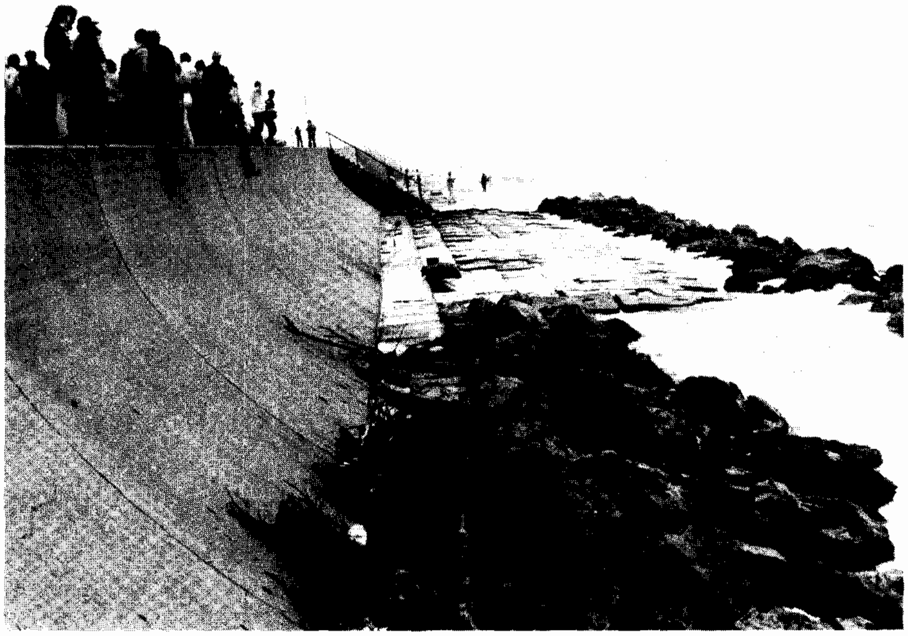

Figure 18. Although seawalls can protect property, the beach is eventually lost, as seen in Galveston, Texas (USA).

Figure 19. While expensive, beach nourishment has already been employed at Copacabana Beach, Brazil, and other areas with substantial tourism.

and subsidence of the land. Although dikes protect against flooding in the short run, their long-term impact can be to increase the loss of wetlands and dryland due to sea level rise, and to decreasing the fertility of farmland. If dams are built to address water management problems resulting from climate change, the problem could be further compounded as sediments and nutrients are trapped upstream (Figure 20).

Protecting dryland from inundation would also contribute to the loss of nondeltaic wetlands. As sea level rises, most wetland ecosystems could migrate inland if human activities did not interfere. Bulkheads block the landward migration of wetlands as sea level rises, decreasing wetland area in the short run and eliminating it in the long run (Figure 21).

The loss of both deltaic and nondeltaic wetlands would threaten coastal fisheries. About two-thirds of the fish caught for human consumption depend on coastal wetlands for at least part of their life cycles; in some areas, this is true for nearly all species. The loss of coastal wetlands would greatly diminish these fisheries. In many nations, coastal populations depend on these fish for subsistence. Because a hectare of wetlands often can provide more food than a hectare of cultivated farmland, even nations with insufficient arable land might sometimes be better advised to allow farmland to be inundated as sea level rises. The relative productivity of farmland and wetland should be determined before the decision is made to protect farmland from inundation.

A final response to sea level rise is the creation of marshes and swamps to replace those that are inundated. Such creation, however, can upset preexisting habitats. If the wetlands are created by filling shallow waters, or by excavating terrestrial ecosystems, this response may create one type of habitat at the expense of another. New management approaches may be required to consider these trade-offs.

Water Quality

Response strategies can increase the salinity of estuaries and aquifers, and can cause other pollution problems as well. Perhaps most important, the pumping of water from areas protected with dikes would increase saltwater intrusion into groundwater. Moreover, if warmer temperatures or droughts require increased diversion of water for agricultural, residential, and industrial uses, saltwater would migrate upstream in estuaries. This would, in turn, modify the circulation within the estuary, possibly affecting flocculation and sediment transport.

Enclosure could increase other water pollution problems by decreasing flushing. To prevent flooding, areas may be protected with tidal barriers. As sea level rises, these barriers would be closed more frequently. Initially they might be closed at every high tide, and eventually during all but low tide. Reducing tidal flushing would increase the concentrations of pollutants, endangering fish, wildlife, and adjacent water tables, and possibly creating health problems. The resulting changes in water circulation and other properties, such as temperature and salinity, may also harm fisheries.

Figure 20. Dams and flood control levees block the supply of sediment to wetlands, resulting in their gradual submersion as seen in Louisiana, United States.

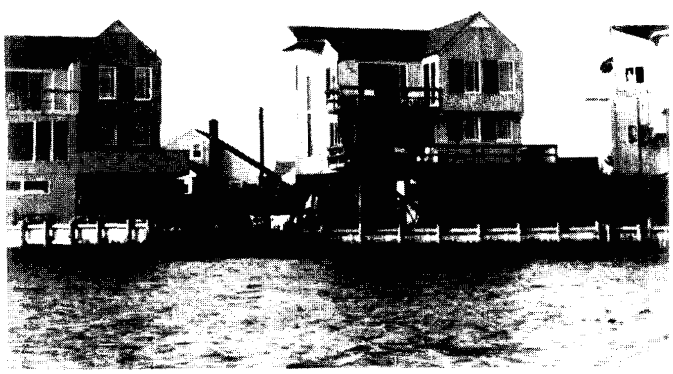

Figure 21. Bulkheads prevent wetlands from migrating inland as sea level rises.

SOCIAL AND CULTURAL IMPLICATIONS

To a large degree, human existence takes place within a particular social and cultural framework. Although the lifestyles of one society may seem alien to another, all cultures should be respected, preserved, and nurtured. While the industrial nations would face similar physical and environmental impacts from sea level rise, it is primarily in the developing world -- particularly small island nations -- where societies and cultures themselves might be threatened.

Several examples were provided by the representatives from Western Africa, where there is considerable concern over a wide range of issues related to success or failure in dealing with sea level rise and other impacts of a changing global climate. In some circumstances, there may be a need to relocate people, or even entire communities. This would be a traumatic social process affecting all social strata and cultures, although in terms of populations at risk, the most affected may be the poor families. Undertaking such a social reconstruction would require numerous steps -- from collecting appropriate data for understanding the implications, to managing a resettlement program and securing the necessary funding. Doing so must involve understanding of the physical, social, cultural, and occupational environment of the affected population, so as to minimize wholesale dislocation and to facilitate the creation of an environment equivalent to the one being displaced.

The question of resettlement, while exerting major financial demands, also seriously stresses the social and cultural norms of the community being relocated. The loss of traditional environments that sustain economic and cultural bases and provide both subsistence and recreational needs could disrupt family life and create social instability. This, in turn, would have negative psychological impacts on entire communities, especially on the young, and give rise to a number of social evils, including unemployment and drug abuse, with a devastating social cost to many communities.

Information is being amassed on a worldwide scale from which social, cultural, economic, and environmental implications can be derived for developing countries. An assessment must be made to determine which populations are most at risk. Thus far, dozens of developing countries with highly populated lowlands have been identified as being vulnerable.

The social aspects associated with sea level rise and its consequences could also be severe in the developed world, particularly for certain subcultures that depend on fishing and other coastal resources. Moreover, the loss of infrastructure, commercial, and community support systems could be astronomically expensive as a result of the high value of the installations. The loss of high-amenity residential areas and of commercial and industrial activities, and the displacement of skills, are all instances of severe community loss and replication of expensive investment. Adaptive options can be constrained by high property values in a free market system and the ability of the population to afford legal action in pursuit of compensation. Apart from these exceptions, the negative aspects of sea level rise are applicable on a global scale, the only real differential being ability to cope in financial and/or human resource terms. This difference reinforces the need to focus international attention and assistance on those nations least able to cope with global warming.

The experience of Venice, Italy, illustrates the response to the 25 cm relative sea level rise that has occurred over the past 80 years, which is analogous to the rise facing most of the world in the next 50 years. The experience gained there with respect to the social and cultural aspects of responding to sea level rise will have indispensable value for others, such as the West African countries, in the future.

Educating the populace is fundamental to the success of any future response. Informing everyone about the impacts of sea level rise and global climate change -- from children to political decisionmakers -- is essential. Only then are wise policy decisions possible.

There is an urgent need to implement disaster relief measures to respond to immediate and sudden sea level rise-induced catastrophes, such as storm surges and increased hurricane frequency. Postdisaster strategies should form an integral part of disaster relief strategies. Nevertheless, disaster avoidance is vastly preferable to disaster mitigation, and prior expenditure on avoidance measures could well alleviate human misery and show substantial economic benefits. Legislation as an economic and immediately available option is recommended to reduce future expenditures on defending lowlands or abandoning them. Sea level rise is a long-term phenomenon; legislation -- e.g. restricting the occupation and development of areas at risk -- could produce rich dividends in the decades to come.

Long-term, research-based, multifaceted educational response strategies in formal and informal settings therefore constitute an urgent priority. International and interdisciplinary in scope, these programs should target the young who are the future managers of the planet and the political decisionmakers who control the important tools of funding and resource allocation. Programs that train teachers to train students should be given preference, and all communication modes should be involved. Developed and developing countries should mobilize fully to cooperate in providing the material and human resources necessary to the success of these programs.

LEGAL AND INSTITUTIONAL IMPLICATIONS

The legal and institutional implications of global warming and sea level rise can be divided into two categories: international and national.

International

The three major international issues that the conference identified are (1) the need to use principles of international law, (2) the potential problems for marine boundaries, and (3) the use of the precautionary principle.

It is important to use established principles of international environmental law, including those of the Stockholm Declaration and the World Commission on Environment and Development Report. An international legal framework for cooperative response should be established. Such a framework (whether global, regional, or subregional) could use existing institutions or establish new institutions. In either case, it should specifically obligate nations to cooperate in their response to the problems posed by sea level rise or climate change and should include provisions for financing, assistance to developing countries, and transfer of the appropriate technology.

A coordinated approach to the problem of changing maritime boundaries resulting from sea level rise is necessary. Movements of low-water mark and disappearance of features used as base points will move the outer limits of maritime zones -- namely, territorial sea, contiguous zone, and economic zone (i.e., exclusive economic zone, exclusive fishing zone and, in some cases, Continental Shelf). Such an approach should address the problems posed by the complete disappearance of islands, which could alter maritime zones, as well as changes to other water-related boundaries.

Finally, the precautionary principle (or the principle of precautionary action) calling for reduction and/or prevention of significant environmental impacts, even in the absence of conclusive evidence or damage, should be considered and incorporated, as appropriate, into international agreements.

National

The workshop examined three national issues. First, there will be a need for coordinated use and improvement of structures, institutions, laws, and organizations (public and private) that already exist at national, state, or local levels and that address the issues raised by sea level rise and climate change. Second, it will be necessary to establish, develop, and/or improve systems of integrated resource management for coastal zones and related areas. Such a management system should address conservation and sustainable development, balance of public/private rights and boundaries, compensation frameworks, financing of responses, and insurance and other financial incentives.

Finally, there is a need for research on, and collection of, national laws as well as comparative studies to identify legal models that nations might wish to use in developing their legal responses to the problems posed by sea level rise and climate change.

ECONOMIC AND FINANCIAL IMPLICATIONS

From an economic and financial perspective, the problem of responding to future sea level rise is one of long-term investment decisions in the face of uncertainty. Future impacts will depend on human responses: that is, on the choice of investment options. Investment is a form of deferred gratification in which the choice is made to pay a price now to obtain future benefits. Because resources (such as natural resources, human skills and effort, and capital facilities and equipment) are limited, choices about trade-offs are unavoidable. Any choice necessarily precludes the use of those resources for other desirable ends.

A related economic problem concerns the distribution of costs and benefits among people and across generations. This is the question of who pays, who benefits, and in what proportions. This is where the issue of winners and losers arises. Very little attention has been given to this issue, but it must be recognized as important in attempts to fashion institutional responses.

People have a great talent for adjusting to change, and their adjustments are often most effective when implemented gradually. Because sea level rise, its resulting impacts, and the appropriate responses will vary widely across locales, decisionmakers closest to the facts are likely to devise the most appropriate incremental responses. In a prescriptive sense, this view tends to be non-interventionist and favors letting things sort themselves out as the facts emerge.

For IPCC purposes, however, the value of cooperative study and planning, and the responsibility of governments and other collective institutions to anticipate and develop effective responses, should be highlighted. Collective intervention may be essential when common property is involved and when decisionmakers ignore the effects of their choices on others. Effects that cross generations, property lines, or national frontiers are obvious examples. In addition, the lack of incentives for private investment in information virtually ensures that without governmental sponsorship, too little will be spent on research and dissemination of information.

Analytic Tools

Methods are being developed to help decisionmakers clarify the relative cost-effectiveness of potential responses even in the face of enormous uncertainty. If sufficient resources are available, the appropriate criterion for ranking potential responses is the "expected present value of net benefits." This is just the sum of the future benefits of a response option, minus associated costs, weighted by their likelihood of being realized, and "discounted" to present value terms. It depends upon (1) the distribution of subjective probability judgments about future sea level rise, (2) the rate at which future costs and benefits are "discounted" for comparison with present values, and (3) the monetary, environmental, social, and cultural cost incurred by various possible responses. Looking at expectations of when critical thresholds might be crossed allows one to consider the timing and level of effort simultaneously with the overall direction the response should take.

"Risk-cost analysis" is a useful framework for making decisions about adaptive options. This approach combines information on natural sources of risk and uncertainty -- i.e., storm surge, wave height, and mean sea level -- with estimates of their physical and economic effects and allows available information to be incorporated in a model to estimate the probability distribution of total costs associated with each adaptive option.

The modeling approach can be especially useful in identifying areas where additional scientific effort would yield the greatest payoff in terms of improving decisions. The value of narrowing current uncertainties, particularly about the rate and magnitude of sea level rise, can then be investigated using sensitivity analysis.

An additional strength of applying such methods is the emphasis on residual risks that remain regardless of the adaptive option. This information can help decisionmakers to avoid choosing options such as an underdesigned dike which could leave a protected area vulnerable to a catastrophe.

An important limitation of this evaluation process is that the adverse effects of sea level rise and the costs of adaptive options may occur at different times. For monetary values, discounting is an appropriate tool to compare future costs with current costs. Higher discount rates depress the estimated cost of future sea level impacts and of future responses. Lower discount rates make them appear larger. Although it makes good economic sense to apply some discount rate to future values, this involves strong judgments about the preferences of society and encounters serious ethical complications when inter-generational effects are at stake.

In assessing the cost of retreat from sea level rise, some automatic responses to the risks will reduce the cost of retreat. For example, the demand for risky shoreside property may decline, leading to reduced property values and thus lowering the loss from abandonment. The potential for market mechanisms to decrease the adverse economic and environmental impacts warrants further exploration. Because market responses will be influenced by other policies (e.g., the definition of property rights, the availability of subsidized insurance), exploring their operation will uncover related and important policy questions that may not presently be part of the climate change dialogue.

Care must be taken to avoid imposing our current understanding (or lack thereof) of the effects of climate change on the decisionmakers of the future. We need to begin to understand now the range of options that might be considered so that the necessary funding and institutional mechanisms can be prepared and the correct signals can be sent to the relevant institutions. Future decisions will nevertheless be made based on future information, and a recognition of the learning process must be incorporated into current activity. The same ranking criteria applied to assessing the relative merits of various possible responses can be used to identify the types of information that would be most valuable for making those future decisions.

Financial and Strategic Planning

The impacts of climate change on coastal areas will not fall evenly across nations. There will be winners and losers, in both relative and absolute terms. It is expected that several developed countries will be among the winners (through economic gains made possible by activities that release greenhouse gases), while some of the developing nations will be the heaviest losers. Many of the developing nations will have insufficient financial and technical resources available for the most desirable adaptive options. In such circumstances, assistance from industrialized nations may be justified. The financial burden for assisting developing nations may be very high; it is important to begin collecting information on the magnitude, timing, and duration of this assistance and its related costs.

With the present uncertainty over the likely coastal effects of climate change, implementing expensive adaptive strategies now would be inappropriate. Emphasis in funding arrangements may be more constructively placed on facilitating the limitation of greenhouse gas emissions. Again, however, virtually nothing is known about these relative costs. The value of further research and improved knowledge must be stressed. Early international assistance may be most valuable for activities that will improve the preparedness and ability of countries to adapt to climate change if it occurs, and that will help even if sea level rise is negligible.

At a local level it may be useful to break down the issues into manageable components through a process of "strategic planning." The steps of such strategic planning include a situation audit (data base); an analysis of the strengths, weaknesses, opportunities, and threats; development of mission statements based on the outcome of the previous steps; and, finally, an implementation strategy.

To address the immediate problems of rising relative sea level in Louisiana (USA), for instance, mission statements and implementation strategies focused on data base collection, improved communications, education, lobbying and funding. To help facilitate these tasks, local governments organized, recruited, and mobilized volunteers, who formed a grass-roots coalition. While education of the youth was taking place in the school system, the coalition initiated programs to improve communication, develop a mutual support system, educate adults and communicate with political decisionmakers.

The driving force behind the subsequent passage of a coordination and funding mechanism was education. To lobby effectively, it is important to have a broad-based, educated population making similar demands of politicians. The nature of the funding mechanism itself is instructive in that it draws its financial resources from a tax on one of the problem's several causes: the extraction of petroleum.

WESTERN AFRICA

Owing to the geological evolution of the Western Africa region, the present-day coasts are mostly low plains, surf beaten, sandy, and, in many places, subsiding. Most of the large sedimentary basins that make up the region are separated by cratons that are outcrops of the Precambrian basement; these constitute the few natural bulkheads in the region. There are considerable stretches of wetlands, particularly mangroves.

As a result of the present geomorphology and coastal activities, marine erosion and flooding are prevalent along much of the coastline. These conditions are causing great ecological damage, and they are disrupting settlements and socioeconomic structures and activities, many of which are located on or near the coast.

The protective measures applied at present in the region are very inadequate when compared to the severity of the problem. If the predicted sea level rise occurs, most low-lying areas would be inundated; this would virtually cripple most economic and social activities. Surface water and groundwater, as well as the soil, flora, and fauna of the region, would be profoundly affected as a result of increased salinity and added sediment and pollutant loads. The fledgling tourist industry could be decimated.

Rising temperature and reductions in rainfall would mean an increased incidence of heat-related diseases and a drastic reduction in the well-being of people, livestock, and crops. Hunger and disease would be prevalent and would increase the present level of human misery.

Sea level rise would increase the need to protect heavily developed areas with high capital values where relocation is not a reasonable option. But the excessive costs and technical requirements of some of the proposed adaptive options to protect such locations are far beyond what the region can afford. Thus, the region will require effective low-cost, low-technology measures. Such adaptive options must minimize the dislocation of social and community structures, avoid interfering with cultural attitudes, and conform with geotechnical and other environmental considerations.

Outside highly urbanized centers, existing populations should be resettled and setback lines for any new development on the coast should be enforced. Where coasts are deemed highly vulnerable, new development must be totally banned. Where new development becomes imperative, appropriate design criteria should be adopted to cope with the predicted rise of sea level as well as increased temperature. Converting coastal lands to forest would dampen wave energy as well as provide relief from increased heat.

Other adjustments would involve the protection of arable land, improved management of water resources, introduction of new agro-technology, controlled land-use policies, maintenance of food reserves, and the introduction of disaster relief measures.

For protecting arable lands, some of the low-cost, low-technology measures mentioned above could be applicable. Improved water management techniques could involve building dams (after an environmental impact assessment), aqueducts, reservoirs, and irrigation systems, and diverting rivers to husband freshwater. The adoption of new agro-technology should introduce more salt- and heat-tolerant crops, development of adaptive irrigation systems for reducing salinity stress, and conversion of flooded agricultural land for aquatic uses, such as mariculture.

Although the region is far from being self-sufficient in addressing its present needs, it will be necessary to stockpile food and institutionalize other disaster relief measures to cope with the emergencies that may arise from sudden flooding or drought.

Other adaptive options include setting up environmental monitoring (in particular tidal gauges) and early warning systems, preparing and providing flood vulnerability and new land-use maps for coastal areas, and above all, providing public education and information. This last option requires that more information be gathered, distributed, and understood.

Public information and education should emphasize the severity of the anticipated impacts from increased atmospheric temperatures and sea level rise, and prepare the public for some of the protective, preventive, or adaptive measures that may be necessary.

The application of most of the adaptive options makes it important that such proposals be embodied in coordinated and enforceable urban and regional development plans. Countries in the region should enact comprehensive coastal zone management policies. The United Nations Environment Programme's (UNEP) Regional Seas Programme for the West and Central African Region provides a platform for discussing and institutionalizing such a regional plan. It is hoped that governments in the region, while pursuing policy options at the national level, will appreciate more than ever the distinct advantages of a regional approach to the problems associated with global warming.

In the meantime, data banks of relevant information (providing for information exchange and transfer) need to be created. There is also a need for developing a regional climate change scenario as well as the increased involvement of regional scientists in global climate-related programs (e.g., World Ocean Circulation Experiment, Tropical Ocean and Global Atmosphere Program, World Climate Research Program).

The above recommendations can be brought to fruition only through sustained funding by United Nations organizations, potential donor agencies, and national governments.

NORTHERN MEDITERRANEAN AND BLACK SEA

The coasts of the Northern Mediterranean region have varied topography and land use. Land use is most intensive in France, Italy, eastern Spain, and parts of Greece; it is moderate in Yugoslavia, and light in Turkey. The major uses are summer recreation, maritime cities, harbors, agricultural activities, lagoonal fishing, and agriculture. With the exception of Turkey, national populations are not likely to increase significantly, although populations in coastal zones may grow somewhat.

Areas of High Priority and Concern at Risk From Sea Level Rise

The following types of areas are most likely to be damaged by a rise in sea level: (1) towns and cities by the sea; (2) harbors; (3) industrial installations built on lowlands and lagoonal areas; (4) tourist beaches; (5) pleasure harbors and marinas; (6) coastal "hard" protection works (jetties, groins, seawalls, etc.); (7) roads, railways, airports by the coast; (8) lagoonal fishing (due to higher water and salinity levels); (9) coastal sand barriers and barrier islands; (10) reclaimed lands, usually at sea level, and associated irrigation systems; (11) desalination facilities; and (12) coastal archaeological sites.

The present levels of protection of these areas vary. Although there are stretches of low coast at the margins of agricultural land that are still in a natural state, defenses against storm wave attack are found throughout the region, in the form of bulkheads, seawalls, groins, and submerged reefs.

However, in many areas the level of protection is inadequate to prevent coastline retreat. This problem is particularly evident in areas where dams have blocked the sediment that rivers would have discharged into littoral systems. Erosion is also caused by the interference of fixed shoreline structures, in such places as the Po Delta, and by accelerated land subsidence. Other problems include the destruction of dunes for construction and the conversion of wetlands to agricultural and urban areas.

A special situation occurs in the Venice area, where concern for recurring risk of storm surge flooding has involved scientific, engineering, and political considerations. Plans for defending the lagoon and safeguarding the historical city are under way. A tidal barrier designed under government mandate is expected to be completed by 1997. The project design explicitly considers global warming: as sea level rises, the gates will simply have to be closed more frequently.

Impacts of Sea Level Rise

Even the rise of 10 to 25 cm predicted for the year 2030 would magnify the impact of storm waves and surges and the extent of inland flooding during high tides, especially in those areas with no current works to protect against erosion and flooding. The impact on existing hard structures that protect infrastructures (cities, industrial establishments, communications) would be minimal in most cases, as they are built to accommodate exceptionally high water levels during storms. However, if the frequency of exceptional events increases, in many cases the structures would need to be raised.

A more significant impact is to be expected on water and salinity levels in canals, estuaries, and lagoons, with an increased frequency of flooding near the coast and farther inland. In lagoons, even a small rise in sea level would affect the ecosystems of open waters and marshlands, and particularly, the management of fisheries and agriculture. Moreover, the upstream migration of salt wedges would invade agricultural soils and groundwater, threatening the quality of irrigation water.

A rise greater than 30 cm would magnify these impacts, to the extent that seafront land uses would have to shift inland or would have to be protected more extensively (which would require additional protective walls, drainage systems, and elevation of roads, railways, and other infrastructure). The impacts are likely to be the least in more sheltered areas that have less attack by waves (e.g., Yugoslavia, Northern Greece, Albania, and Southern Turkey).

Adaptive Strategies

Technical capabilities and financial resources for structural responses to sea level rise will continue to be adequate in Italy, France, Spain, and Greece. In the other countries, this capability will depend on the improvement of current economic difficulties.

Responses to sea level rise would involve two levels of action: the near term, while sea level is still rising fairly slowly, and the long run, when substantial acceleration is possible. In the near term, there will be a continuation of the present situation, perhaps with a moderate strengthening of present defenses, and the addition of new ones in some areas.

However, site-specific adaptations have to be considered wherever protection of a particular land use is no longer cost-effective -- e.g. some sea resorts and installations at seafront settlements. Such adaptations imply the shifting of the land uses -- e.g., the abandonment of roads, buildings, industries, and small harbors and the return of some reclaimed lands to the original lagoonal state, because fishing and aquaculture would be more profitable than grain cultivation on saline soils.

In the long run, current land use practices would become untenable in an increasing number of areas. For land uses on low coastlines, the main options are planned adjustment by means of coastal planning and imposition of guidelines, or planned retreat of the more exposed areas (mainly deltas) that are not too developed or heavily populated. Nevertheless, in the many isolated fishing villages at the bottoms of cliffs in Turkey, and wherever the physical nature of the coastline leaves little room for retreat, the policy of hard defenses will have to be continued.

Social acceptability is unlikely to be a major barrier to implementing adaptive responses. Because the changes would be largely confined to specific localities, they would be affordable at the national level. In cases where changes are imposed by sudden catastrophes, the public would often demand immediate responsive action. When they occur gradually, there would be ample time for the implications of the response options to be explained to the public.

Recommendations for Priority Action

A number of immediate actions seem to be appropriate:

1. Increase the awareness of the implications of sea level rise for coastal zone uses and management, especially the awareness of decisionmakers and politicians. For example, conduct national seminars and workshops using maximum (though appropriately guided) media exposure with international support.

2. Identify and further evaluate areas at risk, considering technical evaluation of the impacts and costs and implications of various options. Incorporate sea level rise scenarios into all engineering coastal protection projects.

3. Create, strengthen, or streamline institutions that can carry out the necessary research and further the legal processes by which governments can implement policy choices and facilitate coastal zone management in the next decades. In most Mediterranean countries, create study centers on the hazards of climate change at the interministerial level to advise the government on impacts, responses, and policies.

SOUTHERN MEDITERRANEAN

Although the Southern Mediterranean is presented separately, the Mediterranean is one region with a common set of sea level rise problems. Nevertheless, population patterns and growth will create different challenges for the northern and southern coasts. While the population along the northern Mediterranean coast is fairly stable, the southern Mediterranean coast is experiencing rapid population growth confined to a very narrow zone of usable land. New urban areas are developing, and existing ones are expanding.

The interrelationship between projected problems due to sea level rise and problems due to rapid population growth in the limited coastal zone area of North Africa should emphasized. More than 50 percent of the population in this area lives within 50 kilometers of the shore, and the coastal zone is expected to experience significant urban growth over the next 50 years.

Adaptive options for the northern Mediterranean will concentrate on the preservation of an existing and entrenched infrastructure that is protecting heavily urbanized areas. By contrast, in the southern Mediterranean, the adaptive options may be oriented more toward planning and controlled community and urban development. However, this is an interpretive generalization; in reality, many of the same adaptive options are needed for both coasts.

Many coastal cities have portions at or near present sea level, including Algiers and Alexandria (Figure 22). Low-lying portions of existing cities, future plans for urban development, port facilities and small harbors, the tourist industries' beaches, and aquatic resources in the Red Sea and the Suez Canal are at possible risk. Port facilities have been designed for existing sea level rise and could be flooded. Large losses of the freshwater supply as a result of saltwater intrusion are anticipated as sea level rises.

The two major sections of the Egyptian coast that are most vulnerable to sea level rise are the east end of the Nile Delta at Port Said and the west end adjacent to Alexandria. Although Alexandria itself is 3 to 5 meters above sea level, it is surrounded by low land. Thus, if sea level rises, the city could become an island.

Long-term tidal gauge records from France and Italy suggest that the Mediterranean countries have historically experienced 1-2 mm per year of sea level rise. An accelerated rise in sea level would exacerbate existing local problems with subsidence, erosion, and storm damage. There are already

Figure 22. Alexandria's beaches have already eroded.

tremendous erosion problems along the central Nile Delta and at its distributary promontories (e.g., the Rosetta). The Nile Delta is experiencing rapid erosion due to blockage of its sediment supply by the Aswan Dam. Tidal gauge data from stations located at Alexandria and Port Said document subsidence in the area of 1-2.5 mm per year. The Algerian-Tunisian shore is particularly susceptible to wave attack from the west, and this phenomenon could be exacerbated with a rise in sea level.

The three main adaptive approaches are the same as for other regions: (1) withdrawing from the coast, (2) building protective structures, or (3) remaining and adjusting to the expected change.

Regional Recommendations

Improving forecasts of sea level rise is a top priority. In addition, future urbanization should be limited to appropriate areas in view of the anticipated sea level rise in order to avoid future problems and expense. Plans for new structures should take into consideration the anticipated rise, and existing structures will need to be raised as the problem evolves.

Hard protective structures should be constructed where buildings or public works are at risk. More flexible measures, such as establishing set-back lines should be used in currently nonurbanized areas. The major difficulty with the latter option will be to convince officials to accept a loss of precious land today to prevent some very distant uncertain consequences.

The various stages for the development of response strategies include: (1) evaluating high-risk areas; (2) developing options (i.e., defensive, adaptive, retreat); (3) defining and developing policy strategies; (4) developing funding mechanisms; (5) creating appropriate institutional and legal frameworks; and (6) defining the time frame for implementation.

The regional representative proposed a schedule for responding to sea level rise and global warming. Over the next 10 years, the focus would be to define the problem, develop legal structures, and control development. From the years 2000 through 2020, coastal zone planning should define responses and how to implement them. Adjustment actions, such as retreat, should be initiated. Sea level rise concerns could be incorporated into current plans for coastal construction from the years 2020 through 2050.

Country-Specific Recommendations: Egypt

The following adaptive options for Egypt are appropriate today:

1. Upgrade and update the quality of information available on areas vulnerable to a sea level rise, and use Geographic Information Systems to analyze it.

2. Adapt new agricultural practices with improved efficiencies for using freshwater.

3. Develop salt-tolerant agricultural plants.

4. Strengthen existing institutions, and create new ones to deal with water and coastal resource research, allocation, and management.

5. Incorporate a protective plan into the design of an international road currently planned for the coast.

6. Control the exploitation of quarries along the coast west of Alexandria in order to preserve the ridge.

7. Incorporate beach erosion studies and erosion control practices into coastal zone development plans.

8. Move waste dumping sites to suitable locations to reduce risk of water pollution.

9. Encourage land reclamation projects at higher land elevations.

10. Assess the technical and economic feasibility of bypassing sediments at the Aswan High Dam.

The consequences of an accelerated sea level rise are not expected to materialize until 2030-2050. However, the longer the implementation of appropriate adaptive strategies is delayed, the greater the eventual cost in human and economic terms. Costs are escalating and the population is doubling, so it is imperative to work on adaptive activity now.

NON-MEDITERRANEAN EUROPE

Problem Identification

The technical problems related to coastal zone management in Europe are no different from those found elsewhere in the world. Low-lying coastal areas are faced with inundation (Figure 23), erosion, saltwater intrusion, and the threat of extreme climate events, such as the extreme storm surge in 1953 that led to the collapse of coastal defenses in countries bordering the North Sea (Figure 24).

Anthropogenic problems play less of a role in Europe than in other parts of the world, as coastal regulations in most countries have existed and have been enforced for a considerable period of time. The fundamental difference between most European countries and other countries is that the former have both the technological and financial resources to respond appropriately to the above problems.

The present level of coastal defense structures varies among countries. In countries like the Netherlands, the structures may be considered adequate, whereas in other countries, such as Poland and Portugal, limited financial resources constrain coastal protection efforts.

European countries should be able to cope with the possible effects of sea level rise alone. However, if a relatively steady rate of eustatic sea level rise is accompanied by changes in the frequency, direction, intensity, and duration of extreme events (storms), coastal defenses may be insufficient.

Figure 23. Near Helsinki, Finland -- while the Scandinavian coast is not vulnerable to erosion, some developed low areas are vulnerable to inundation.

Implementation of Adaptive Strategies

Most European countries could respond to the threat of sea level rise by either coastal defense or retreat. The regional representatives do not see significant barriers to the implementation of these adaptive strategies. The financial, technical, and institutional capabilities exist for addressing sea level rise, particularly with coastal defense measures. Public awareness of the problem is high, and environmental issues are a priority for policymakers.

Because of the generally high economic, environmental, cultural, and social values of the coastal areas in European countries, the adaptive measures would be cost-effective; however, their implementation would depend on site-specific considerations. For European countries, cost considerations are directly related to the value of capital investment in coastal areas. In areas where there is significant investment, there is more incentive to pay the cost of protection. This is particularly true in highly industrialized countries where the percentage of coastal defense expenditures is relatively small in relation to the gross national product. In less industrialized countries, that

Figure 24. The 1953 flood almost devastated London, England. This picture, showing what could have happened, was instrumental in creating the public awareness necessary to construct the Thames Barrier.

percentage could be higher, making the defense option less affordable and less feasible.

A high level of technological expertise in coastal defense measures is readily available in most European countries. In those countries with large coastal areas that are extensively protected, this expertise is constantly being improved and expanded.

The institutional framework to facilitate adequate response to the threat of sea level rise exists in most countries, although in some of them this threat has not yet been incorporated into the planning and decisionmaking processes.

Because of its long historical experience with flooding and other catastrophes, the general public is keenly aware of the risks to coastal areas, particularly in the countries bordering the North Sea, which have extensive protective systems. In some countries, the level of awareness probably requires further stimulation. In all cases, awareness is directly linked to the values (economic, environmental, cultural, social, etc.) attributed to the potentially threatened area. However, at the same time, the public still expects that provisions for public safety will be continued. Strategies involving any reduction in safety standards or abandonment of protective systems would be strongly resisted.

While uncertainty remains concerning the problem of sea level rise, there would be little or no opposition in European countries to consider or, in some cases, to incorporate preventive measures into coastal zone management plans in the light of scientifically acceptable projections for sea level rise.

Although coastal defense can sometimes cause adverse environmental effects, (see the "Environmental Implications" section) these concerns are increasingly taken into consideration and have high priority in the national decision-making processes.

Recommendations

1. Expand climate-related research.

2. Stimulate public awareness about the problem by developing and providing educational programs.

3. Develop new "tools," such as the Impact of Sea Level Rise on Society study done by the Netherlands, to encourage a multidisciplinary integrated response to the threat of sea level rise and all its implications. Use these tools in the countries where these efforts have not yet been undertaken.

4. Through international action, facilitate the transfer of developed technologies to all countries in need of these "tools," within European countries and, in particular, within developing nations.

5. Provide international and national assistance for the training of coastal managers in the European countries that have developed relevant technologies.

CENTRAL AND SOUTH AMERICA

Problem Identification

The coastal zones of this region face a variety of common problems, including flooding, elevation of water tables and resulting impacts on agriculture, increasing population concentrations, inappropriate construction in low-lying areas, recent intensification of climate anomalies, and ongoing changes in wave climates, the patterns of littoral drift, and other aspects of coastal morphology.

These problems would probably be magnified if sea level rises. Flooding would be exacerbated, causing inland sedimentation problems and silting of river beds in addition to direct risks to life and property. Coastal erosion would impede government efforts to develop tourism and other economic activities. Saltwater intrusion into rivers and aquifers could cause severe problems. Because many cities discharge sewage into fluvial waters through gravity drainage systems, a rise in sea level could block the flow of these wastes away from coastal urban areas. Finally, changes in physio-chemical properties in coastal waters and flooding of coastal ecosystems could damage the biological chain, particularly fisheries resources.

Adaptive Strategies and Barriers to Implementation

Existing measures include hard and soft options for shore protection and preservation of coastal areas. These strategies have been put in place to deal with existing physical coastal processes (such as wave erosion) and have not been designed to deal with a rise in sea level.

The representatives from the region see a variety of barriers to implementing adaptive measures. Perhaps most important, the uncertainty of the phenomenon and the existence of more pressing socioeconomic problems prevent the decisionmakers from assigning a high priority to formulation of adaptive strategies specifically for sea level rise.

Other barriers include cost, the lack of technical and public awareness, poverty, and the international debt crisis. Countries in the region do not have the financial resources to invest in adaptive options, given their own development requirements. Moreover, technical expertise is very limited; there are not enough knowledgeable people to teach others or address the problem, given the wide range of competing needs. There is a corresponding lack of public awareness of the problem that needs to be addressed by formal and informal educational programs.

Moreover, the poor -- who constitute the majority of people in the region -- simply do not have the resources to relocate or protect themselves, no matter how well informed they might be. There are financial problems at the national level as well: governmental decisionmakers and politicians are constrained by the pressing need to service international debts, which severely inhibits national ability to invest in protection of the environment. There are too many other critical, immediate demands on scarce financial resources.

Adaptive responses also face cultural, institutional, and environmental constraints. Besides the natural human tendency to resist change, especially when cultural values and a sense of community are directly related to a particular environment, different values are placed on the present versus the future. The present, especially for poor people concerned with basic subsistence, is immediate and real. The future, which could include a possible rise in sea level of undetermined magnitude, is too far away and unreal to be a serious preoccupation, particularly given the existing socioeconomic constraints.

The greatest factor inhibiting effective institutional response is the lack of coordination between a variety of disparate agencies, each responsible for addressing different coastal problems and activities. There is a tendency to create more agencies or institutions to deal with a problem, rather than to streamline the existing system to address it more effectively.

Finally, response strategies would undoubtedly have important environmental implications. Unfortunately, there is not enough knowledge or research data about ecosystem responses to determine how a particular strategy might affect the environment.

Effectiveness of Adaptive Strategies

Although adaptive options for this region have not been considered in depth, the regional representatives recognized that a number of issues would have to be addressed to evaluate their effectiveness. Maintaining public safety is important, for example, and the present systems used to protect the coast from existing problems would be inadequate to cope with an acceleration of sea level rise.

One must also compare the costs of a strategy with the likely benefits. The region's representatives concluded that the opportunity cost of investing in defenses against long-term sea level rise is not currently competitive with other socioeconomic investment. Another important consideration is the protection of environmental and cultural resources. Unfortunately, in some cases, sea level rise has not even been recognized as a possible threat to these resources.

Finally, given our inability to predict the future, strategies that perform well under uncertainty should be preferred. But the regional representatives felt that until preliminary assessments of the impacts and possible responses are undertaken, an evaluation of this criterion is at best premature and probably irrelevant.

Recommendations

Despite of the limitations of current understanding, the regional representatives concluded that existing knowledge is sufficient to support a number of recommendations at the national and international levels.

<u>National Level</u>

1. Create local and regional panels on climate change to advise national authorities. At the national level, there should be a centralized authority dealing specifically with global climate change.

2. Create and fund formal and informal education programs on climate change and sea level rise, and establish information systems to maintain a high public profile for these issues.

3. Develop appropriate technology for adaptive options specifically related to local conditions.

4. Reallocate funding from reduced military expenditure to address the physical and social aspects of environmental issues.

5. Encourage national earth science agencies and institutions to place a high priority on the study of global climate change.

International Level

1. Expand the global monitoring network for the collection and dissemination of data relevant to sea level rise and climate change, including the establishment of data banks.

2. Increase the transfer of appropriate technology related to adaptive options.

3. Reallocate some military expenditures to assist developing countries in addressing the physical and social aspects of environmental issues.

4. Establish regional cooperation/coordination regarding global climate change.

5. Create and fund formal and informal regional educational programs on global climate change and sea level rise, including the training of human resources necessary to support a comprehensive defense approach to the effects of sea level rise.

6. Make available the latest state-of-the-art data in research and appropriate adaptive measures adopted in the developed world to ensure swift transfer of the newest technology, sometimes denied by financial and similar constraints.

NORTH AMERICA

North America has a wide range of coastal land forms and development patterns. Hence, its vulnerability to global warming and accelerated sea level rise will vary from region to region. In general, the continent can be characterized by Arctic/Pacific and Atlantic/Gulf coastal landforms. The Pacific coast is typified by cliffed shorelines, often rocky and rugged, with relatively few low-lying human population centers (e.g., Los Angeles, San Diego, Acapulco). By contrast, the Atlantic and Gulf coastal plains are low, flat, and densely populated; the outer barrier islands have become some of the most valuable real estate in the United States, and an important source of foreign exchange for Mexico.

Canada and the northern United States were subject to glaciation during the past ice age. With a few exceptions, these areas tend to be more rocky, with higher relief terrain than their southern counterparts. They are also still experiencing isostatic rebound from the last glaciation, so that the land is actually rising out of the sea from Oregon north, around the Arctic, and south to Maine. Tectonic processes are also causing uplift along the Pacific coast between Oregon and Alaska. In areas with substantial uplift, sea level rise will be markedly less important for the coastal ecosystems and local economy. By contrast, the unconsolidated sediment of the Atlantic and Gulf coastal plains are slowly subsiding about 15 cm per century, and a few areas such as Louisiana and Galveston are subsiding several times as rapidly.

Impacts of Sea Level Rise

From an economic standpoint, Canada appears to be least vulnerable to sea level rise owing to both its rocky coasts (Figure 25) and its low population density. Nevertheless, St. John, Charlottetown, and a few other cities have low-lying developed areas that might be threatened. Moreover, a number of planned major infrastructure projects would be vulnerable to sea level rise.

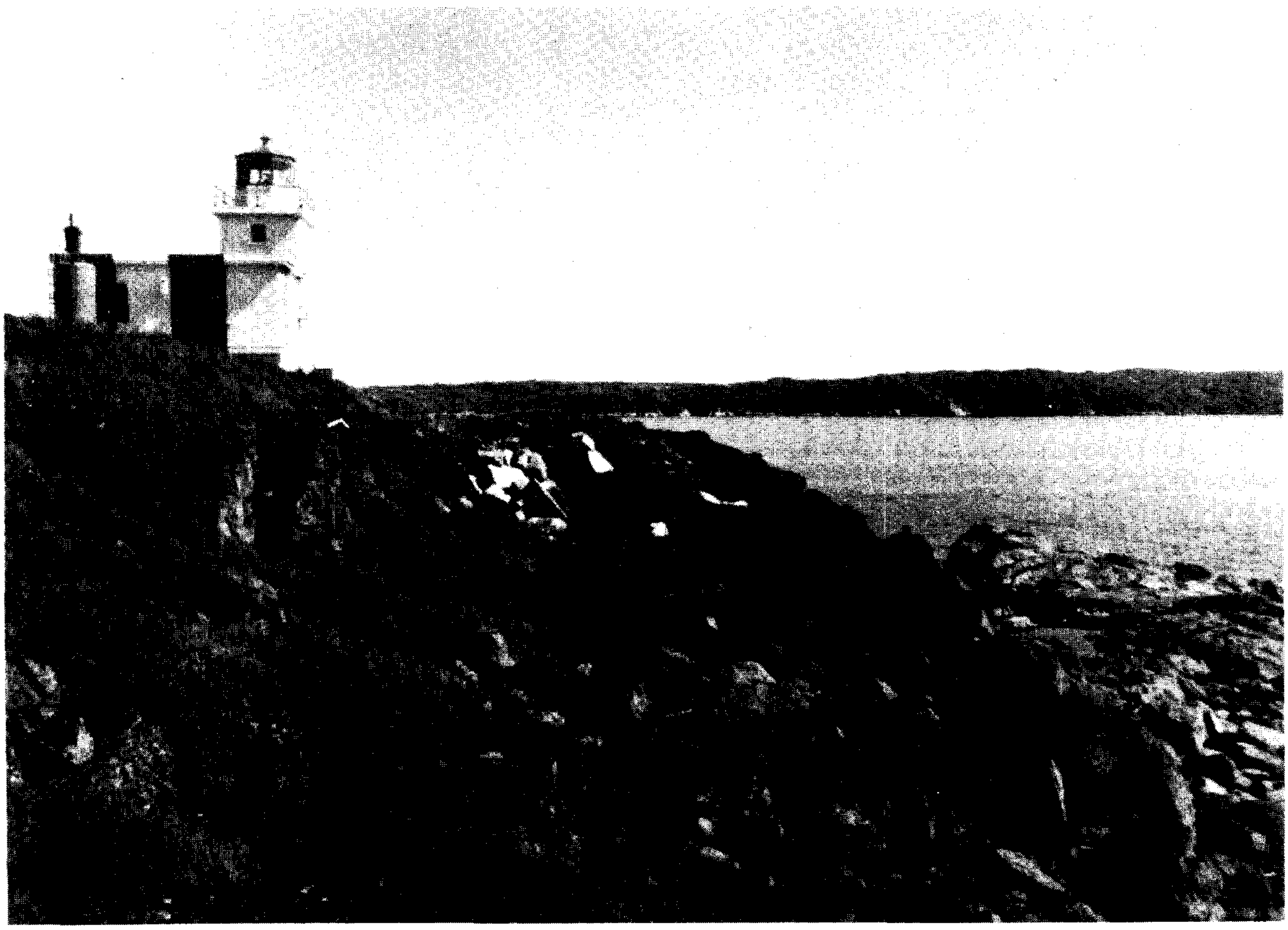

Figure 25. Mouth of Belle Isle Straits on the Atlantic coast of Newfoundland (Canada).

By contrast, 2.8 million Mexicans live within a few meters of sea level, and many beach resorts would be extremely vulnerable. Although the United States could lose the most land of the three nations -- about 20,000 square kilometers -- such a loss would be small compared to the total land area of the country. In both Mexico and the United States, the threat to recreational beach resorts would be particularly great.

From an environmental standpoint, the greatest threat from sea level rise appears to be the loss of coastal wetlands in Mexico and the United States. A one-meter rise would inundate over half of the U.S. coastal wetlands; the low tidal range in the Gulf of Mexico suggests that Mexico's wetlands would be at least as vulnerable as those of the United States. Particularly vulnerable would be the Mississippi Delta in the United States and the Grihalva Delta in Mexico. The larger tidal ranges and relative scarcity of wetlands in Canada suggest that this nation would have less of a problem.

Adaptive Responses

Potential responses include structural solutions, such as dikes; soft solutions, such as beach nourishment; and nonstructural measures, such as bulkhead prohibitions, long-term leases, and requirements that structures be set back from the shore. In general, structural and soft solutions can be deferred until sea level rise is more firmly established and closer at hand. (Because the problems are already occurring in Louisiana owing to subsidence, structural solutions are being actively pursued even today.) By contrast, planning measures require long lead times commensurate with the lifetimes of coastal development. Although houses may have useful lifetimes of 30-50 years, planning requires a longer time horizon because roads and other infrastructure channel development for centuries.

A major theme throughout this conference has been that countries with the greatest vulnerability to sea level rise are also the least able to respond. This principle applies in North America, where millions of people subsist on low-lying, erodible coastal plains near the water's edge and lack the institutional and financial means to erect shore protection structures or to relocate inland. The present level of protection in urban areas is barely sufficient, as evidenced by the Hurricane Gilbert in 1988, which caused major destruction in Mexico.

Preliminary assessments in the United States indicate that the cost to protect the most densely developed 15% of the land threatened by sea level rise could total approximately $100 billion. By contrast, the only study of Canada suggests that the cost of rebuilding coastal infrastructure would be only $3-4 billion; moreover, the net cost of sea level rise would be much less because adjustments could be incorporated in the renovations that would take place anyway. Although no assessments have been conducted for Mexico, the similarities between its coasts and those of the southern United States suggest that if structural solutions were used to protect developed areas, the cost would be high.

Barriers to Implementing Response Strategies

Adaptive strategies would face many barriers. In Mexico and some parts of the United States and Canada, the necessary financial resources simply would not be available. In the United States, structural protection measures could eventually result in the loss of most wetland shores, with consequent impacts on coastal fisheries. Cultural problems must be considered as well. For example, the highly developed Long Beach Island in New Jersey could probably afford a dike, and the environmental consequences would be small if the undeveloped portion were left outside the dike; but the loss of beaches and waterfront views may not be acceptable to the public. Current legal constraints make it difficult to abandon areas for the sake of wetland protection without compensation, unless a plan to do so is put in place decades before an abandonment is necessary.

Moreover, when one gets into the details of necessary responses, one begins to see that our understanding of the implications of response options is superficial at best. The feasibility of raising land, for example, depends in part on the availability of inexpensive fill material, which in turn may depend on shipping costs. But climate change may alter these costs, particularly if sea level rise reduces clearance under bridges or more frequent droughts diminish the flow in rivers.

Perhaps the most important barrier to implementing anticipatory strategies is the lack of public awareness, which is the product of educational, social, and cultural backgrounds. However, it may also be the most important problem that can be theoretically dealt with by existing institutions. Most people do not think about underlying <u>processes</u> (e.g., the gradual rise in sea level). Instead, they respond only to <u>events</u> (e.g., catastrophic damage and loss of life caused by a hurricane). Tragedies are blamed on the flukes of nature, and people view themselves as victims of bad luck. Nevertheless, in the United States there is a growing awareness among public officials and the general public of the hazards of flooding, the importance of coastal wetlands, and the risks due to sea level rise; in the last three years, many agencies have begun to incorporate sea level rise in their coastal management policies. Mexico and Canada have only begun to undertake impact assessments; neither has yet implemented measures as a direct response to accelerated sea level rise.

Vulnerability is obvious from even a casual inspection of the present situation, not to mention the continuing urbanization along the U.S. coasts and the population explosion in Mexico. The picture looks bleak without even a hint of a rainbow within the darkened clouds. Scant and incomplete as our data are now, it is apparent that there is already trouble at the water's edge, which will only be exacerbated by accelerated sea level rise.

CONCLUSIONS AND RECOMMENDATIONS

In many parts of the world, as a result of population growth and economic development, the natural function of coastal areas and resources is being degraded and impaired. These problems will be aggravated and compounded by future sea level rise and other effects of global climate change unless appropriate response strategies are adopted. With a view toward sustainable development, the current status of coastal areas and resources is a matter of national and international concern, and care must be taken to avoid additional adverse impacts.

Although coastal zone management is a national responsibility, international cooperation among nations with shared concerns can improve the management of coastal resources in general and can facilitate adaptive responses to climate change in particular. International cooperation is particularly valuable in the collection and use of information on available response options and their implications.

Existing international organizations, such as the UNEP and its Regional Seas Programme, should be used to identify and evaluate solutions for present and future problems in the management of coastal areas and resources, especially for developing countries.

While uncertainty remains regarding the magnitude and timing of accelerated sea level rise, current information from the IPCC Working Group I suggests that a rise in sea level of 25 to 40 cm is possible by the middle of the next century. Even if measures are adopted to limit emissions of greenhouse gases, sea level is expected to continue rising for some time. Thus, coastal states must consider how to adapt.

The highest priority tasks include:

1. Identifying coastal areas, populations, and resources at risk from sea level rise, and undertaking topographic mapping with improved vertical resolution.

2. Developing global and regional systems to research, monitor, and predict sea level rise and its consequences.

3. Educating the public, to develop awareness of the risks to coastal resources from both existing activities and future sea level rise, and also to keep these critical issues in the forefront of public and government attention.

4. Elaborating or amending national policies and legal structures for integrated management of coastal and related areas and resources.

5. Ensuring that new coastal projects do not place further stress on coastal areas and resources.

6. Enhancing research programs and encouraging collection and dissemination of all relevant data and information to improve our understanding of (a) the status and trends of the physical systems at the national and cross-boundary level (geomorphological, hydrological, hydraulic, etc.); (b) the economic implications of resource allocation, planning, analysis, and implementation at both the national and cross-boundary levels; (c) the environmental and ecological implications involved in effective coastal zone

management; and (d) the social and cultural implications and constraints facing adaptive strategies. This research will help us to develop the necessary legal, planning, and institutional capabilities for integrated management of coastal resources and related areas.

7. Providing technical and financial assistance to developing countries for research and management of coastal areas and resources.

8. Using country-specific studies to evaluate available adaptive options.

9. Adopting a framework convention on climate change to facilitate cooperative efforts to limit and/or adapt to global climate change.

PROBLEM IDENTIFICATION

CAUSES OF SEA LEVEL RISE[1]

PAST TRENDS IN SEA LEVEL

The worldwide average sea level depends primarily on (1) the shape and size of ocean basins, (2) the amount of water in the oceans, and (3) the average density of seawater. The latter two factors are influenced by climate, but the first is not. Subsidence and emergence due to natural factors such as isostatic and tectonic adjustments of the land surface, as well as human-induced factors such as oil and water extraction, can cause trends in "relative sea level" at particular locations to differ from trends in "global sea level."

Hays and Pitman (1973) analyzed fossil records and concluded that over the last 100 million years, changes in mid-ocean ridge systems have caused sea level to rise and fall over 300 meters. However, Clark et al. (1978) have pointed out that these changes have accounted for sea level changes of less than one millimeter per century. No published study has indicated that this determinant of sea level is likely to have a significant impact in the next century.

The impact of climate on sea level has been more significant over relatively short periods of time. Geologists generally recognize that during ice ages, the glaciation of substantial portions of the Northern Hemisphere has removed enough water from the oceans to lower sea level 100 meters below present levels during the last (18,000 years ago) and previous ice ages (Donn et al., 1962; Kennett, 1982; Oldale, 1985).

Although the glaciers that once covered much of the Northern Hemisphere have retreated, the world's remaining ice cover contains enough water to raise sea level over 75 meters (Hollin and Barry, 1979). Hollin and Barry (1979) and Flint (1971) estimate that existing alpine glaciers contain enough water to raise sea level 30 or 60 centimeters, respectively. The Greenland and West Antarctic ice sheets each contain enough water to raise sea level about 7 meters, while East Antarctica has enough ice to raise sea level over 60 meters. There is no evidence that either the Greenland or East Antarctic ice sheet has completely disintegrated in the last two million years. However, it is generally

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[1] Editor's note: Workgroup 1 has not been authorized to provide a paper to the proceedings. For completeness, we reprint the following, adapted from Effects of Changes in Stratospheric Ozone and Global Climate, published by UNEP and EPA.

recognized that sea level was about seven meters higher than today during the last interglacial, which was 1-2°C warmer (Mercer, 1970; Hollin, 1972). Because the West Antarctic ice sheet is marine-based and thought by some to be vulnerable to climatic warming, attention has focused on this source for the higher sea level. Mercer (1968) found that lake sediments and other evidence suggested that summer temperatures in Antarctica have been 7 to 10°C higher than today at some point in the last two million years, probably the last interglacial 125,000 years ago, and that such temperatures could have caused a disintegration of the West Antarctic ice sheet. However, others are not certain that marine-based glaciers are more vulnerable to climate change than land-based glaciers; Robin (1986) suggests that the higher sea level during the last interglacial period may have resulted from changes in the East Antarctic ice sheet.

Tidal gauges have been available to measure the change in relative sea level at particular locations over the last century. Studies combining these measurements to estimate global trends have concluded that sea level has risen 1.0 to 2.5 millimeters per year during the last century (Peltier and Tushingham, 1989; Barnett, 1984; Gornitz et al., 1982; Fairbridge and Krebs, 1962). Barnett (1984) found that the rate of sea level rise over the last 50 years had been about 2.0 mm/yr, whereas in the previous 50 years there had been little change; however, the acceleration in the rate of sea level rise was not statistically significant. Emery and Aubrey (1985) have accounted for estimated land surface movements in their analyses of tidal gauge records in Northern Europe and western North America, and have found an acceleration in the rate of sea level rise over the last century.

Several researchers have sought to explain the source of current trends in sea level. Barnett (1984) and Gornitz et al. (1982) estimate that thermal expansion of the upper layers of the oceans resulting from the observed global warming of 0.4°C in the last century could be responsible for a rise of 0.4 to 0.5 mm/yr. Roemmich and Wunsch (1984) examined temperature and salinity measurements at Bermuda and concluded that the 4°C isotherm had migrated 100 meters downward, and that the resulting expansion of ocean water could be responsible for some or all of the observed rise in relative sea level. Roemmich (1985) showed that the warming trend 700 meters below the surface was statistically significant. Meier (1984) estimates that retreat of alpine glaciers and small icecaps could be currently contributing between 0.2 and 0.72 mm/yr to sea level. The National Academy of Sciences Polar Research Board (Meier et al., 1985) concluded that existing information is insufficient to determine whether the impacts of Greenland and Antarctica are positive or zero. Although the estimated global warming of the last century appears to be at least partly responsible for the last century's rise in sea level, studies have not yet demonstrated that global warming is responsible for acceleration in the rate of sea level rise.

The Greenhouse Effect

Although global temperatures and sea level have been fairly stable in recent centuries, the future may be very different. Increasing concentrations of carbon dioxide, methane, chlorofluorocarbons, and other gases released by human activities could heat the Earth to temperatures warmer than at any time in the last two million years and thereby accelerate the rate of sea level rise.

A planet's temperature is determined primarily by the amount of sunlight it receives, the amount of sunlight it reflects, and the extent to which its atmosphere retains heat. When sunlight strikes the Earth, it warms the surface, which radiates the heat as infrared radiation. However, water vapor, carbon dioxide, and a few other gases found naturally in the atmosphere absorb some of the energy instead of allowing it to pass undeterred through the atmosphere to space. Because the atmosphere traps heat and warms the Earth in a manner somewhat analogous to the glass panels of a greenhouse, this phenomenon is generally known as the greenhouse effect; the relevant gases are known as greenhouse gases. Without the greenhouse effect of the gases that occur naturally, the Earth would be 33°C (60°F) colder than it is currently (Hansen et al., 1984).

Since the industrial revolution, the combustion of fossil fuels, deforestation, and cement manufacture have released enough CO_2 into the atmosphere to raise the atmospheric concentration of CO_2 by 20 percent; the concentration has increased 10 percent since 1958 (Keeling, 1983). Carbon cycle modelers and energy economists generally expect the concentration of CO_2 to increase 50 percent by 2050 and to double by 2075. Recently, the concentrations of chlorofluorocarbons, methane, nitrous oxide, carbon tetrachloride, ozone, and dozens of other trace gases that also absorb infrared radiation have also been increasing (Lacis et al., 1981). Ramanathan et al. (1985) estimated that the combined impacts of these other gases are likely to be as great as CO_2, which implies that by 2050, the atmospheric concentration of greenhouse gases will be equivalent to a doubling of carbon dioxide.

All projections of future concentrations have been based on the assumption that current trends will continue and that governments will not regulate emissions of greenhouse gases. However, in the fall of 1987, most of the industrial nations agreed to cut emissions of the chlorofluorocarbons by 50 percent over the following decade. Moreover, the United Nations has created an Intergovernmental Panel on Climate Change to develop strategies to reduce emissions of greenhouse gases in general. Nevertheless, curtailing emissions will be difficult. There is considerable doubt regarding the global warming that would result from a doubling of carbon dioxide. There is general agreement that the average temperature would rise 1.2°C if nothing else changed. However, warmer temperatures would allow the atmosphere to retain more water vapor, which is also a greenhouse gas, increasing the warming. A retreat of ice cover would also amplify the warming, while possible changes in cloud cover could increase or decrease the warming. Two reports by the National Academy of Sciences have developed a consensus estimate that the average warming will be 1.5 to 4.5°C, and that the polar areas will warm two to three times as much.

Impact of Future Global Warming on Sea Level

Concern about a substantial rise in sea level as a result of the projected global warming stemmed originally from Mercer (1968), who suggested that the Ross and Filchner-Ronne ice shelves might disintegrate, causing a deglaciation of the West Antarctic ice sheet and a resulting 6- to 7-meter rise in sea level, possibly over a period as short as 40 years.

Subsequent investigations have concluded that such a rapid rise is unlikely. Hughes (1983) and Bentley (1983) estimated that such a disintegration would take at least 200 or 500 years, respectively. Other researchers have estimated that this process would take considerably longer (Fastook, 1985; Lingle, 1985).

Researchers have turned their attention to the magnitude of sea level rise that might occur in the next century. The best understood factors are the thermal expansion of ocean water and the melting of alpine glaciers. In the National Academy of Sciences (NAS) report "Changing Climate," Revelle (1983) used the model of Cess and Goldenberg (1981) to estimate temperature increases at various depths and latitudes resulting from a 4.2°C warming by 2050-2060. While noting that his assumed time constant of 33 years probably resulted in a conservatively low estimate, he estimated that thermal expansion would result in an expansion of the upper ocean sufficient to raise sea level 30 cm.

Using a model of the oceans developed by Lacis et al. (1981), Hoffman et al. (1986) examined a variety of possible scenarios of future emissions of greenhouse gases and global warming. They estimated that a warming of between 1 and 2.6°C could result in thermal expansion contributing between 12 and 26 cm by 2050. They also estimated that a global warming of 2.3 to 7.0°C by 2100 would result in thermal expansion of 28 to 83 cm by that year.

Revelle (1983) suggested that while he could not estimate the future contribution of alpine glaciers to sea level rise, a contribution of 12 cm through 2080 would be reasonable. Meier (1984) used glacier balance and volume change data for 25 glaciers where the available record exceeded 50 years to estimate the relationship between historic temperature increases and the resulting negative mass balances of the glaciers. He estimated that a 28-mm rise had resulted from a warming of 0.5°C, and concluded that a 1.5 to 4.5°C warming would result in a rise of 8 to 25 cm in the next century. Using these results, the NAS Polar Board concluded that the contribution of glaciers and small ice caps through 2100 is likely to be 10 to 30 cm (Meier et al., 1985). They noted that the gradual depletion of remaining ice cover might reduce the contribution of sea level rise somewhat. However, the contribution might also be greater, given that the historic rise took place over a 60-year period, while the forecast period is over 100 years. Using Meier's estimated relationship between global warming and the alpine contribution, Hoffman et al. (1986) estimated alpine contributions through 2100 at 12 to 38 cm for a global warming of 2.3 to 7.0°C.

The first published estimate of the contribution of Greenland to future sea level rise was Revelle's (1983) estimate of 12 cm through the year 2080. Using estimates by Ambach (1980 and 1985) that the equilibrium line (between snowfall accumulation and melting) rises 100 meters for each 0.6°C rise in air temperatures, he concluded that the projected 6°C warming in Greenland would be likely to raise the equilibrium line 1,000 meters. He estimated that such a change in the equilibrium line would result in a 12-cm contribution to sea level rise for the next century.

The NAS Polar Board (Meier et al., 1985) noted that Greenland is a "significant potential contributor of meltwater." They found that a 1,000-meter rise in the equilibrium line would result in a contribution of 30 cm through 2100. However, because Ambach (1985) found the relationship between the equilibrium line and temperature to be 77 meters per degree Celsius, the panel concluded that a 500-meter shift in the equilibrium line would be more likely. Based on the assumption that Greenland will warm 6.5°C by 2050 and that temperatures will remain constant thereafter, the panel estimated that such a change would contribute about 10 cm to sea level through 2100, but also noted that "for an extreme but highly unlikely case, with the equilibrium line raised 1000 meters, the total rise would be 26 cm."

The potential impact of a global warming on Antarctica in the next century is the least certain of all the factors by which a global warming might contribute to sea level rise. Meltwater from East Antarctica might make a significant contribution by the year 2100, but no one has estimated the likely contribution. Several studies have examined "deglaciation," which also includes the contribution of ice sliding into the oceans. Bentley (1983) examined the processes by which a deglaciation of West Antarctica might occur. The first step in the process would be accelerated melting of the undersides of the Ross and Filchner-Ronne ice shelves as a result of warmer water circulating underneath them. The thinning of these ice shelves could cause them to become unpinned and would cause their grounding lines to retreat. Revelle (1983) concluded that the available literature suggests that the ice shelves might disappear in 100 years, after which time the Antarctic ice streams would flow directly into the oceans, without the back pressure of the ice shelves. He suggested that this process would take 200 to 500 years.

Although a West Antarctic deglaciation would occur over a period of centuries, it is possible that an irreversible deglaciation could commence before 2050. If the ice shelves thinned more than about one meter per year, Thomas et al. (1979) suggested that the ice would move into the sea at a sufficient speed that even a cooling back to the temperatures of today would not be sufficient to result in a reformation of the ice shelf.

To estimate the likely antarctic contribution for the next century, Thomas (1985) developed four scenarios of the impact of a 3°C global warming by 2050, estimating that a 28-cm rise would be most likely, but that a rise of 1 to 2.2 meters would be possible under certain circumstances. The NAS Polar Board (Meier et al., 1985) evaluated the Thomas study and papers by Lingle (1985) and Fastook (1985). Although Lingle estimated that the contribution of West Antarctica through 2100 would be 3 to 5 cm, he did not evaluate East Antarctica, while Fastook made no estimate for the year 2100. Thus, the panel concluded that "imposing reasonable limits" on the model of Thomas yields a range of 20 to 80 cm by 2100 for the antarctic contribution. However, they also noted several factors that would reduce the amount of ice discharged into the sea: the removal of the warmest ice from the ice shelves, the retreat of grounding lines, and increased lateral shear stress. They also concluded that increased precipitation over Antarctica <u>might</u> increase the size of the polar ice sheets there. Thus, the panel concluded that Antarctica could cause a rise in sea level up to 1 meter, or a drop of 10 cm, with a rise between 0 and 30 cm most likely.

Using a range of estimates for future concentrations of greenhouse gases, the climate's sensitivity to such increases, oceanic heat uptake, and the behavior of glaciers, Hoffman et al., (1983) estimated that the rise would be between 56 and 345 cm, with a rise of 144 to 217 cm most likely; however, they did not examine the impact of deliberate attempts by society to curtail emissions. Revelle (1983) estimated that the rise was likely to be 70 cm, ignoring the impact of a global warming on Antarctica; he also noted that the latter contribution was likely to be 1 to 2 m/century after 2050, but declined to add that to his estimate. The NAS Polar Board (Meier et al., 1985) projected that the contribution of glaciers would be sufficient to raise sea level 20 to 160 cm, with a rise of "several tenths of a meter" most likely. Thus, if one extrapolates the earlier NAS estimate of thermal expansion through the year 2100, the 1985 NAS report implies a rise between 50 and 200 cm. The estimates from Hoffman et al. (1986) for the year 2100 (57 to 368 cm) were similar to those by Hoffman et al. (1983). However, for the year 2025, they lowered their estimate from 26-39 cm to 10-21 cm. More recently, IPCC Work Group 1 has tentatively concluded that a rise of 20-50 cm by 2050, and 50-100 cm by 2100, seems likely.

Future Trends in Local Sea Level

Although most attention has focused on projections of global sea level, impacts on particular areas would depend on local relative sea level. Local subsidence and emergence are caused by a variety of factors. Rebound from the retreat of glaciers after the last ice age has resulted in the uplift of northern Canada, New England, and parts of Scandinavia, while emergence in Alaska is due more to tectonic adjustments. The uplift in polar latitudes has resulted in subsidence in other areas, notably the U.S. Atlantic and gulf coasts. Groundwater pumping has caused rapid subsidence around Houston, Texas, Taipei, Taiwan, and Bangkok, Thailand, among other areas (Leatherman, 1983). River deltas and other newly created land subside as the unconsolidated materials compact. Although subsidence and emergence trends may change in the future, particularly where anthropogenic causes are curtailed, no one has linked these causes to future climate change in the next century.

However, the removal of ice from Greenland and Antarctica would immediately alter gravitational fields and eventually deform the ocean floor. For example, the ice on Greenland exerts a gravitational pull on the ocean's water; if the Greenland ice sheet melts and the water is spread throughout the globe, that gravitational attraction will diminish and could thereby cause sea level to drop along the coast of Greenland and nearby areas such as Iceland and Baffin Island. Eventually, Greenland would also rebound upward, just as northern areas covered by glaciers during the last ice age are currently rebounding. Clark and Lingle (1977) have calculated the impact of a uniform 1-meter contribution from West Antarctica. They concluded that relative sea level at Hawaii would rise 125 cm, and that along much of the U.S. Atlantic and gulf coasts the rise would be 15 cm. On the other hand, sea level would drop at Cape Horn by close to 10 cm, and the rise along the southern half of the Argentine and Chilean coasts would be less than 75 cm.

Other contributors to local sea level that might change as a result of a global warming include currents, winds, and freshwater flow into estuaries. None of these impacts, however, has been estimated.

CONCLUSION

There is a growing body of evidence that sea level rise will accelerate in the coming decades. Although recent assessments have generally suggested that the rise will not be as great as people thought possible in the early 1980s, they have further increased the certainty that at least some rise will take place. Accordingly, coastal nations throughout the world need to begin considering the effects and possible responses.

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AN OVERVIEW OF THE EFFECTS OF GLOBAL WARMING ON THE COAST

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Global warming could raise sea level several tens of centimeters in the next fifty years, about one meter in the next century, and several meters in the next few centuries by expanding ocean water, by melting mountain glaciers, and by causing ice sheets to melt or slide into the oceans. Such a rise would inundate deltas, coral atoll islands, and other coastal lowlands; erode beaches; exacerbate coastal flooding; and threaten water quality in estuaries and aquifers.

Most nations have sufficient high ground to permit a gradual adaptation, but not without substantial investments in infrastructure and the loss of important ecosystems. About 50 to 80 percent of coastal wetlands could be lost, with river deltas particularly important. In a few cases, a rise in sea level would threaten an entire nation. The Republic of Maldives and other coral atoll nations are mostly less than two meters above sea level. Bangladesh, already overcrowded, would lose 20 percent of its land if sea level rose one meter. Although most of Egypt is well above sea level, its only inhabited area, the Nile Delta, is not.

This chapter examines the consequences of future sea level rise. After briefly summarizing the impacts of global warming on sea level, we describe the physical effects of sea level rise, their interactions with current activities, and the implications for particular nations.

PAST AND FUTURE SEA LEVEL RISE

Ocean levels have always fluctuated with changes in global temperatures. During the ice ages, when the Earth was 5°C colder than today, much of the ocean's water was frozen in glaciers and sea level was often more than 100 meters below its current level (Donn et al., 1962; Kennett, 1982; Oldale, 1985). Conversely, during the last interglacial period (120,000 years ago) when the average temperature was 1-2°C warmer than today, sea level was about 6 meters higher than today (Mercer, 1968).

Problem Identification

When considering shorter periods of time, worldwide sea level rise must be distinguished from relative sea level rise. Although global warming would alter worldwide sea level, the rate of sea level rise relative to a particular coast has more practical importance and is all that monitoring stations can measure. Because most coasts are sinking (although a few are rising), relative sea level rise varies from more than one meter per century, in some areas with high rates of groundwater or mineral extraction, to a drop in extreme northern latitudes. Global sea level trends have been generally estimated by combining trends at tidal stations around the world. Studies combining these measurements suggest that during the last century, worldwide sea level has risen 10 to 25 centimeters (Fairbridge and Krebs, 1962; Barnett, 1984; Peltier and Tushingham, 1989).

Future global warming could raise sea level by expanding ocean water, by melting mountain glaciers, and eventually, by causing polar ice sheets in Greenland and Antarctica to melt or slide into the oceans. Hughes (1983) and Bentley (1983) suggested that over a period of 200-500 years, it might be possible for global warming to induce a complete disintegration of the West Antarctic ice sheet, which would raise sea level about 6 meters. Most recent assessments, however, have focused on the rise that could occur in the next century. As Figure 1 shows, the estimates are generally between 50 and 200 centimeters, with recent estimates being at the low end of the range.

All assessments of future sea level rise have emphasized that much of the data necessary for accurate estimates are unavailable. As a result, studies of the possible impacts generally have used a range of scenarios. Nevertheless, for convenience of exposition, it is often necessary to refer to only a single estimate. For illustrative purposes, we follow the convention of referring to a one-meter rise in sea level.

PHYSICAL EFFECTS OF SEA LEVEL RISE

We now examine the impact of sea level rise assuming that society's impact on the coastal environment does not change. We first summarize the most important processes, then discuss a few examples of the interaction of these physical impacts with human activities.

Processes

A rise in sea level would (1) inundate wetlands and lowlands, (2) erode shorelines, (3) exacerbate coastal flooding, (4) increase the salinity of estuaries and aquifers and otherwise impair water quality, (5) alter tidal ranges in rivers and bays, (6) change the locations where rivers deposit sediment, (7) increase the heights of waves, and (8) decrease the amount of light reaching the bottoms. Previous assessments have mostly focused on the first four factors (e.g., Barth and Titus, 1984; Dean et al., 1987).

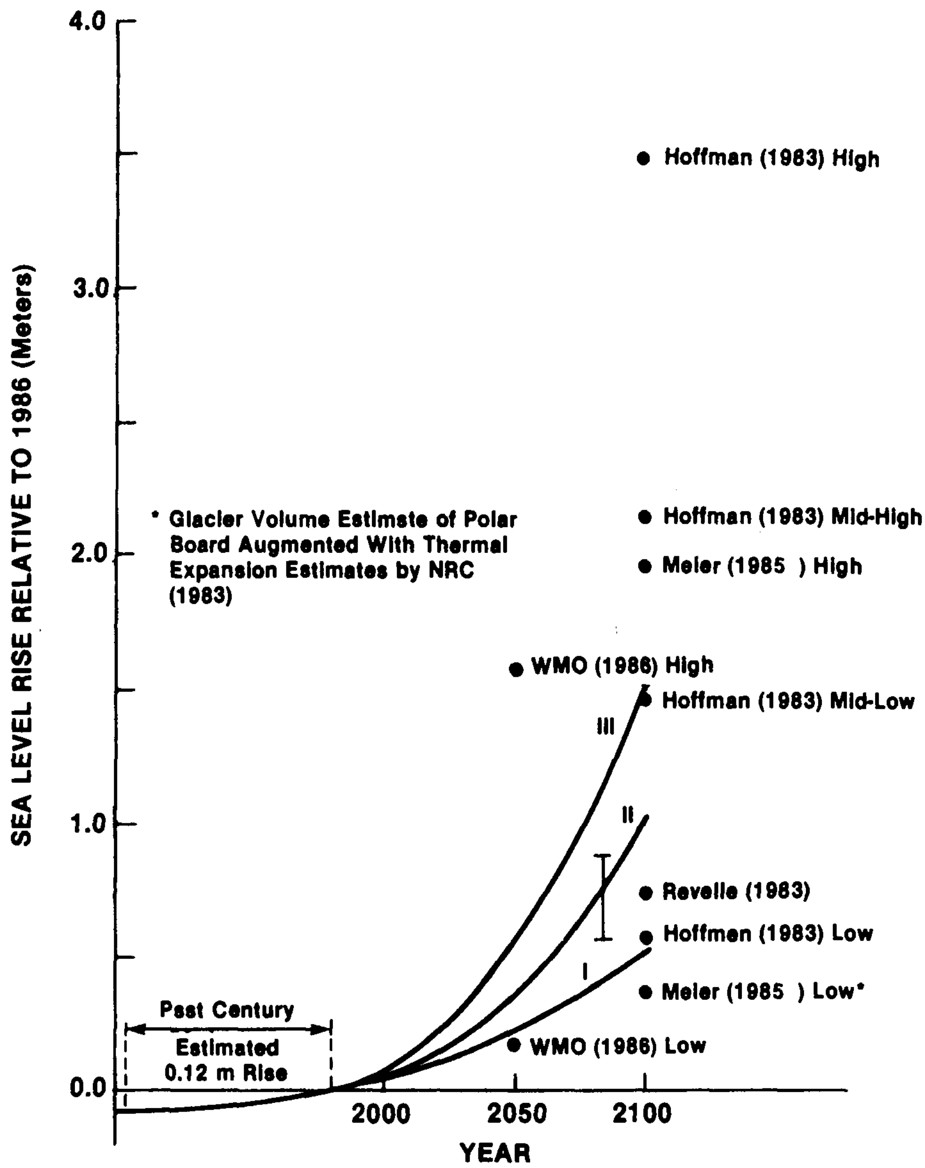

Figure 1. Estimates of future sea level rise.

Inundation

"Inundation," the most obvious impact of sea level rise, refers both to the conversion of dryland to wetlands and to the conversion of wetlands to open water. Consider a bay with a tide range of one meter and a parcel of dryland that is currently 75 centimeters above sea level, that is, 25 centimeters above high water. If the sea rose 25 centimeters overnight, the land would be flooded at high tide and hence would convert to wetland, while a 125-cm rise would convert it to open water.

Problem Identification

Nature requires coastal wetlands and the dryland found on coral atolls, barrier islands, and river deltas to be just above sea level. If sea level rises slowly, as it has for the last several thousand years, these lands can keep pace with the sea: Wetlands collect sediment and produce peat that enable them to stay just above sea level; atoll islands are sustained by sand produced by the coral reefs; barrier islands migrate landward; and deltas are built up by the sediment washed down major rivers. If sea level rise accelerates, however, at least some of these lands will be lost.

A one-meter rise in sea level would inundate 17 percent of Bangladesh (Ali and Huq, 1989; see Figure 2), and a two-meter rise would inundate the capital and

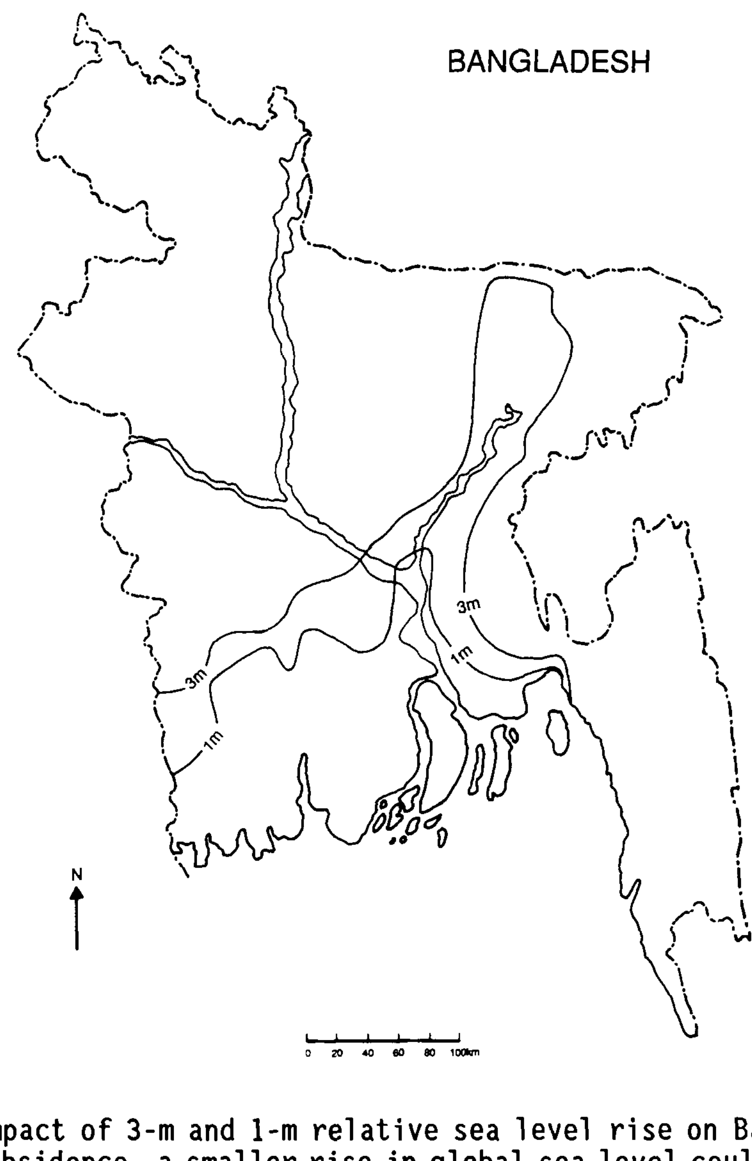

Figure 2. Impact of 3-m and 1-m relative sea level rise on Bangladesh. Because of current subsidence, a smaller rise in global sea level could cause this effect (Bangladesh Center for Advanced Studies).

over half the populated islands of the atoll Republic of Maldives. Although the land within a few meters of sea level accounts for a relatively small fraction of the area of most nations, populations are often concentrated in the low areas owing to the fertility of coastal lowlands, the historic reliance on water transportation, and more recently, the popularity of living by the sea. Shanghai and Lagos -- the largest cities of China and Nigeria -- are less than two meters above sea level, as is 20 percent of the population and farmland of Egypt (Broadus et al., 1986).

Coastal plains in general would be less vulnerable than atolls, deltas, and barrier islands, because they typically range in elevation from zero to 70 meters above sea level. Nevertheless, because they account for much more land and do not keep pace with sea level, they would probably account for the majority of dryland lost to inundation, particularly for a large rise in sea level. A recent study of the United States illustrates the situation: If sea level rose 50 cm, the Mississippi Delta alone would account for 35 percent of the nation's lost dryland; but because a 50-cm rise (along with current subsidence) would inundate most it, the delta would account for only 10 percent of U.S. dryland lost if sea level rose 2 meters (U.S. EPA, 1989).

Unlike most dryland, all coastal wetlands can keep pace with a slow rate of sea level rise. As Figure 3 shows, this ability has enabled the area of wetlands

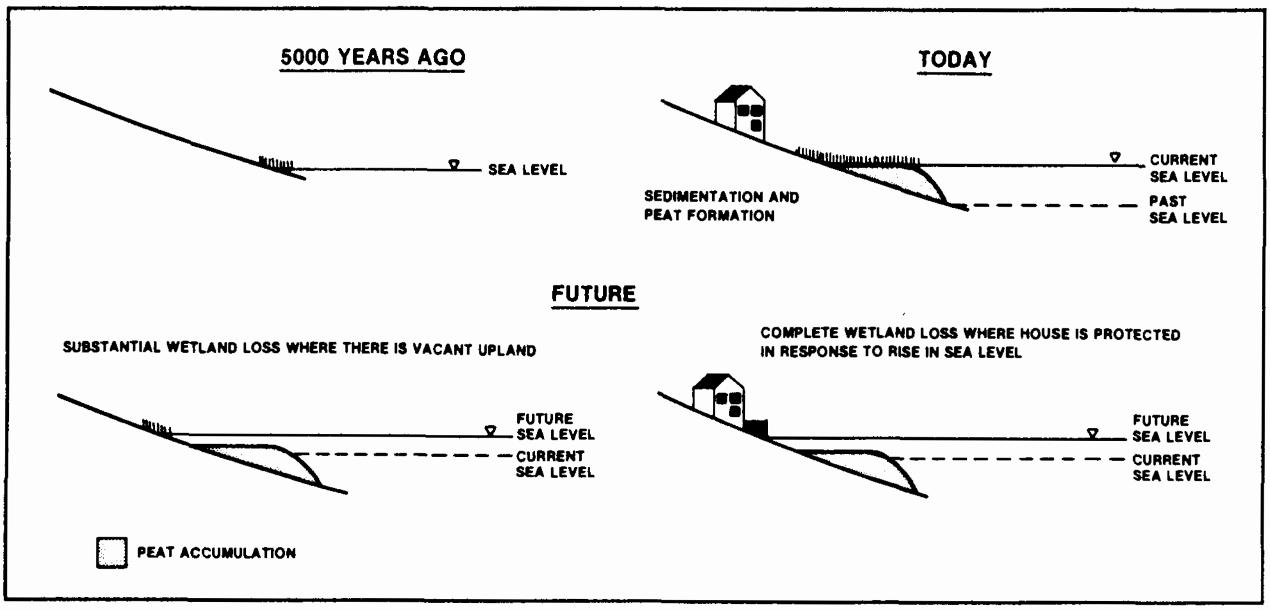

Figure 3. Evolution of marsh as sea rises. Coastal marshes have kept pace with the slow rate of sea level rise that has characterized the last several thousand years. Thus, the area of marsh has expanded over time as new lands have been inundated. If, in the future, sea level rises faster than the ability of the marsh to keep pace, the marsh area will contract. Construction of bulkheads to protect economic development may prevent new marsh from forming and result in a total loss of marsh in some areas (Titus, 1986).

to increase over the last several thousand years. However, most authors have concluded that wetlands could not keep pace with a significant acceleration in sea level rise (Kearney and Stevenson, 1985), and thus, that the area of wetlands converted to open water will be much greater than the area of dryland converted to wetlands (Titus et al., 1984; Park et al., 1986; Armentano et al., 1988). Moreover, in areas where dikes protect farmland or structures, all the wetlands could be lost (Titus, 1986, 1988).

Because they are found below the annual high tide, the most vulnerable wetlands would tend to be those in areas with tidal ranges of less than one meter, such as the Mediterranean and Black Seas, the Gulf of Mexico, and estuaries with narrow openings to the sea. The least vulnerable would be those in areas with large tidal ranges, such as the Bay of Fundy. Although areas with substantial sediment supplies could maintain more wetlands than those with little sediment, the percentage loss would not necessarily be less, since these areas currently have more wetlands.

Erosion

In many areas, the total shoreline retreat from a one-meter rise would be much greater than suggested by the amount of land below the one-meter contour on a map, because shores would also erode. While acknowledging that erosion is also caused by many other factors, Bruun (1962) showed that as sea level rises, the upper part of the beach is eroded and deposited just offshore in a fashion that restores the shape of the beach profile with respect to sea level, as shown in Figure 4; the "Bruun Rule" implies that a one-meter rise would generally cause shores to erode 50 to 200 meters along sandy beaches, even if the visible portion of the beach is fairly steep.

On coastal barrier islands, wave erosion may transport sand in a landward as well as a seaward direction, a process commonly known as "overwash." By gradually transporting it landward, overwash can enable a barrier island to rise with sea level, in a fashion similar to rolling up a rug, as shown in Figure 5. Leatherman (1979) suggests that barrier islands would generally erode from their ocean sides until reaching a width of 100-200 meters, at which point they would wash over. Although barrier islands have been able to maintain themselves in this fashion with the relatively slow historic rate of sea level rise, coastal scientists are uncertain about the extent to which they could do so with a more rapid rise in sea level. In the Mississippi Delta, for example, where relative sea level has risen one meter in the last century, many barrier islands have gradually broken up and disintegrated.

Wetlands and other muddy coasts would be even more vulnerable to erosion. Under the Bruun formulation, erosion due to sea level rise is a self-limiting process: a given storm can wash up sand and pebbles only several hundred meters before they settle out; the material thus remains in the beach system. By contrast, muddy sediments can be carried great distances before settling out, and the peat that constitutes part of wetland coasts can oxidize into carbon dioxide, methane, and water (Reed, 1988).

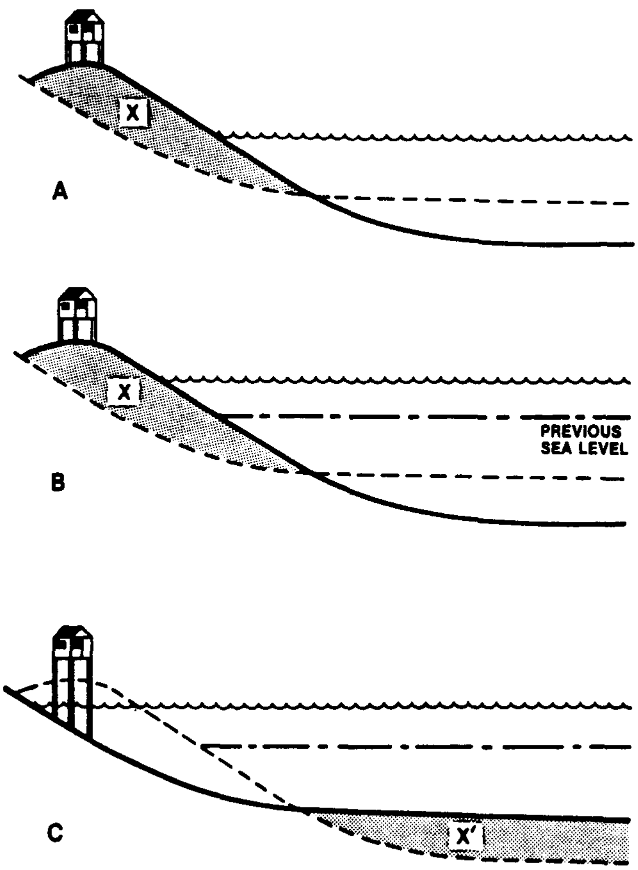

Figure 4. The Bruun Rule: (a) initial condition; (b) immediate inundation when sea level rises; and (c) subsequent erosion due to sea level rise. A rise in sea level immediately results in shoreline retreat due to inundation, shown in the first two examples. However, a 1-meter rise in sea level implies that the offshore bottom must also rise 1 meter. The sand required to raise the bottom (X') can be supplied by beach nourishment. Otherwise, waves will erode the necessary sand (X) from upper part of the beach as shown in (c) (Titus, 1986).

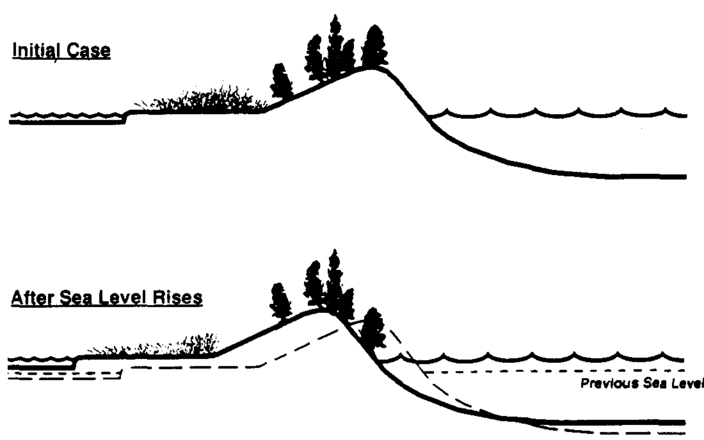

Figure 5. Overwash: natural response of undeveloped barrier islands to sea level rise.

Problem Identification

The practical importance of distinguishing erosion from inundation varies (Park et al., 1989). Along the very low deltaic coasts, erosion would merely reclaim land for a few decades before it was inundated anyway. On barrier islands and sandy cliffed coasts, however, where a one-meter rise would inundate only 5-20 meters of beach, erosion would account for the majority of land lost.

Flooding

Sea level rise could increase the risk of flooding in four ways: (1) There would be a higher base upon which storm surges would build. If sea level rises one meter, an area flooded with 50 cm of water every 20 years would now be flooded with 150 cm every 20 years; surges would also penetrate farther inland (Kana et al., 1984). (2) Beaches and sand dunes currently protect many areas from direct wave attack; by removing these protective barriers, erosion from sea level rise would leave some areas along ocean coasts more vulnerable. (3) Mangroves and marshes slow the inland penetration of floodwater by increasing the friction of estuaries and by blocking the waves; losses of wetlands would thus increase coastal flooding (Louisiana Wetland Protection Panel, 1988). finally, (4) Sea level rise could also increase flooding from rainstorms and river surges as a result of decreased drainage (Titus et al., 1987).

The higher base for storm surges would be particularly important in areas where hurricanes are frequent, such as islands in the Caribbean Sea, the southeastern United States, and the Indian subcontinent; if flood defenses were not already erected, London and the Netherlands would also be at risk as a result of winter storms. By contrast, because storm surges in these areas are rarely more than 50 centimeters, flood damage would not be a major problem for the Maldives (though the absence of high ground for evacuation would justify treating the risk seriously). Erosion would be particularly important on U.S. barrier islands, many of which have houses within 30 meters of the shore at high tide. Because mangroves provide the major protection against flooding for many countries too poor to erect flood defenses, wetland loss could be a major problem there. Reduced drainage would be a chief concern in coastal areas frequently flooded by river surges -- particularly deltas -- as well as other flat areas such as the Florida Everglades, where water lingers several days after a rainstorm.

Floods in Bangladesh would be worse for all of these reasons. In 1971, the storm surge from a cyclone killed 300,000 people. Much of the country is flooded by surges in both the Ganges and Brahmaputra Rivers; when the surges coincided in 1987, about one-third of the country was under water. Although the government has found it difficult to prevent people from cutting them down, mangroves still provide important flood protection buffers. Should the mangroves die, the outer islands erode, natural drainage decline, and storm surges rise a meter higher than today, much of the land not lost to inundation would still experience consequences of sea level rise.

<u>Saltwater Intrusion and Other Impacts on Water Quality</u>

Sea level rise would generally enable saltwater to advance inland in both aquifers and estuaries. In estuaries, the gradual flow of freshwater toward the oceans is the only factor preventing the estuary from having the same salinity as the ocean. Prevailing salinities result from the overall balance between freshwater and processes that bring saltwater into the estuary such as tidal mixing and advection. A rise in sea level would increase salinity in open bays because the increased cross-sectional area would slow the average speed at which freshwater flows to the ocean (see Figure 6).

Wetlands could experience increased salinity even if the salinity of the adjacent bay did not increase. In many areas, wetland zonation depends on proximity to open water, with salt marshes and salt-tolerant mangroves adjacent to the bay, brackish wetlands farther inland, and freshwater marshes and swamps still farther inland. If sea level rise inundates the most seaward wetlands, the inland wetlands will be much closer to the bay, and hence exposed to higher salinities. Although salt-tolerant species may be able to replace the freshwater species, cypress swamps and floating freshwater marshes often lack a suitable base for salt-tolerant wetlands, and saltwater intrusion is already converting wetlands to open water lakes in Louisiana (Wicker et al., 1980).

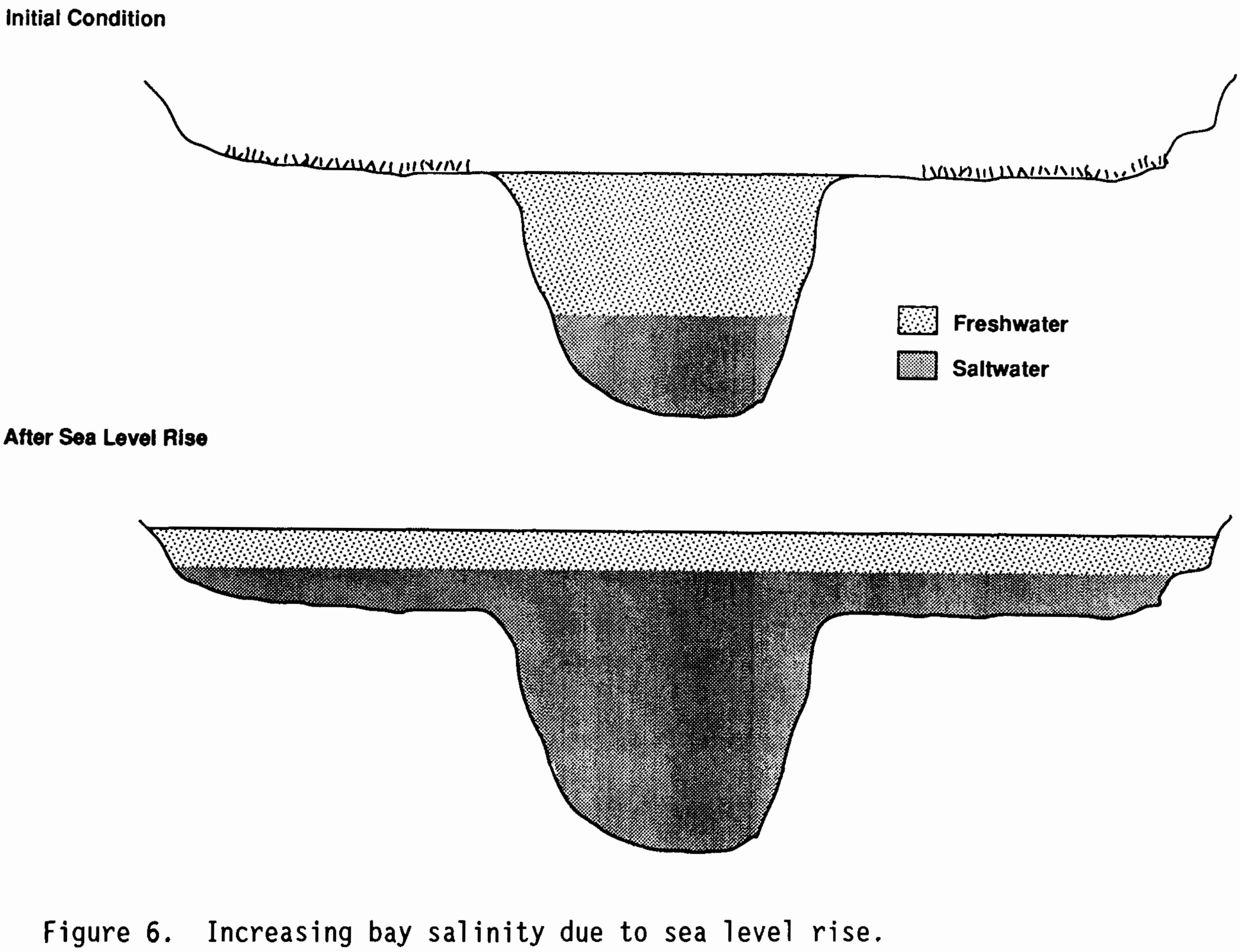

Figure 6. Increasing bay salinity due to sea level rise.

Problem Identification

Sea level rise could increase groundwater salinity for two reasons. First, some aquifers pumped well below sea level by human activities are recharged by currently fresh rivers; if sea level rise enables saltwater to advance farther up the Delaware River during droughts, for example, salty water would recharge the aquifers in central New Jersey, rendering its water unfit for human consumption (Hull and Titus, 1986).

More common would be the problem confronting communities that rely on unconfined aquifers just above sea level. Generally, these aquifers have a freshwater "lens" floating on top of the heavier saltwater. According to the Ghyben-Herzberg (Herzberg, 1961) principle, if the top of the aquifer is one meter above sea level, the interface between fresh and saltwater is 40 meters below sea level. If sea level rises one meter, aquifers will usually rise one meter as well (Figure 7A-B). In areas where the freshwater always extends 40 meters below sea level, this situation would pose little problem.

In many areas, however, freshwater supplies are not so plentiful. Droughts and wells can deplete the lens to a meter or less. Thus, wells that are currently able to draw freshwater during a drought would be too deep if sea level rose one meter. Fortunately, in areas with several meters of elevation, there would still be as much freshwater; people would merely have to drill new wells. In the lowest-lying areas, however, the actual amount of freshwater under the ground would decline; the Ghyben-Herzberg principle implies that if the top of the freshwater lens does not rise, the bottom of the lens will rise 40 times as much as the sea (7B-C).

Consider the island of Tulhadoo (Republic of Maldives), which is entirely less than 50 centimeters above high tide. Even when the ground is entirely saturated, the lens can extend no more than 50 centimeters above sea level. But the permeable coral material of the island allows much of this water to drain fairly rapidly after storms, and evaporation and transpiration further lower the water table during the typical dry season. As a result, the freshwater lens is so small that people must obtain water by digging a hole, withdrawing a liter or so of water, and refilling the hole, perhaps coming back the next day. A one-meter rise in sea level would leave many more islands with this situation.

Sea level rise could impair water quality in other ways as well. Saltwater intrusion could impair the effectiveness of septic tanks, while reduced drainage could decrease dilution of the wastes and enable the septic discharges to remain longer in the vicinity of wells. Reduced drainage could diminish the dilution of wastes in rivers, and in some cases might enable them to flow upstream and contaminate freshwater intakes. Higher water levels would compel municipal authorities to close existing tidal gates more often, which would reduce flushing.

By deepening shallow bodies of water, sea level rise could cause them to stagnate. Fish ponds in Malaysia, the Philippines, and China have been designed so that the tides provide sufficient mixing; deeper ponds, however, would require more flushing. In the United States, many coastal housing developments have finger canals to enable residents to park boats in their backyards. While

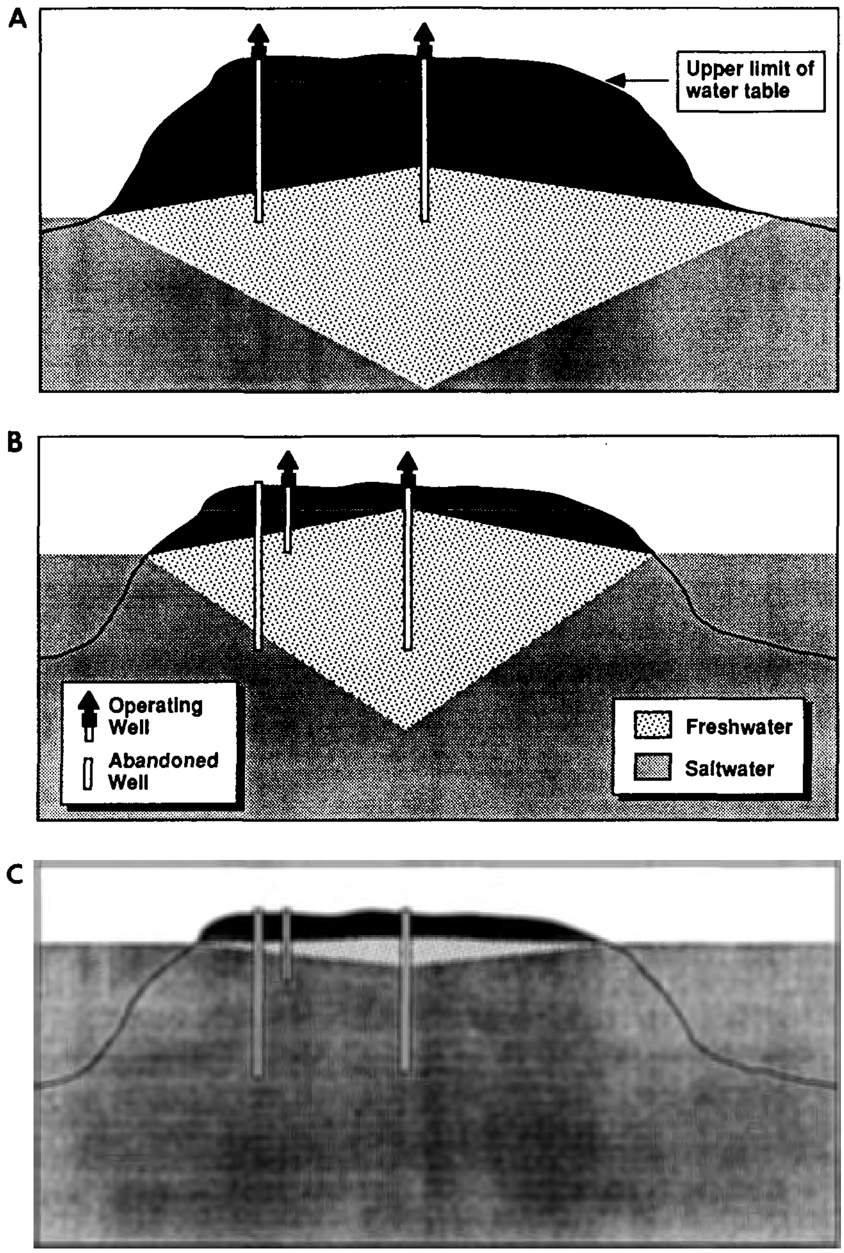

Figure 7. Impacts of sea level rise on groundwater tables. (A-B) According to the Ghyben-Herzberg relation, the freshwater/saltwater interface is 40 cm below sea level for every cm by which the top of the water table lies above sea level. When water tables are well below the surface, a rise in sea level simply raises the water table and the fresh/salt interface by an equal amount. Where water tables are near the surface, however, drainage and evapotranspiration may prevent the water table from rising. In such a case (C), the freshwater table could narrow greatly with a rise in sea level: for every 1-cm rise in sea level, the fresh/salt interface would rise 41 cm.

the current practice of keeping them less than two meters deep prevents stagnation today, it may not in the future if sea level rise deepens them to three meters.

Secondary Impacts

A number of other impacts of sea level rise that are unimportant by themselves may be important because of their impacts on inundation, erosion, flooding, and saltwater intrusion. We briefly discuss changes in tidal ranges, sedimentation, and reduced light reaching the bottom.

Sea level rise could change tidal ranges by (1) removing barriers to tidal currents and (2) changing the resonance frequencies of tidal basins. Many estuaries have tidal ranges far lower than found on the open coast because of narrow inlets and other features that slow tidal currents; if sea level rise inundates wetlands or erodes the ends of barrier islands, more water may flow into and out of some estuaries and thereby increase the tidal range.

The implications of sea level rise for tidal resonance, however, is more ambiguous. The Bay of Fundy, for example, has a tidal range of 15 meters because the resonance frequency of the bay itself is very close to the diurnal frequency of the astronomic tides on the ocean; the bay tends to increase the amplitude of the tides. (One can simulate this effect by moving a hand back and forth in a filled bathtub at different rates; at certain speeds -- the resonance frequency of the tub -- the waves wash much higher than at other speeds.) Scott and Greenburg (1983) note that the one-meter rise in sea level over the last few centuries has altered the resonance frequency of the bay enough to increase the tidal range by about a meter. This is just a coincidence, however; it is just as likely that changes in sea level will shift resonance frequencies in a way that reduces the tidal range. Nevertheless, tidal ranges also appear to be increasing along the North Sea coast (Bruun, 1986).

Changes in tides could alter all of the basic processes discussed so far. A greater tidal range would increase the inundation of dryland, while increasing (or limiting the loss) of intertidal wetlands. Besides eroding inlets, greater tidal currents would tend to form larger ebb tidal deltas, providing a sink for sand washing along the shore and thereby causing additional erosion. Flooding due to storm surges would also increase: other than resonance, the bathymetric changes that might amplify or mitigate tides would have the same impact on storm surges. Finally, higher tidal ranges would further increase the salinity in estuaries because of increased tidal mixing.

Under natural conditions, most of the sediment washing down rivers is deposited in the estuary because of settling and flocculation. Settling occurs downstream from the head-of-tide because the slowly moving water characterized by estuaries cannot carry as much sediment as a flowing river. Flocculation is a process by which salty water induces easily entrained fine-grained sediment to coalesce into larger globs that settle out. A rise in sea level would cause both of these processes to migrate upstream, and would thereby assist the ability of wetlands in the upper parts of estuaries to keep pace with sea level, while hindering their ability in the lower parts.

A rise in sea level would also increase the size of waves. In shallow areas, the depth of the water itself limits the size of waves; hence deeper water would permit larger waves. Moreover, erosion and inundation would increase the fetch over which waves develop (i.e., the width of the estuary). Finally, the breakup of barrier islands would enable ocean waves to enter some estuaries.

Larger waves could be the most important impact of sea level rise along shallow (e.g., less than 30 cm at low tide) tidal creeks with steep, muddy shores. The steep slopes imply that inundation would not be a problem. However, with water depths one meter deeper, waves could form that were large enough to significantly erode the muddy shores. Bigger waves could also increase the vulnerability of lands protected by coral reefs. In many areas, these reefs protect mangrove swamps or sandy islands from the direct attack by ocean waves; but deeper water would reduce the reef's ability to act as a breakwater. The extent to which this would occur depends on the ability of the coral to keep pace with sea level rise.

Finally, sea level rise could decrease the amount of light reaching water bottoms. The depth at which submerged aquatic vegetation can grow depends primarily on how much light reaches the bottom. Corals in clear water can grow 10 meters below the surface, while the more productive vegetation in some turbid areas is generally found in water less than 2 meters deep. By limiting the ability of light to reach the bottom, deeper water would reduce the productivity of virtually all submerged vegetation to some degree.

In atolls, coral reefs supply the sand necessary to keep the islands from being eroded and inundated. In the long run, any limitation of coral productivity could increase the risk that these islands will be eroded or inundated.

Other Impacts of Global Warming

One must consider the implications of sea level rise in the context of other impacts of global warming, which could alter all of the impacts except inundation. Warmer temperatures could convert marshes to mangroves. If hurricanes or storms become more severe (Emmanuel, 1988), flooding and erosion will be worse. More droughts would exacerbate salinity and other water quality problems, while if droughts become less frequent, most salinity problems associated with sea level rise might be completely offset. Low islands, However, are an important exception; if an island with a few meters' elevation comes to resemble Tulado in the Maldives, wells will be of little use during the dry season.

Interaction with Human Activities

The impacts of sea level rise cannot be fully understood without some discussion of human activities in the coastal zone, the ways humanity has already disrupted natural coastal environments (partly in response to historic sea level rise), and the activities that can be expected if current policies continue.

In this section, we focus primarily on the implications for (1) river deltas, (2) other wetland shorelines, (3) beach resorts, and (4) coastal cities.

River Deltas

Most of the basic processes described above would manifest themselves in river deltas. Because deltaic wetlands and lowlands were created by the deposition of river sediments, these lands are generally within a few meters of sea level and hence vulnerable to inundation, erosion, and flooding. During droughts, saltwater intrusion is already a problem in many of these areas. Nevertheless, under natural conditions, the sediment washing down the river could enable at least a significant fraction of the typical delta to keep pace with sea level rise.

Human activities in many deltas, however, have disabled the natural ability of deltas to create land. Over the last few thousand years the Chinese -- and over the last few hundred years the Dutch -- have erected sea dikes and river levees to prevent flooding from storm and river surges. As a result, the annual floods no longer overflow the river banks, and as sea level rises, it has left the adjacent land below sea water level, necessitating more coastal defense to prevent the land from being inundated as sea level rises.

Over the last century, the United States has sealed off Mississippi River distributaries, forcing the flow of water through a few main channels, to prevent sedimentation in shipping lanes. More recently, river levees have also been constructed. Unlike the Chinese and Dutch deltas, however, the Mississippi Delta is not encircled with dikes; as sea level rises and the deltaic mud settles, Louisiana is losing 100 square miles of land per year (Louisiana Wetland Protection Panel, 1988). In Egypt, the Aswan Dam prevents the Nile River from overflowing its banks, and its delta is now beginning to erode as well (Broadus et al., 1986). Similarly, a major dam on the Niger River is causing the coast of Nigeria to erode 10-40 meters per year (Ibe and Awosika, 1989).

The natural land-building processes in some major deltas are still allowed to operate. Most notable is Bangladesh, located in the delta of the Ganges and Brahmaputra Rivers. About 20 percent of the nation is less than one meter above sea level, and close to one-third of the nation is regularly flooded by annual river surges. People in agricultural areas are generally accustomed to the flooding, which in addition to depositing sediment provides farmland with important nutrients. Nevertheless, floods have disrupted the capital, and the government is considering river levees to curtail flooding.

Paradoxically, a one-meter rise in sea level threatens to permanently inundate deltas that are protected from river flooding, while protected areas may be able to avoid inundation through natural sedimentation. Nevertheless, at least parts of these deltas would probably be inundated. In the case of overcrowded nations such as Bangladesh, the resulting migration away from the coast may exacerbate social tensions and possibly result in massive emigration.

Other Wetland Shorelines

Although human activities would have the greatest impact on deltaic wetlands, they would also influence the ability of other coastal wetlands to survive a rising sea level. Perhaps most important, ecosystems could shift landward under natural conditions in most areas. However, in many areas people have already developed the adjacent dryland onto which the ecosystem would have to migrate. If these areas are protected with bulkheads or levees, the wetlands will be squeezed between the rising sea and the flood-protection structure.

Current efforts to control water pollution may have a beneficial impact on wetlands. Healthy marshes and swamps in unpolluted estuaries would be more likely to maintain the vertical accretion rates necessary to keep pace with sea level rise. Furthermore, to prevent estuaries from being polluted by septic tanks, some jurisdictions require houses to be set back 50-100 meters from the wetlands; these setbacks will leave some room for landward migration.

Beach Resorts

Along the ocean coasts of Australia, Brazil, Nigeria, Portugal, the United States, and many other nations, one of the most important impacts of sea level rise would be the threat to recreational beach communities. Particularly in the United States, even a small rise in sea level would erode the existing recreational beaches and leave oceanfront houses standing in the water. In areas where these buildings are protected by seawalls, the entire beach would vanish, removing the primary reason people visit these communities in the first place.

Moreover, many resorts are located on barrier islands where typical elevations are only one or two meters above sea level. Although natural barrier islands can migrate landward, developed barrier islands do not, both because structures prevent the landward transport of sand and because public works departments tend to bulldoze back onto the beach whatever sand is washed landward. Thus, in addition to oceanside erosion, the low bay sides of these islands would be threatened with inundation.

Coastal Cities

Throughout history, small towns have often been relocated in response to erosion and sea level rise; but cities have generally erected the structures necessary to remain in their current locations. One can reasonably expect that sea level rise will force Dakka, Lagos, Shanghai, and Miami to erect the dikes and pumping systems necessary to avoid inundation. While the primary socioeconomic impact in industrialized nations many be higher taxes, budgets in developing nations may be constrained, forcing them to reduce expenditures on health, education, economic development, and other requirements.

Problem Identification

Many cities not immediately threatened with inundation would be flooded. While flood defense is possible, the history of coastal protection suggests that this generally will happen only after a disaster or near-catastrophe demonstrates the need for these projects; one can only hope that the latter occurs first. Case studies in the United States suggest that areas flooded once or twice a century today will be flooded every decade if sea level rises one meter (Barth and Titus, 1984).

Environmental Implications

The impacts of sea level rise on ecosystems can be broadly classified into effects of (1) wetland loss, (2) salinity increases, and (3) beach erosion.

Estuarine fisheries depend on coastal wetlands because they account for a major fraction of primary productivity and because they provide important nurseries owing to their ability to protect fish larvae and juveniles from predators. Although primary productivity depends on the total area of wetlands, the productivity of fisheries is widely believed to depend more on the total length of wetland/water interfaces (Browder et al., 1985); unless there is a channel through the wetlands, fish rarely swim more than a few tens of meters into the wetlands.

Although sea level rise would reduce the area of wetlands, at first it would tend to increase the length of the wetland/water interface. Figure 8 illustrates the disintegration of the birdfoot delta of the Mississippi River, where many researchers believe that wetland loss temporarily improved fish catches. In the long run, however, the decline in wetland area will eventually decrease the total length of the interface, with a roughly proportional impact on estuarine fisheries.

In industrialized nations, the decline of these fisheries would imply higher prices for shrimp, crab, flounder, and other fish that depend on marshes for parts of their life cycles, as well as chicken, which are often fed fishmeal from estuarine species. In some developing nations, however, the decline in these fisheries could threaten subsidence.

Increasing estuarine salinity would also threaten some seafood species, largely because the major predators of these species are unable to tolerate freshwater. Even today, excessive salinity during droughts has been a contributing factor in the decline of oyster harvests in the Delaware and Chesapeake Bays (Gunter, 1974; Hull and Tortoriello, 1979).

Under natural conditions, a rise in sea level would not threaten life along the beach; ecosystems would merely migrate landward. However, the presence of buildings behind the beaches would often prevent landward migration. Along the coast of Florida, for example, beach erosion is already forcing sea turtles in some areas to build their nests under people's houses.

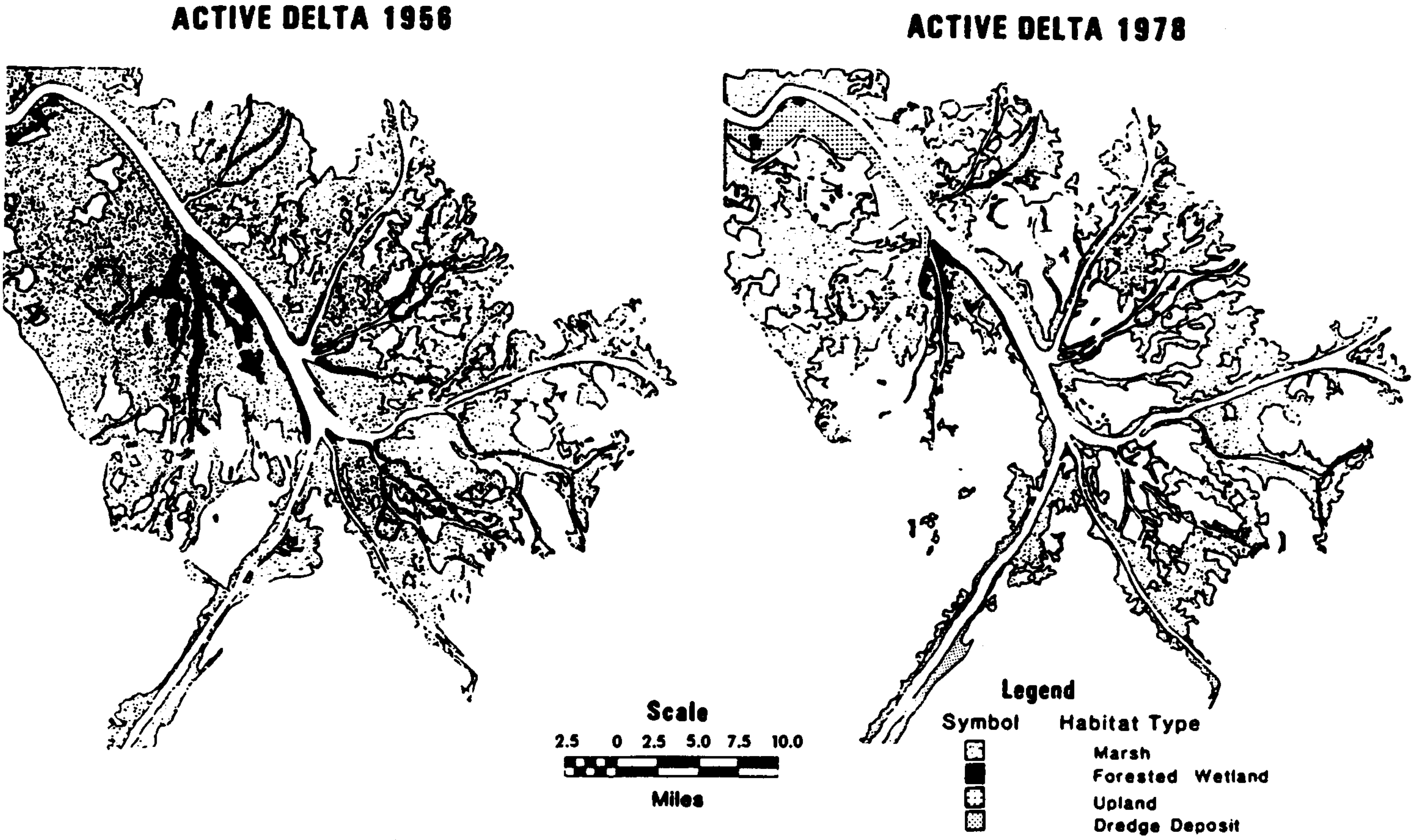

Figure 8. Wetland loss at the mouth of the Mississippi River (National Coastal Ecosystems Team, U.S. Fish and Wildlife Service).

SOCIOECONOMIC IMPLICATIONS FOR PARTICULAR NATIONS

We now examine the implications for two nations: the United States and the Republic of Maldives. Future drafts of this paper for the IPCC work group and report will have a more balanced treatment.

United States

If no measures were taken to counteract its effect, a one-meter rise in sea level would inundate 7,000 square miles of coastal lowlands and a similar area of wetlands. Recreational beaches in the Northeast and Mid-Atlantic would erode about 50-100 meters, while those in the Southeast and west coast would erode 100-200 meters (Titus, 1986). Moreover, coastal cities such as Charleston, South Carolina, and Galveston, Texas, would experience three times as much damage from a 10-year storm than they do today (Kana et al., 1984; Leatherman, 1984). Finally, saltwater migrating upstream in the Sacramento Delta, Delaware River, and the Everglades would threaten the water supplies of southern California, Philadelphia, New York, and Miami, respectively (Williams, 1989; Hull and Titus, 1986, Miller et al., 1989).

Because the United States is a wealthy nation, the cost of protecting developed areas from a rise in sea level would generally be affordable. Spread over the course of a century, the $100 billion necessary to protect the 700 square miles of most densely developed areas would amount to approximately $3,000 dollars per acre per year -- hardly a welcome prospect, yet hardly beyond the taxing powers of local governments given current property values, which frequently exceed $1 million per acre on barrier islands and are rarely less than $200,000 per acre in developed areas.

The most notable exception is the Mississippi River Delta, which would account for 20 percent of the dryland and half of the wetland lost. Whether the area is protected with dikes or the land is allowed to vanish, the loss of wetlands and the fisheries that depend on them would drive traditional Cajun fishermen away to more fertile areas or into new professions. While the music and cooking the Cajuns have contributed to American society would probably endure, the core of the culture has been life in the marshes and swamps of Louisiana; without the homeland of their heritage, the ability of Cajuns to maintain a distinct cultural identity is doubtful. Only by dismantling the infrastructure that has disabled natural deltaic processes could these wetlands survive; doing so, however, would force ships bound to the Port of New Orleans to pass through a set of locks, causing delays that under current policies are even less acceptable (Louisiana Wetland Protection Panel, 1988).

Even in Louisiana, the major socioeconomic impact would not be the economic impact of sea level rise, but its environmental implications. Although wetland loss elsewhere would not be on such a massive scale, over half the wetlands in most estuaries would be lost. In many areas, the wetlands would erode up to a bulkhead protecting development, making it impossible for many fish to find the marshes necessary for reproduction (Titus, 1988). Sport fishing and duck hunting would decline; the general population would notice the impacts as prices of crabs, shrimp, and other estuarine species began to reflect levels of scarcity that already apply to oysters and lobsters.

So far, the news media have focused the most on implications for barrier islands and other beach resorts. Unless remedial measures are taken, even a small rise in sea level would substantially increase the vulnerability of these communities, which already face the risk of being devastated if a major hurricane crosses their paths. These risks would be further compounded if hurricanes become more intense as a result of global warming. Nevertheless, the value Americans place on owning or renting a seaside cottage suggests that the measures necessary to defend these resorts from sea level rise would be affordable.

Republic of Maldives

This island nation consists entirely of coral atolls. As a result, the entire nation is less than four meters above high water. Several of its most populated islands, including the capital, are less than two meters above high tide; and some islands are less than 50 centimeters above high tide.

Over 90 percent of the islands are uninhabited. Because storm surges rarely exceed 25 centimeters, people hardly considered elevation in deciding which islands to settle. In the Baa Atoll, for example, Tulhadoo, about 40 cm above high water, has five times the population of the similarly sized island of Goia, which has elevations greater than three meters. The most important distinction today is that the higher islands have ample groundwater, while lower islands have little if any during parts of the year. Thus, the most immediate impact of sea level rise would be to further diminish the availability of freshwater.

If sea level rises a meter, the lower islands would be threatened with inundation. Although it would be possible to move to higher areas, people outside the capital are generally so attached to their home islands that many have visited other islands only a few times in their lives; efforts to encourage migration to less developed islands are generally recognized as a major factor contributing to the downfall of their previous president.

In the very long run, the Maldives could survive a rising sea level only if measures were taken to elevate the islands. Fortunately, the nation would have to focus only on protecting land for industrial and residential uses; the greater areas necessary for food production in their case refer primarily to the sea itself, which is largely unaffected by changes in sea level. Despite the potential for remedial measures, the prospect of the entire nation being inundated motivated the president of this nation to become the first head of state to address the United Nations and the British Commonwealth on the implications of global warming.

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REASONS FOR BEING CONCERNED ABOUT RISING SEA LEVEL

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A GLOBAL PERSPECTIVE

Value of the Coastal Zone

This paper lays out the resources at risk to a rise in sea level. The local economies of virtually all coastal communities rely heavily on the quality of their estuaries and adjacent coastal areas. Coastal habitats such as wetlands, dunes, and beaches are important areas for fish and wildlife, including many endangered species, as well as for many types of recreation.

Coastal zones provide critical habitat for commercially important fisheries, filter and process agricultural and industrial wastes, buffer inland areas against storm and wave damage, and help generate revenues from a variety of commercial and recreational activities. Commercial, recreational, and subsistence fisheries are, at the very least, important to the economies of most nations and are the lifeblood of many others.

Uses of the Coastal Zone Today

In many parts of the world, as a result of population growth and development, the natural function of coastal zones and their resources is being degraded and impaired. This is particularly apparent in deltaic regions served by large rivers and inhabited by large human populations.

River deltas are vulnerable to the activities of upstream states. For example, activities by India, Nepal, China, and Bhutan all affect the flow and water quality characteristics of the Ganges, which is felt downstream by Bangladesh. Disputes arise over the construction of dams on major rivers, over the use of major tributaries, and over river diversions. Upstream activities can affect water availability, the ecology of the delta, and the formation and subsidence rates of the delta, which normally offers some protection from storm surges and sea level rise. Other obvious examples are the Nile and the Mississippi Deltas.

Decreased or diverted riverflow also can lead to increased saltwater intrusion and thus to drastically altered biological productivity. Declining health of salt-sensitive mangrove forests may lead to loss of habitat for many species of fish and shellfish and to increased loss of entrapped sediments.

Removal of groundwater or hydrocarbons from deltas can accelerate greatly the rate of local subsidence. Subsidence in low-lying deltas, either natural or exacerbated by fluid withdrawal, can accentuate greatly the apparent local rise in sea level. Clearly, coastal and fluvial planning for future coastal zone uses requires careful attention in view of potential human-induced changes in global climate and associated sea level rise.

Potential Threats

Most shorelines have already experienced significant and almost constant change, with enormous commercial, recreational, and environmental values at risk. Flooding, beach erosion, habitat modification and loss, structural damage, and silting and shoaling (resulting from natural factors) all pose major public safety and economic consequences. Yet, while these risks are substantial, the benefits of coastal resources in many areas significantly outweigh them and continue to attract human activity and development. When a human-induced, accelerated rise in global sea level is added to the equation, however, the potential for loss of life, injury, and economic damage increases.

Some general observations can be made about the differences in vulnerability to sea level rise of industrialized and developing countries. Most major cities in industrialized countries probably will be protected from sea level rise, but at great expense. In developing countries, however, sea level rise will be most severely felt by exposed coastal populations and by agricultural developments in deltaic areas. Three highly populated developing countries -- India, Bangladesh, and Egypt -- are thought to be especially vulnerable because their low-lying coastal plains are already extremely susceptible to the effects of storms. Since 1960, India and Bangladesh have been struck by at least eight tropical cyclones, each of which killed more than 10,000 people. In late 1970, storm surges killed approximately 300,000 people in Bangladesh and reached over 150 kilometers inland over the lowlands. Recent estimates suggest that a climatically induced one-meter rise in sea level would cover scarce arable land in Egypt and Bangladesh presently occupied by 8 and 10 million people, respectively. A far greater fraction of the population of these countries would be threatened by the increased consequences of storms.

Small island nations are also especially vulnerable to sea level rise and to the other coastal effects of climate change. This vulnerability is reflected in their very high ratios of coastline length to land area. The most seriously affected island microstates are those consisting solely, or mostly, of atolls with little or no land at all a few meters above sea level. The majority of developing island microstates are also experiencing rapid rates of population growth. Moreover, they are most frequently characterized by having large proportions of their populations in low-lying coastal areas. The location of most small island countries in the latitudes where tropical cyclones may be experienced further adds to their vulnerability. The effects of such disasters, while of smaller magnitude than those described above for some of the world's great deltas, are proportionally often much more devastating.

A Need for Action

These circumstances require political, scientific, legal, and economic actions at the international and national level. It is imperative that such actions focus on human safety and on sustainable approaches to the management of coastal resources.

One of the first steps is to heighten awareness among governments and citizens alike of the possibility of sea level rise and its potential impacts in the coastal zone. It is important to begin now the process of identifying, analyzing, evaluating, and planning for adaptive responses to build a foundation for timely implementation of response strategies, should the need arise.

Even though sea level rise is predicted to be a relatively gradual phenomenon with site-specific consequences, strategies appropriate to unique physical, social, economic, environmental, and cultural considerations may require long lead times.

Nature has provided us some time -- it must be used wisely by all nations, collectively and individually.

A FORECAST FOR GLOBAL CHANGE

Global Warming

There is growing consensus among scientists that the atmospheric buildup of greenhouse gases may lead to global climate changes and to an associated acceleration in the rate of sea level rise.

The IPCC Working Group II has projected a series of global consequences for a doubling of the carbon dioxide concentration in the atmosphere by the year 2050. It constructed its scenario based on the global warming projections of Working Group I, including an increase in air temperature of 3.5°C and a sea surface temperature increase of up to 2°C by the year 2050.

During this period, seawater may become slightly more acidic, in turn releasing more heavy metals in a biologically available, toxic form. The intensity and areal extent of coastal upwelling may decrease, thereby lowering the level of primary food production in marine ecosystems. The amount, rate, and regional variability of these consequences are uncertain. In general, the global warming scenario assumed by Working Group II would lead to a reduction in fishery productivity and a partial loss of spawning areas in the coastal zone, with a net redistribution of fishery regions.

An accelerated rise in sea level would have direct effects in the coastal zone. While the rise in sea level would most likely be incremental, the damages from flooding and erosion related to this rise would occur during extreme events such as tsunamis or storm surges associated with hurricanes and typhoons.

Climate changes associated with global warming probably will also affect freshwater availability and quality, food productivity, and access to other resources, goods, and services. The societal impacts of these climate changes could be widely distributed, but they are likely to be felt more severely by poorer nations, posing important and still unresolved questions about equity, fairness, and international environmental ethics.

An Accelerated Rise in Sea Level

Current information from the IPCC Working Group I indicates that, while secular sea level trends extracted from tide gauge records over the last century indicate an average global sea level rise of 1 to 2 mm/year, new models of climatic warming and thermal expansion of the ocean, and considerations of melting of small glaciers and large ice sheets, suggest an average rate of global sea level rise of 4 to 6 mm/year by the year 2050. This projected rise of 25 to 40 cm by the year 2050 is 2 to 6 times faster than that experienced during the last 100 years, and would result principally from the thermal expansion of the ocean and melting of small mountain glaciers. The Working Group I concluded from its modeling studies that the contribution to sea level rise from melting of the Greenland ice sheet may be offset by an addition of ice to Antarctica and a consequent lowering of global sea level. Working Group I believes that there is enough inertia in the human-induced global warming that some rise in sea level is probably inevitable in the future.

In addition to sea level rise, a number of researchers have suggested that extreme events may occur more regularly as a result of climate change. For example, increased ocean temperatures may result in more frequent occurrence of tropical cyclones. Of particular concern is the effect of storm surges, associated with tropical cyclones, which in conjunction with increased sea levels may play havoc on low-lying coasts. Inundation of coastal areas is already common during tropical cyclones and any increases in the extent or frequency of inundation may render numerous heavily populated areas marginal or uninhabitable.

Uncertainties

The complexity of climate modeling means that the necessary research may be slow and difficult, and global monitoring of sea level may not detect significant changes for another decade. Consequently, considerable uncertainties remain about the nature, timing, magnitude, and regional details of climate changes.

POTENTIAL IMPACTS OF CLIMATE CHANGE AND ASSOCIATED SEA LEVEL RISE

Inundation, Erosion, and Flooding

A rise in sea level would (1) inundate wetlands and lowlands, (2) erode shorelines, (3) exacerbate coastal flooding, (4) increase the salinity of estuaries and aquifers and otherwise impair water quality, (5) alter tidal ranges in rivers and bays, and (6) change the locations where rivers deposit sediment.

For example, a one-meter rise in sea level could inundate 15% of Bangladesh, and a two-meter rise could inundate Dhaka (the capital of Bangladesh) and over one-half of the populated islands of the Republic of Maldives, an atoll in the Indian Ocean. In the Pacific, the atolls of Tokelau, Tuvalu, Kiribati, and those of the Marshalls could be devastated. Shanghai and Lagos -- the largest cities of China and Nigeria, respectively -- are less than two meters above sea level, as is 20% of the population and farmland of Egypt.

Sea level rise will increase the risk of storm-related flooding. The higher base for storm surges would be particularly important in areas where hurricanes and typhoons are frequent, such as islands in the Caribbean Sea, the southeastern United States, the tropical Pacific, and the Indian subcontinent; had flood defenses not already been erected, London and the Netherlands would also be at risk from winter storms.

Population and Infrastructure

In some circumstances, there may be a need to relocate people or even entire communities. The issue of resettlement, while exerting major financial demands (particularly in developing countries), has an even greater effect on the social and cultural norms of the community being relocated. The loss of the traditional environment, which normally sustains an economic and cultural base and provides for recreation for the community, could severely disrupt family life and create social instability with a resulting negative psychological impact on the entire population, especially on the young and the elderly.

Community disruption and other negative social impacts associated with sea level rise and its consequences can also have severe, although different, effects on an industrialized country. The scale of loss of infrastructure, commercial, and community support systems can prove astronomically expensive as a result of the high value of the installations and equipment.

Problem Identification

Backwater effects can cause the lower river water levels to rise with rising sea level, affecting certain river-related infrastructural facilities such as bridges, port structures, quays, embankments, and river-training works.

Higher water levels in the lower reaches of rivers and adjacent coastal waters may affect the drainage capacity of adjacent lands and result in damage to production activities and facilities such as roads and buildings.

Ecosystems and Living Resources

Estuaries, lagoons, deltas, and wetlands are all components of the coastal zone ecosystem, usually characterized by intensive tidal influence, high turbidity and productivity, and a high degree of human activity (fisheries, navigation, recreation, waste disposal). From a conservation, economic, and ecological point of view, they are the most valuable areas found in the nearshore shallow waters.

The main potential effect of sea level rise in shallow coastal waters is an increase in water depth. Intertidal zones may be modified radically and mangroves could disappear. The physical and morphological boundary conditions of shallow waters may change considerably, affecting the functioning of ecological systems. In turn, this may cause the loss of natural resource values, such as bird life, fish spawning and nursery grounds, and fish and shellfish production.

In general, the effects on shallow coastal ecosystems are strongly determined by local circumstances, and a good understanding of the physical and biological processes is required to forecast local impacts. But if the accretion of sea floor sediments cannot keep pace with rising waters and inland expansion of intertidal area is not possible (because of infrastructure or a steeply rising coast), major impacts are to be expected.

Coastal wetlands provide critical habitats for high percentages of commercially important fisheries in many countries. They also filter and process agricultural and industrial wastes, buffer coastal areas against storm and wave damage, and help generate large revenues from a variety of commercial and recreational activities. The United States estimates that coastal wetlands contribute to an annual marine fisheries harvest valued at over $10 billion. Equally important may be the wetlands contributions to subsistence fisheries that are critical for many coastal nations.

Raised sea levels may influence some coastal marine fishes by altering the shallow estuaries in which the juveniles find early shelter and food. If existing shorelines are maintained by embankments, these shallow estuaries with their productive mudflats may become too deep. A change in estuarine salinity also is likely to have an effect on juvenile fish and their food, as will changes in inflow and outflow currents.

Despite numerous protective laws, the degradation of estuaries and the disappearance of coastal wetlands continues because of shoreline erosion, landfill developments, flow diversions, turbidity, and sea level rise. An accelerated rise in sea level would only exacerbate these losses.

The estuarine response to climate change is likely to be a slow but continually adjusting environment. With a change in estuarine vegetation, there will be an adjustment in the animal species living in and around the estuary margins. An increase in mudflat vegetation such as the mangrove, will trap fine sediments within a harbor and gradually convert sand banks to mudflats. The wetter climate conditions projected by many models would lead to increased flow and sediment yields and consequently to increased turbidity of the estuary waters. These changes, together with a rise in sea level of up to one meter over the next 100 years, would modify the shape and position of many banks and channels within the estuary and permanently submerge others. Provided there are no barriers, wetlands and salt marshes around the landward margins of the estuary may increase with rising sea level. Where barriers occur, wetlands may be submerged by the rising water levels and permanently covered by shallow waters. Pastoral land around the estuaries may become saline and, hence, unproductive.

The adjustments to global sea level rise, outlined above for the estuarine environment, indicate the possibility of some far-reaching impacts. There will be changes in fisheries and nursery functions of the estuaries together with changes in plant and bird life as the sediment and streamflow regimes adjust to the changing level of the sea.

EXISTING PROBLEMS IN COASTAL ZONES: A CONCERN OF IPCC?

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INTRODUCTION

The effects of an acceleration of sea level rise on coastal lowlands can be summarized as an inundation of parts of the wetlands and the coastal plains, an increase in flooding frequency, an increase in the rate of coastal retreat and coastal erosion, and an increase in saltwater intrusion (UNEP/Delfts Hydraulics, 1988; Titus, 1989). These types of impacts, however, also may result from other processes, including subsidence and upstream river management (Figure 1). These problems, which are related to present detrimental coastal processes other than sea level rise, are defined as the "existing problems" in the coastal zone.

The causes of the existing problems are often human induced:

- Population pressure in the coastal zone leads to occupation, an increase in human activities, and exploitation of coastal areas.
- The exploitation of natural resources (oil/gas/water) often results in subsidence.
- Upstream river construction, such as the building of dams, retains the sediment supply that otherwise would nourish the coastal zone.

All of these processes increase coastal erosion, and lead to inundation of the floodplains and saltwater intrusion, as will the expected acceleration of sea level rise (Figure 2).

One of the tasks of the IPCC-Response Strategies Working Group-Coastal Zone Management subcommittee is to unravel existing and future problems in the coastal zone and their respective causes.

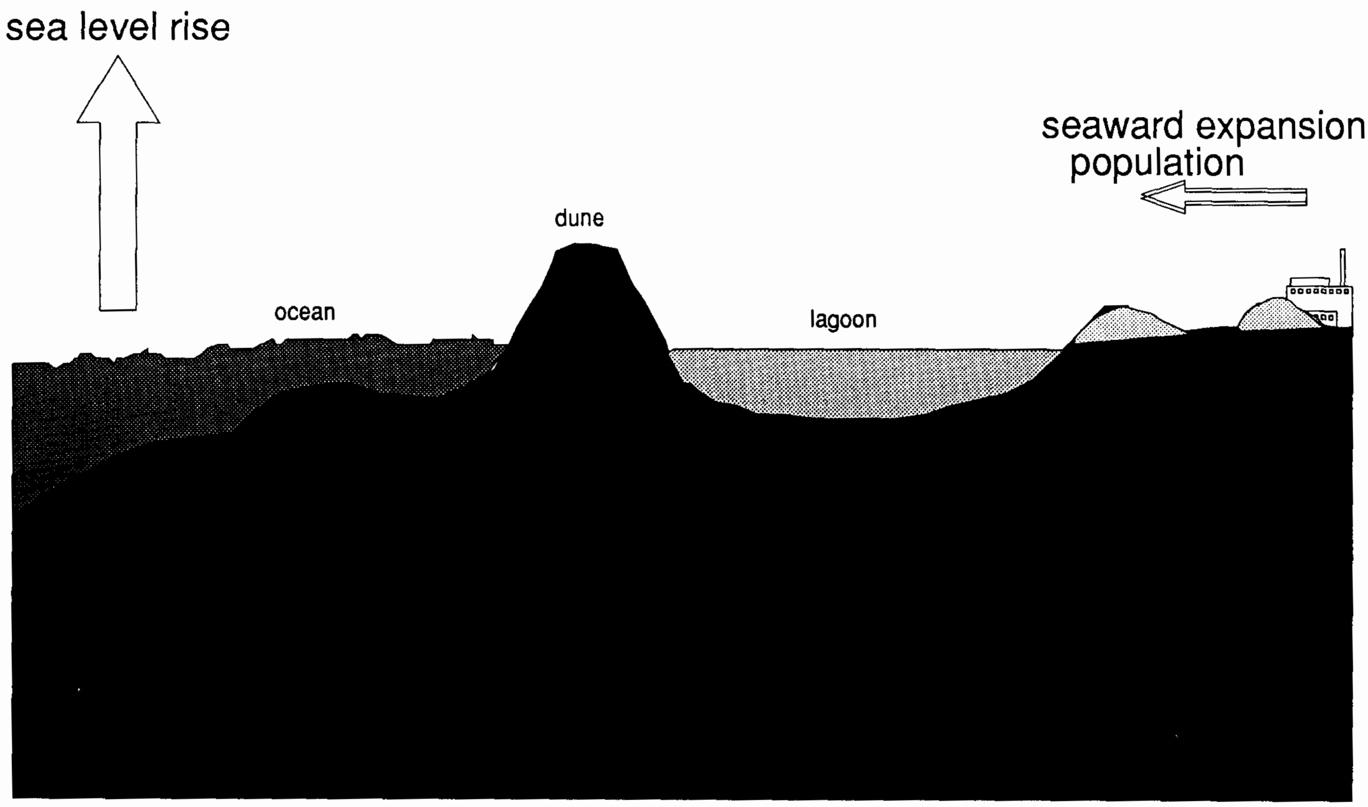

Figure 1. The main factors affecting coastal zones.

SOME EXAMPLES OF EXISTING COASTAL PROBLEMS

Subsidence in coastal zones that is mainly related to human activities is illustrated by the following examples:

- The Chao Phraya delta basin in Bangkok (5.5 million inhabitants) shows an increase of maximum subsidence (Nutulaya, 1988) from 1.2 m/century (1933-1978) to 7 m/century (1978-1987) (Figures 3 and 4).

- An example of a low rate of subsidence is found in the Netherlands. The subsidence in the western part of the Netherlands is tectonic in origin and amounts to maximum values of only slightly more than 0.06 m/century (Figure 5). This subsidence rate of the Pleistocene subsoil was observed during the period 1926-1985 (Noonen, 1989). In coastal areas with maximum subsidence rates, retreat of the coastline (mean low water line) amounted to 150-220 m/century (Kohsiek, 1988) during 1885-1985.

- Coral mining on the foreshore of Male (50,000 inhabitants/1.6 km^2), the principal island of the fast-growing Maldives (maximum height 2-3 m above sea level) is deepening the foreshore, with a subsequent increase in wave action and coastal erosion (UNEP/Delfts Hydraulics, 1989) (Figure 6).

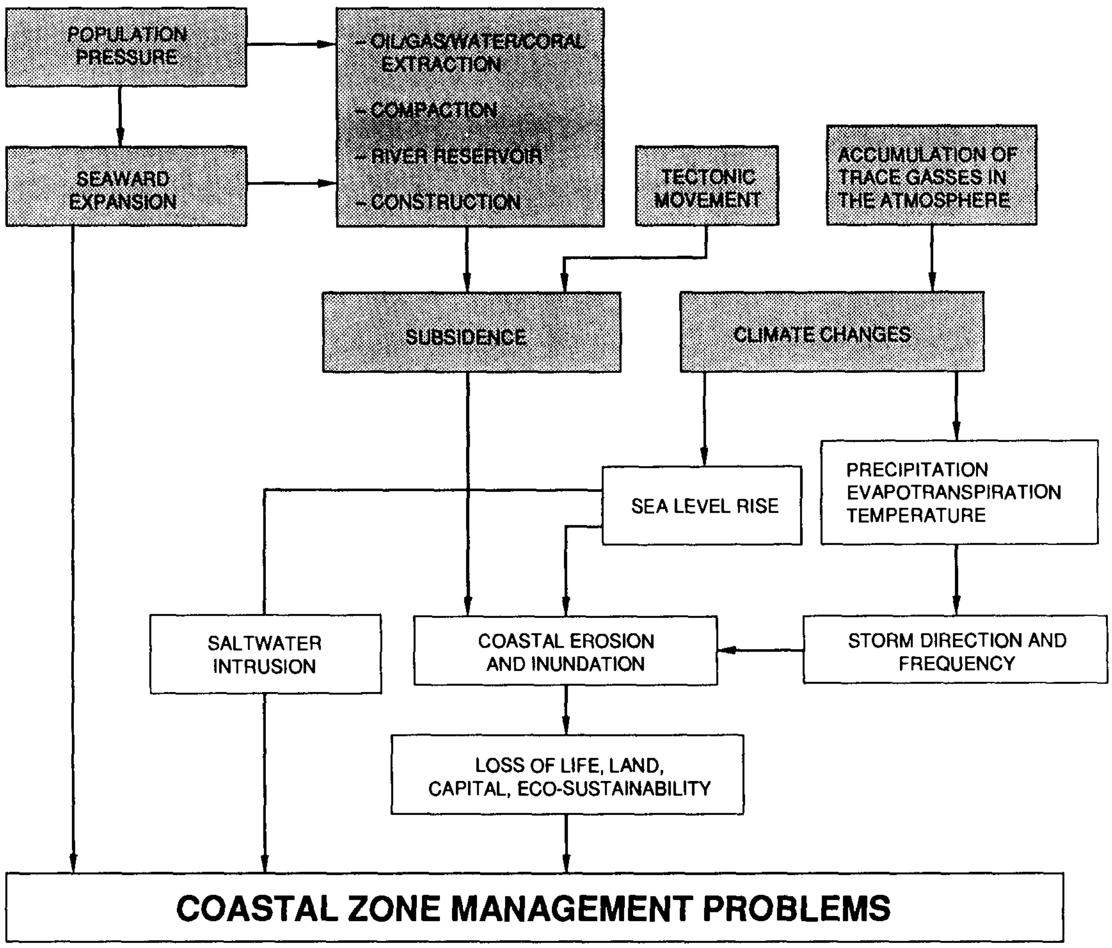

Figure 2. Schematic representation of the main factors affecting the coastal zone.

The construction of dams in rivers is accompanied by withdrawal of sediments on their way to the coast:

- The sediments of the annual highly turbid Nile flood are completely trapped in the artificial Lake Nasser (500 x 10 km) since the construction of Aswan High Dam (1964). Water and sediment discharges of the Nile's branches into the Mediterranean Sea ceased to exist after 1964. The subsequent observed acceleration of coastal retreat of the protruding subdeltas of the Nile Delta reached maximum values of 150 m/year (Rosetta peninsula, Figure 7; Misdorp and Pluym, 1986). Since 1964, the overall yearly coastal erosion along the 250-km-long Nile Delta coastal zone has been on the same order as the Nile sediment discharge before 1964 (about 100 million m^3).

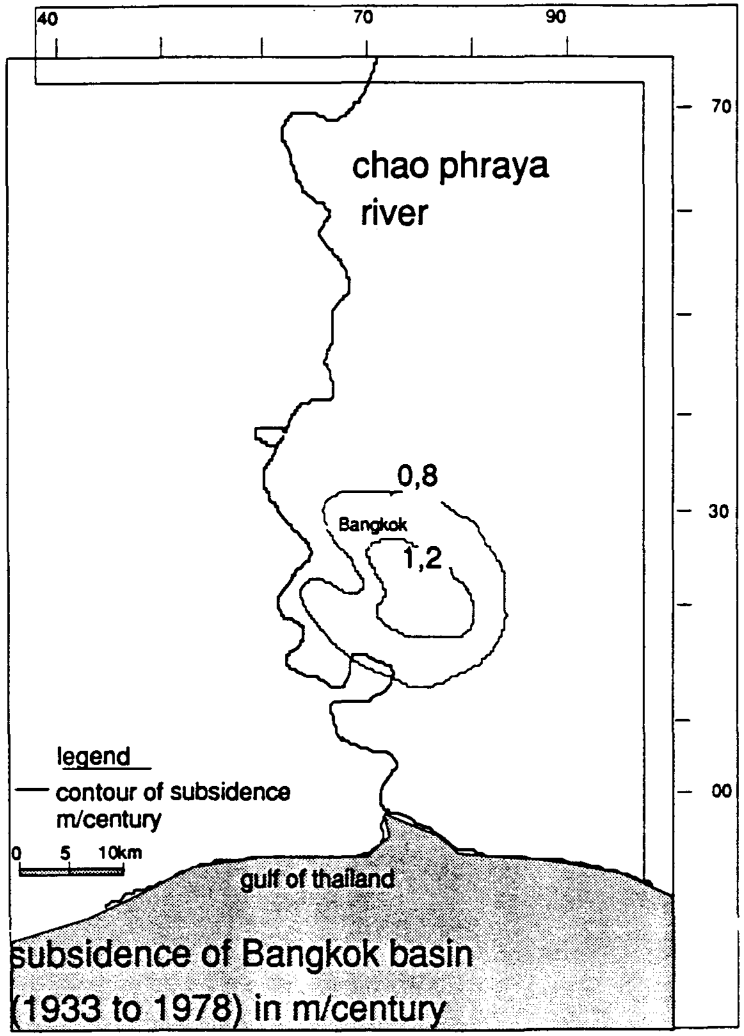

Figure 3. Subsidence of the Bangkok basin (1933 to 1978).

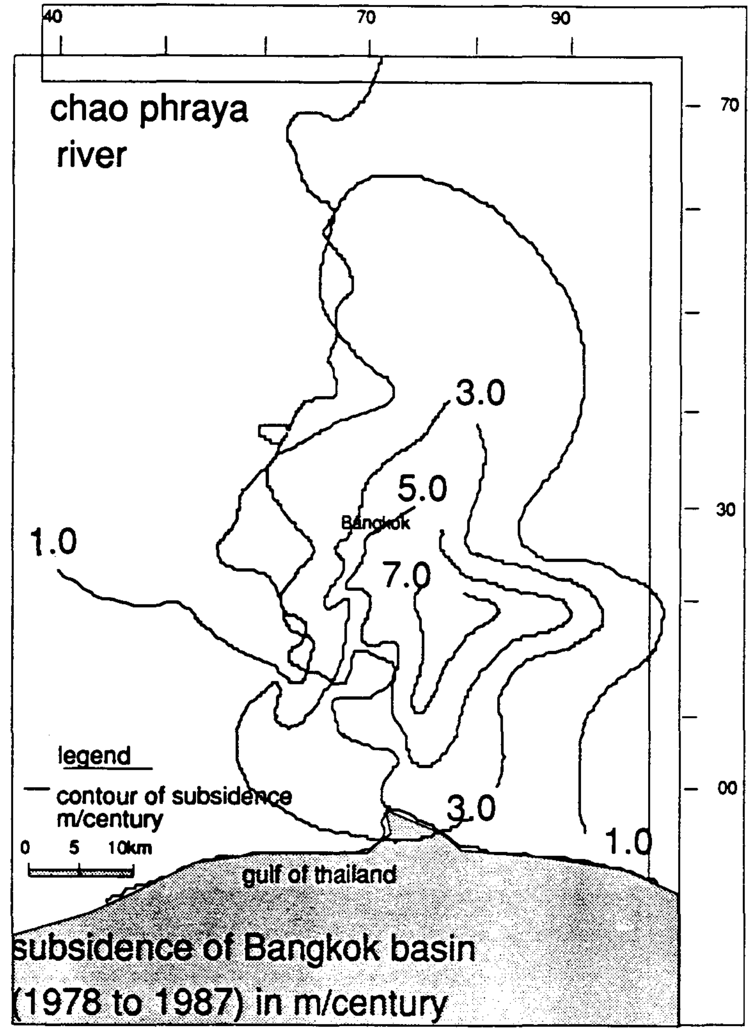

Figure 4. Subsidence of the Bangkok basin (1978 to 1987).

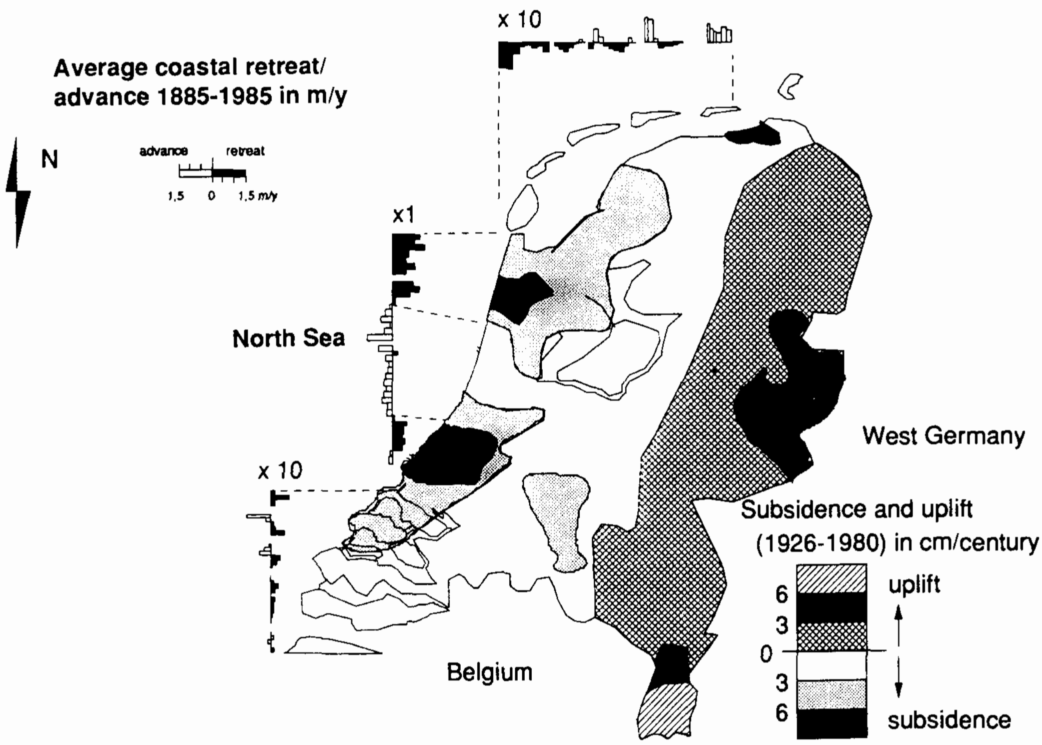

Figure 5. Coastal retreat/advance and subsidence in the Netherlands.

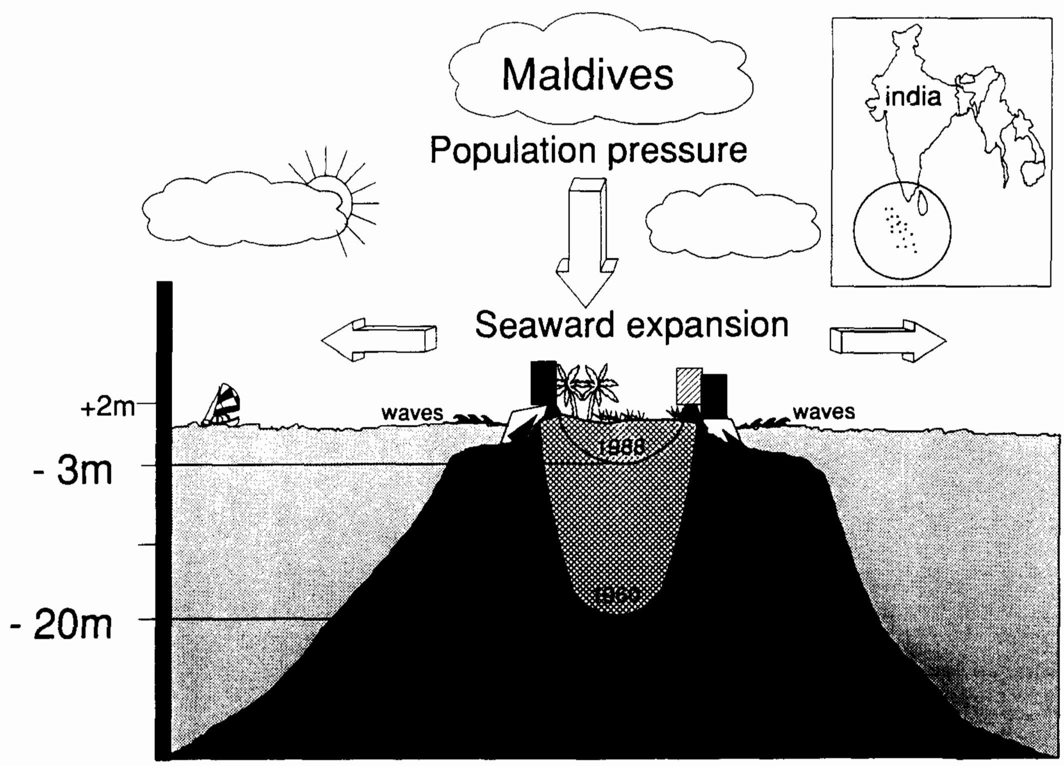

Figure 6. Coastal zone activities in the Maldives.

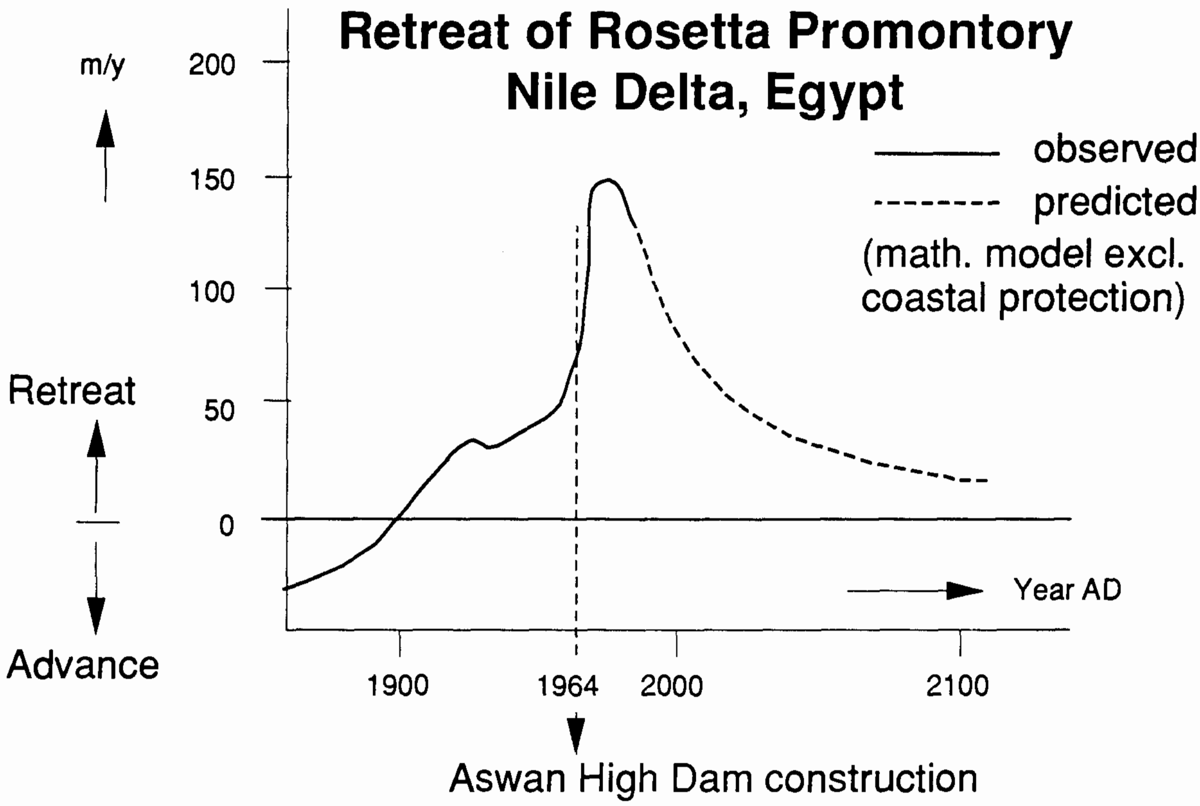

Figure 7. Maximum annual retreat rate (m/year observed during 1900-1985 and calculated by mathematical model 1985-2110) (excluding coastal protection measures).

EXISTING COASTAL MANAGEMENT PROBLEMS AND IPCC

Two policies are possible for handling the existing and future problems in coastal zones: adaptation or limitation of the cause.

Limitation of the causes of existing problems in the coastal zone means:

- intensifying measures to reduce population pressures;
- changes in the manner of exploitation of coastal areas: water/oil/gas extraction and upstream river management.

These types of limitation measures should receive high priority.

HOLDING BACK THE SEA

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A quick study of a world map illustrates an obvious but rarely considered fact: much of human society is defined by the planet's oceans. The boundary between land and water determines a great deal that is often taken for granted, including the amount of land available for human settlement and agriculture, the economic and ecological productivity of deltas and estuaries, the shape of bays and harbors used for commerce, and the abundance or scarcity of freshwater in coastal communities.

The rapid settlement of coastal areas over the past century implies tacit expectation of a status quo between sea and shore that, according to most scientific models, is about to change. On a geological time scale, sea level is far from static. Cycles of cooling and warming that span 100,000 years, accompanied by glaciation and melting, keep the level of the oceans in constant flux. Still, for most of recorded history, sea level has changed slowly enough to allow the development of a social order based on its relative constancy.

Global warming will radically alter this. Increasing concentrations of greenhouse gases in the atmosphere are expected to raise the earth's average temperature between 2.5 and 5.5 degrees Celsius over the next 100 years. In response, the rate of rise in sea level is likely to accelerate from thermal expansion of the earth's surface waters and from a more rapid melting of alpine and polar glaciers and of ice caps. Although the issue of how quickly oceans will rise is still a matter of conjecture, the economic and environmental losses of coastal nations under various scenarios are fairly easy to predict. One thing is clear: no coastal nation, whether rich or poor, will be totally immune (Hansen et al., 1988).

Accelerated sea level rise, like global warming, represents an environmental threat of unprecedented proportion. Yet most discussions of the impending increase in global rates obscure a critical issue -- in some regions of the world, relative sea level (the elevation as measured at a given point on the map) is already rising quickly. Bangladesh, Egypt, and the United States are just a few of the countries where extensive coastal land degradation, combined with even the recent small incremental changes in global sea level, is contributing to large-scale land loss. These trends will be exacerbated in a greenhouse world.

A preliminary assessment of the likely effects of global and relative sea level rise done by the United Nations Environment Programme (UNEP) in 1989 identified the 8 regions and 27 countries at greatest risk. While pointing out that potential losses from rising seas are far greater in some areas than others, the report warned that a large majority of nations will be affected to some degree by higher global average rates, since only 30 countries in the world are completely landlocked (UNEP, 1989).

Low- to middle-range estimates by the U.S. Environmental Protection Agency (EPA) indicate a warming-induced rise by 2100 of anywhere from a half-meter to just over two meters. A one-meter rise by 2075, well within the projections, could result in widespread economic, environmental, and social disruption. G.P. Hekstra of the Dutch Ministry of Housing, Physical Planning, and Environment asserts that such a rise could affect all land up to five meters elevation. Taking into account the effects of storm surges and saltwater intrusion into rivers, he estimates that 5 million square kilometers are at risk. Although only a small percentage of the world total -- about 3 percent -- this area encompasses one-third of global cropland and is home to a billion people (Hoffman et al., 1986, 1983; Hekstra, 1989).

As sea level rises, coastal communities face two fundamental choices: retreat from the shore or fend off the sea. Decisions about which strategy to adopt must be made relatively soon because of the long lead time involved in building dikes and other structures and because of the continuing development of coasts. Yet allocating scarce resources on the basis of unknown future conditions -- how fast the sea will rise and by what date -- entails a fair amount of risk.

Questions also arise about how far nations should go in safeguarding and insuring investments already made in coastal areas. Protecting beaches, homes, and resorts can cost a country with a long coastline billions of dollars -- money that is well spent only if current assumptions about future sea level are borne out. Assessing the real environmental costs is difficult because traditional economic models do not reflect the fact that structural barriers built to hold back the sea often hasten the decline of ecosystems important to fish and birds. Moreover, protecting private property on one part of the coast often contributes to higher rates of erosion elsewhere, making one person's seawall another's woe.

International equity is another important issue. Low-lying developing countries stand to lose the most from accelerated sea level rise yet can least afford to build levees and dikes on a grand scale. These regions face consequences grossly disproportionate to their relatively small contribution to the greenhouse effect. At the same time, however, development projects now in progress are putting enormous pressure on regional ecosystems, while aggravating the current and likely consequences of sea level rise.

GLOBAL CHANGES, LOCAL OUTCOMES

Worldwide average sea level depends primarily on two variables. One, the shape and size of ocean basins, involves geological changes over many millions of years. The other, the amount of water in the oceans, is influenced by climate, which can have a more rapid impact (Milliman, 1989; Titus, 1987a, 1989; The Oceanography Report, 1985).

Ocean basins change their shape and size in a process similar to the buildup of land recorded in stratified rock. The sea floor builds out from ocean ridges via the accumulation of lava, which forms multiple layers. The weight of new layers causes the earth's crust to settle and subside. If subsidence occurs more rapidly than new volcanic rock is formed, the basin deepens and the water level falls (assuming a constant volume of water). If the production of new rock exceeds subsidence, on the other hand, the basin's volume decreases and the water level rises (Milliman, 1989).

Seawater volume may change much more quickly than basin size and shape. A higher global average temperature can alter sea level in four ways. The density can decrease through the warming and subsequent expansion of seawater, which increases volume. The volume can also be raised by the melting of alpine glaciers, by a net increase in water as the fringes of polar glaciers melt, or by more ice being discharged from ice caps into the oceans.

Glaciers and ice shelves, such as those in Antarctica and Greenland, freeze or melt in a cycle on the order of every 100,000 years. In the last interglacial period, average temperatures were 1 degree Celsius warmer, and sea level was 6 meters (20 feet) higher. During the Wisconsin glaciation 18,000 years ago, the most recent ice age, enough ocean water was collected in glaciers to drop the sea off the northeastern U.S. coast 100 meters below its level today (Milliman et al., 1989; Pirazzoli, 1985).

Globally and locally, sea level also fluctuates day to day and year to year as a result of short-term meteorological and physical variables that may also be affected by global warming. Tidal flows, barometric pressure, the actions of wind and waves, storm patterns, and even the earth's rotational alignment all influence sea level (Titus, 1987a; Barnett, 1983).

The slight variations in global climate of the last 5,000 years are responsible for correspondingly small fluctuations in sea level. Over the past 100 years, however, global sea level rose 10-15 centimeters (4-6 inches), a somewhat faster pace than the rate during the previous several thousand years. Scientists continue to debate the cause of this rise; many argue that no evidence yet indicates it is due to human-induced warming, while others are not so sanguine (Milliman, 1989).

Faster global average sea level rise is not the only threat to coastal areas, nor are changes in the earth's atmosphere the only consequences of human activity likely to accelerate this trend. Discussions that focus only on global averages mask important differences in relative, or local, sea level. Although the two are fundamentally different, global average sea level rise can be compounded by local fluctuations in land elevation and geological processes, such as tectonic uplift or subsidence in coastal areas. Local rates of sea level rise in turn depend in large part on the sum of the global pattern and local subsidence.

Land subsidence is a key issue in the case of river deltas, such as the Nile and Ganges, where human activities are interfering with the normal geophysical processes that could balance the effects of rising water levels. These low-lying regions, important from both ecological and social standpoints, will be among the first lost to inundation under even slight rises in sea level.

Under natural conditions, deltas are in dynamic equilibrium, forming and breaking down in a continuous pattern of accretion and subsidence. Subsidence in deltas occurs naturally on local and regional scales through the compaction of recently deposited riverborne sediments. As long as enough sediment reaches a delta to offset subsidence, the area either grows or maintains its size. The Mississippi River delta, for example, was built up over time by sediments deposited during floods and laid down by the river along its natural course to the sea. If sediments are stopped along the way, continuing compaction and erosion cause loss of land relative to the sea, even if the absolute level of the sea remains unchanged.

Large-scale human interference in natural processes has had dramatic effects both on relative rates of sea level rise and on coastal ecosystems in several major deltas. Channeling, diverting, or damming rivers can greatly reduce the amount of sediment that reaches a delta, as has happened in the Ganges, the Mississippi, and most other major river systems, resulting in heavier shoreline erosion and an increase in water levels. Furthermore, the mining of subterranean stores of groundwater and of oil and gas deposits can raise subsidence rates. In Bangkok, local subsidence has reached 13 centimeters per year, as the water table has dropped because of excessive withdrawals of groundwater over the past three decades (Salinas et al., 1986; Milliman, 1988).

These factors can dramatically affect the local outcome of global changes. Subsidence can result in a local sea level rise in some delta regions that is up to five times that of a global mean increase. Under a 20-centimeter worldwide average increase, for example, local sea level rise may range from 33 centimeters along the Atlantic and gulf coasts of the United States to one meter in rapidly subsiding areas of Louisiana and in parts of California and Texas. As the rate of global rise accelerates, the rise in local sea level on rapidly subsiding coasts will multiply severalfold (Sestini et al., 1989; Titus, 1989).

Uncertainties abound on the pace of all the possible changes expected from global warming. The most immediate effect will probably be an increase in volume through thermal expansion. The rate of thermal expansion depends on how quickly ocean volume responds to rising atmospheric temperatures, how fast surface layers warm, and how rapidly the warming reaches deeper water masses. The pace of glacial melt and the exact responses of large masses such as the antarctic shelf are equally unclear. Over the long term, however, glaciers and ice caps will make the largest contribution to increased volume if a full-scale global warming occurs. (Melting of the Arctic Ocean ice pack would have no effect on sea level, since the ice is floating, displacing an amount of water roughly equal to that in the submerged ice) (Titus, 1989).

Over the past five years, a number of scientists have estimated the possible range of greenhouse-induced sea level rise by 2100. Gordon de Q. Robin projects an increase of anywhere from 20 to 165 centimeters. Computations by other scientists yield projections as high as 2-4 meters over the next 110 years. Widely cited EPA estimates of global average sea level rise by 2100 range from 50 to 200 centimeters (1.6 to 6.5 feet), depending on various assumptions about the rate of climate change. The discussion in this chapter uses the EPA figures unless otherwise noted. Most models do agree that initial rates of increase will be small relative to the much more rapid acceleration expected after 2050. After 2100, the rate is anybody's guess. In any case, even the low range of estimates portends a marked increase over the current global pace (Robin, 1986; Titus, 1989).

If global warming runs its course unabated, resulting in average temperatures toward the higher end of the range, the earth may eventually be awash in seawater. In theory, the world's total remaining ice cover contains enough water to raise sea level over 70 meters. Some early reports, taking this fact to its extreme, predicted changes of similar magnitude within a brief period of time. But such an increase is more science fiction than fact, since complete melting of all ice packs would take several thousand years (Henderson-Sellers and McGuffie, 1986).

What is important about the sea level rise expected from global warming is the pace of change. The rate expected in the foreseeable future -- one meter by 2075 is certainly plausible -- is unprecedented on a human time scale. Higher rates of global increase mean more rapid relative rise where subsidence is excessive. Unfortunately, with today's level of population and investment in coastal areas, the world has much more to lose from sea level rise than ever before.

LANDS AND PEOPLES AT RISK

From the atmosphere to the ocean, humans are proving themselves to be forceful -- if unintentional -- agents of change. By and large, the costs of higher seas tomorrow will be determined by patterns of development prevalent in river systems and coastal areas today. Intense population pressures and economic demands are already taking their toll on deltas, shores, and barrier islands. Rapid rates of subsidence and coastal erosion ensure that many areas of the world will experience a one-meter increase in sea level well before a global average change of the same magnitude. As a result, countless billions of dollars worth of property in coastal towns, cities, and ports will be threatened, and problems with natural and artificial drainage, saltwater intrusion into rivers and aquifers, and severe erosion of beaches will become commonplace.

Problem Identification

The ebb and flow of higher tides will cause dramatic declines in a wide variety of coastal ecosystems. Wetlands and coastal forests, which account for most of the world's land area less than a meter above the mean, are universally at risk. Loss of coastal wetlands in Louisiana today provides a good case study for the future.

Deterioration of the Mississippi River delta began early in the nineteenth century, shortly after levees (embankments to prevent flooding) became extensively used. Subsidence and land loss accelerated after 1940 with an increase in river diversions and the tapping of fossil fuel and groundwater deposits. Combined with sea level rise, these processes are now drowning Louisiana's coastal marshes at rates as high as 130 square kilometers per year, giving that state the dubious distinction of losing more land to the sea on an annual basis than any other region in the world (Salinas et al., 1986).

Coastal swamps and marshes are areas of prodigious biological productivity. Louisiana's marshes, for example, cover 3.2 million hectares and constitute 41 percent of all wetlands in the United States. The region supplies 25 percent of the U.S. seafood catch and supports a U.S. $500-million-a-year recreational industry devoted to fishing, hunting, and birding. The ecological benefits derived from these same wetlands are inestimable. Nearly two-thirds of the migratory birds using the Mississippi flyway make essential use of this ecosystem, while existing marshlands and barrier islands buffer inland areas against devastating hurricane surges. Marshes not only hold back the intrusion of the Gulf of Mexico's saltwater into local rivers and aquifers, but they are also a major source of freshwater for coastal communities, agriculture, and industry (Hawxhurst, 1987).

What was laid down over millions of years by the slow deposit of silt washed off the land from the Rockies to the Appalachians may disappear in little over a century. The combination of global sea level rise subsidence could overrun Louisiana's famous bayous and marshland by 2040, by allowing the Gulf of Mexico to surge some 53 kilometers (33 miles) inland. With the delicate coastal marsh ecology upset, fish and wildlife harvests would decline precipitously, and a ripple effect would flatten the coastal economy. Communities, water supplies, and infrastructure would all be threatened. Most of these trends are already apparent in Louisiana and are becoming evident in other parts of the United States (Salinas et al., 1986; Hawxhurst, 1987).

According to EPA estimates, erosion, inundation, and saltwater intrusion could reduce the area of U.S. coastal wetlands up to 80 percent if current projections of future global average sea level are realized. Not only the Mississippi Delta, but the Chesapeake Bay and other vital wetland regions would be irreparably damaged. Dredged, drained, and filled, coastal wetlands in the United States are already under siege from land and sea. Were it not for the enormous pressure that human encroachment puts on them, these swamps and marshes might have a chance to handle rising seas by reestablishing upland. But heavy development of beach resorts and other coastal areas throughout the country means that few wetlands have leeway to "migrate" (Titus, 1987b).

The extent of wetland loss will depend on the degree to which coastal towns and villages seek to protect beachfront property under different scenarios of sea level rise. An analysis by the U.S. EPA showed that some 46 percent of all U.S. wetlands would be lost under a one-meter rise (from global sea level rise and local subsidence) if shorelines were allowed to retreat naturally. Building bulkheads and levees that block the path of wetland migration would entail higher losses. Fully 66 percent of the U.S. wetlands would be lost if all shorelines were protected. If only currently developed mainland areas and barrier islands were protected, the loss could be kept to 49 percent. Loss of up to 80 percent of the country's wetlands is envisioned under a more rapid rate of rise (Titus, 1987b).

In any case, there will be severe reductions in food and habitat for birds and juvenile fish. No one has yet calculated the immense economic and ecological costs of such a loss for the United States, much less extrapolated them to the global level. Yet as global average sea level rises, these problems will surely become more severe and widespread in ecosystems around the world.

A one-meter rise in sea level would wipe out much of England's sandy beaches, salty marshes, and mud flats, according to a 1989 study by the Natural Environment Research Council in London, for example. The most vulnerable areas lie in the eastern part of the country, including the low-lying fens and marshes of Essex and north Kent. More than half of Europe's wading birds winter in British estuaries, and they are destined to lose this vital habitat (Boorman et al., 1989).

Highly productive mangrove forests throughout the world will also be lost to the rising tide. Mangroves are the predominant type of vegetation on the deltas along the Atlantic coast of South America. On the north coast of Brazil, active shoreline retreat is less of a problem because little human settlement exists; the mangroves may be able to adapt. In the south, however, once-extensive mangroves have already been depleted or hemmed in by urban growth, especially near Rio de Janeiro. No more than 100 square kilometers of mangroves remain where thousands once stood. As sea level rises, these remaining areas will disappear too (Bird, 1986).

Eric Bird of the University of Melbourne in Australia notes that mangrove-fringed coastlines have become much less extensive in Australia, Africa, and Asia in recent decades as a result of fishpond construction and land reclamation for mining, settlement, and waste disposal. Where they remain, mangroves stand on the frontlines between salt marshes and freshwater vegetation. Bird argues that submergence will kill off large areas of the seaward mangroves, especially where human developments abutting mangrove forests prevent their landward retreat. In Asia, for example, the land behind mangroves is often intensively used for fishponds or rice fields. Thus, as sea level rises, it will threaten not only the mangrove species that cannot reestablish upland, but also the economic value of products derived from rice fields and brackish-water fishponds within the flood zone (Bird, 1986).

Problem Identification

In the Bight of Bangkok, the mangrove fringe has already largely been cleared and converted into fish and shrimp ponds and salt pans. Landward canals have been built to irrigate rice fields. A one-meter sea level rise would threaten to submerge all existing mangroves and an additional zone up to 300 meters landward, wiping out the fish farms. This is likely to happen on the southwestern coast of Bangladesh as well, where 6,000 square kilometers of mangroves, locally known as "sunderbans," are at risk. A maze of heavily forested waterways that is both economically and ecologically valuable, this area shields the heavily settled region behind it from the sea (Broadus et al., 1986).

Worldwide, erosion of coastlines, beaches, and barrier islands has accelerated over the past 10 years as a result of rising sea level. A survey by a commission of the International Geophysical Union demonstrated that erosion had become prevalent on the world's sandy coastlines, at least 70 percent of which have retreated during the past few decades (Bird, 1987, 1990; Dean, 1989).

Changes on beaches vary with the amount of sand supplied to and lost from the shore as a result of wave activity. The U.S. Army Corps of Engineers found that of the 134,984 kilometers of American coastline, 24 percent could be classified as "seriously" eroding. Over the past 100 years the Atlantic coastline has eroded an average of 60-90 centimeters (2-3 feet) a year; on the gulf coast, the figure is 120-150 centimeters. Relatively few of the most intensively developed resorts along the U.S. coast have beaches wider than about 30 meters at high tide. Projections of sea level rise over the next 40-50 years suggest that most recreational beaches in developed areas could be eliminated unless preventive measures are taken (Titus, 1987a).

Increased erosion would decrease natural storm barriers. Coastal floods associated with storm surges surpass even earthquakes in loss of life and property damage worldwide. Apart from greater erosion of the barrier islands that safeguard mainland coasts, higher seas will increase flooding and storm damage in coastal areas because raised water levels would provide storm surges with a higher base to build upon. And the higher seas would decrease natural and artificial drainage (Murty et al., 1988; Titus, 1987a).

A one-meter sea level rise could turn a moderate storm into a catastrophic one. A storm of a severity that now occurs on average every 15 years, for example, could flood many areas that are today affected only by truly massive storms once a century. Oceanographer T.S. Murty states that as cultivation and habitation of newly formed low-lying delta land continues, "even greater storm surge disasters must be anticipated" (Murty et al., 1985).

Murty's study shows that losses are nowhere more serious than in the Bay of Bengal. About 60 percent of all deaths due to storm surges worldwide in this century have occurred in the low-lying agricultural areas of the countries bordering this bay and the adjoining Andaman Sea. Murty puts the cost of damage from storm surges in the Bay of Bengal region between 1945 and 1975 at U.S. $7 billion, but warns that this number "scarcely expresses the impact of such disasters on developing countries" (Murty et al., 1988).

Bangladesh -- where storm surges now reach as far as 160 kilometers inland -- accounts for 40 percent of this toll. In 1970, this century's worst storm surge tore through the countryside, initially taking some 300,000 lives, drowning millions of livestock, and destroying most of Bangladesh's fishing fleet. The toll climbed higher in its aftermath. As the region's population mounts, so does the potential for another disaster (Murty et al., 1988).

Studies indicate a dramatic increase in the area vulnerable to flooding in the United States as well. A one-meter rise would boost the portion of Charleston, South Carolina, now lying within the 10-year floodplain from 20 to 45 percent. A 1.5-meter rise would bring that figure to more than 60 percent, the current area of the 100-year floodplain. Effectively, once-a-century floods would then occur on the order of every 10 years. In Galveston, Texas, the 100-year floodplain would move from 58 percent of the low-lying to 94 percent under a rise of just 88 centimeters (Hoffman et al., 1983).

Sea level rise will also permanently affect freshwater supplies. Miami is a case in point. The city's first settlements were built on what little high ground could be found, but today most of greater Miami lies at or just above sea level on swampland reclaimed from the Everglades. Water for its 3 million residents is drawn from the Biscayne aquifer, which flows right below the city streets. That the city exists and prospers is due to what engineers call a "hydrologic masterwork" of natural and artificial systems that hold back swamp and sea (Miller et al., 1988).

Against a one-meter rise in ocean levels, Miami's only defense would be a costly system of seawalls and dikes. But that might not be enough to spare it from insidious assault. Freshwater floats atop saltwater, so as sea levels rise, the water table would be pushed nearly a meter closer to the surface. The elaborate pumping and drainage system that currently maintains the integrity of the highly porous aquifer could be overwhelmed. The higher water table would cause roads to buckle, bridge abutments to sink, and land to revert back to swamp. Miami's experience would not be unique. Large cities around the world -- Bangkok, New Orleans, New York, Taipei, and Venice, to name a few -- face similar prospects.

A study by the Delaware River Basin Commission indicates that a rise of 13 centimeters by the end of this decade would pull the "salt front" on that river from two to four kilometers further inland if there were a drought similar to one in the 1960s that contaminated Philadelphia's water supply. A rise of 1-2.5 meters would push saltwater up to 40 kilometers inland under drought conditions. The resulting contamination of freshwater would exceed New Jersey's health-based sodium standard 15 to 50 percent of the time (Titus, 1987a).

Countries bordering the Mediterranean would suffer significant economic losses. Greece and Italy, for example, face threats to their tourism industries and to specialized agricultural industries, as well as to important harbors. A 1989 UNEP report points out that, though they make up only 17 percent of the total land area of the Mediterranean region, the alluvial and coastal plains of most countries bordering this sea "have [considerable] demographic and economic importance." The coast is home to 37 percent of the region's population, some 133 million people. The report cautions that, while serious environmental problems -- from water pollution and salinization to shoreline erosion and loss of habitat -- already exist in the region, owing to agricultural and industrial practices, tourism, and urbanization, "sea level rise will considerably affect the economy and well-being of many countries, especially because many low coasts will increasingly experience physical instability" resulting from subsidence and reduced sedimentation (Sestini et al., 1989).

MOST VULNERABLE, LEAST RESPONSIBLE

Social, economic, and environmental costs of sea level rise will be highest in countries where deltas are extensive, densely populated, and extremely food-productive. In these countries, most of which are in the Third World, heavy reliance on groundwater and the completed or proposed damming and diversion of large rivers -- for increased hydropower and agricultural use, for flood control, and for transportation -- have already begun to compound problems with sea level rise. Almost without exception, the prognosis for these vulnerable low-lying countries in a greenhouse world is grim.

The stakes are particularly high throughout Asia, where damming and diversion of river systems such as the Indus, Ganges-Brahmaputra, and Yellow Rivers has greatly decreased the amount of sediment getting to deltas. The sediments feeding Asia's many great river deltas account for at least 70 percent of the total that reaches oceans, and they replenish agricultural land with the fertile silt responsible for a large share of food produced in those nations (Milliman, 1988).

As elsewhere, the deltas reliant on these sediments support sizable human and wildlife populations while creating protective barriers between inland areas and the sea. Large cities, including Bangkok, Calcutta, Dacca, Hanoi, Karachi, and Shanghai, have grown up on the low-lying river banks. These heavily populated areas are almost certain to be flooded as sea level rise accelerates (Milliman et al., 1988; Devoy, 1987; Broadus et al., 1986).

The United Nations Environment Programme's 1989 global survey represents the first attempt to analyze systematically the regions most vulnerable to sea level rise. An overall lack of data posed severe constraints on the assessments of potential impacts. In defining "vulnerability," for example, UNEP sought to evaluate population densities for the total area worldwide lying between 1.5 and 5 meters above mean sea level. At the global level, however, detailed topographic maps are not available for such low elevations (UNEP, 1989).

On a country-by-country basis, four main criteria were used to determine vulnerability. The first two -- the share of total land area between zero and five meters above mean sea level and the density of coastal populations -- were used to assess the likely demographic impacts. Identified as most vulnerable were areas where coastal population density exceeded 100 people per square kilometer.

Potential economic and ecological losses were gauged by the other two criteria: the extent of agricultural and of biological productivity within low-lying areas. First, UNEP isolated countries where lowland agricultural productivity grew on average more than 2 percent a year between 1980 and 1985. Second, it added the regions with the largest inventories of coastal wetlands and tidal mangrove forests.

Under these guidelines, 10 countries -- Bangladesh, Egypt, Indonesia, the Maldives, Mozambique, Pakistan, Senegal, Surinam, Thailand, and The Gambia -- were identified as "most vulnerable." These 10 share many characteristics, including the fact that they are, by and large, poor and populous (see Table 1). Not insignificantly, as a group they also contribute relatively little to the current buildup of greenhouse gases.

UNEP identified both primary and secondary impact areas as important in each of these countries. The primary impact area consists of the coastal region between zero and 1.5 meters elevation, which would be completely lost under a 1.5-meter rise. The secondary area (1.5-3.0 meters above today's mean) is vulnerable not only to a rise in seas of equivalent measures but also to the many pressures -- such as an influx of environmental refugees, and increased regional demand for food, housing, and other resources -- that would arise from inundation of the land closer to the sea (UNEP, 1989).

Table 1. Ten Countries Most Vulnerable to Sea Level Rise

Countries	Population (millions)	Per Capita Income (U.S. dollars)
Bangladesh	114.7	160
Egypt	54.8	710
Indonesia	184.6	450
Maldives	0.2	300
Mozambique	15.2	150
Pakistan	110.4	350
Senegal	5.2	510
Surinam	0.4	2,360
Thailand	55.6	840
The Gambia	0.8	220

Sources: United Nations Environment Programme, Criteria for Assessing Vulnerability to Sea-Level Rise: A Global Inventory to High Risk Areas (Delft, The Netherlands: Delft Hydraulics, 1989); income and population data from Population Reference Bureau, 1989 World Population Data Sheet, Washington, D.C., 1989.

Problem Identification

Detailed information on the land area, population, and economic output likely to be affected by a rise of up to three meters was unattainable for all but Bangladesh and Egypt. For data on these two countries, UNEP drew on a 1988 study by John Milliman and his colleagues at the Woods Hole Oceanographic Institute in Massachusetts. Their study showed the combined effects of sea level rise and subsidence on the Bengal and Nile delta regions, where the homes and livelihoods of some 46 million people are potentially threatened (Milliman et al., 1988).

Bangladesh

The river delta nations of the Indian subcontinent and southeast Asia depend heavily on ocean resources and coastal areas for transportation, mariculture, and habitable land. Bangladesh is no exception. The Bengal delta, the world's largest such coastal plain, accounts for 80 percent of Bangladesh's land mass and extends some 650 kilometers from the western boundary with India to the Chittagong hill tracts. Milliman observes that because the delta is so close to the sea (most of the area is only a meter or two above that level now), an increase in sea level rise accompanied by higher rates of coastal storm erosion is likely to have a greater effect here than on any other delta in the world (Milliman, 1988; Broadus et al., 1986).

Residents of one of the poorest and most densely populated nations in the world, Bangladeshis already live at the margin of survival. Most people depend heavily on the agricultural and economic output derived from land close to the sea and currently subject to annual floods from both rivers and ocean storm surges. Subsidence is already a problem in this region. The Woods Hole study indicates that as global warming sets in, relative sea level rise in the Bengal delta may well exceed two meters by 2050. Because half the country lies at elevations below five meters, losses to accelerated sea level rise will be high (Milliman et al., 1988; for a further discussion of environmental refugees see Jacobson, 1988).

UNEP estimates based on current population size and density show that 15 percent of the nation's land area, inhabited by 15 million people, is threatened by total inundation from a primary rise of up to 1.5 meters. Secondary increases of up to three meters would wipe out over 28,500 square kilometers, displacing an additional 8 million people. These projections do not account for the ongoing increase in Bangladesh's population or for continuing settlement of the delta area. Thus, they clearly understate the potential number of environmental refugees (UNEP, 1989).

By the end of the next century, Bangladesh as it is known today may virtually have ceased to exist. Pressures to develop agriculture have quickened the pace of damming and channeling on the three giant rivers -- the Brahmaputra, the Ganges, and the Meghna -- that feed the delta. As a result, sediment flow is being dramatically reduced and subsidence is increasing.

This situation is being aggravated by the increasing withdrawal of groundwater. Milliman of Woods Hole notes a sixfold increase in the number of wells drilled in the country between 1978 and 1985, raising subsidence to perhaps twice the natural rate. The researchers concluded that interference in the delta ecosystem today may make a far larger area and population susceptible to sea level rise, causing dislocation of more than 40 million people (Milliman et al, 1988).

Egypt

Egypt -- almost completely desert except for the thin ribbon of productive land along the Nile and its delta -- can ill afford the likely costs of sea level rise. The country's millions crowd on to the less than 4 percent of the land that is arable, leading to a population density in the settled area of Egypt of 1,800 people per square kilometer (Milliman et al., 1988).

In the Nile delta, extending from just west of the port city of Alexandria to east of Port Said at the northern entrance of the Suez Canal, local sea level rise already far exceeds the global average because of high rates of subsidence. The construction of the first barrages or dams on the Nile in the 1880s cut massively the amount of sediments that nourished the delta. This situation was exacerbated by the building of the Aswan Dam in 1902 and its enlargement in 1934. Extensive diversion of water for irrigation and land reclamation projects since then has closed down a number of the Nile's former tributaries, greatly reducing the river's outward flow (Broadus et al., 1986).

Even so, approximately 80-100 million tons of sediment were delivered annually to the Nile delta until 1964, when the closure of the Aswan Dam virtually eliminated the silt getting through. High rates of relative sea level rise and the accompanying acceleration in subsidence and erosion have resulted in a frightening rate of coastal retreat, reaching 200 meters annually in some places (Broadus et al., 1986).

Milliman's study suggests that local sea level rise will range from 1.0 to 1.5 meters by 2050, rendering up to 19 percent of Egypt's already scarce habitable land unlivable. By 2100, an expected rise of between 2.5 and 3.3 meters may drown 26 percent of the habitable land -- home to 24 percent of the population and the source of an equal share of the country's economic output (Milliman et al., 1988).

To feed a population growing nearly 3 percent annually, the government has followed a strategy of land reclamation and development of lagoon fisheries on the delta banks. The principal existing natural defenses against transgression by the sea are a series of dunes and the freshwater (but increasingly brackish) lakes that fall behind them. According to James Broadus of Woods Hole, these lakes -- Burullos, Idku, Manzalah, and Maryut -- are the major source of the nation's approximately 100,000 tons of annual fish catch, 80 percent of which are freshwater fish. Ironically, the lakes and surrounding areas now slated for development in the regions of Port Said and Lake Maryut will most likely be inundated some time in the next century (Broadus et al., 1986).

Problem Identification

Unless steps are taken now to slow sea level rise, Egyptians can also look forward to damage to ports and harbors, increasing stress on freshwater supplies due to saline encroachment, and the loss of beaches that support tourism, such as those in Alexandria.

Extending these scenarios of Bangladesh and Egypt to the eight other most endangered nations presents a sobering picture. Despite the lack of data, preliminary findings show the situation to be equally grave. In another study, Milliman notes that when the impact of the global rise is added to that of regional subsidence and of damming and diversion, Indian Ocean deltaic areas may register a relative subsidence of at least several meters, leading to coastal regression of several tens of kilometers by the twenty-second century (Milliman, 1988).

Indonesia

At least 40 percent of Indonesia's land surface is classified as vulnerable to sea level rise. In terms of both size and diversity, the country is home to one of the world's richest and most extensive series of wetlands. Here, too, population pressures are already threatening these fragile ecosystems. Transmigration programs have resettled millions of people in the past several years from the overpopulated islands of Java and Bali to the tidal swamps of Sumatra and Kalimantan, a policy decision that may be much regretted when these lands give way to the sea. Although studies remain to be done on how many people will eventually be affected by the ocean's incursion, the numbers are certain to be high (Hekstra, 1989).

China

A one- to two-meter rise in sea level could be disastrous for the Chinese economy as well. The Yangtze delta is one of China's most heavily farmed areas. Damming and subsidence have contributed to a continuing loss of this valuable land on the order of nearly 70 square kilometers per year since 1947. A sea level rise of even one meter could sweep away large areas of the delta, causing a devastating loss in agricultural productivity in China (Broadus et al., 1986).

PAYING BY THE METER

China's 2,400-kilometer-long Great Wall is considered the largest construction project ever carried out, but it may soon be superseded in several countries by modern-day analogues: great seawalls. Assuming a long-run increase in rates of global average sea level rise, societies will have to choose some adaptive strategies. Broadly speaking, they face two choices: fight or flight. Many governments see no alternative to building jetties, seawalls, groins, and bulkheads to hold back the sea. Yet the multibillion-dollar price tags attached to these may be higher than even some well-to-do countries can afford, especially when accounting for the long-term ecological damage such structures can cause.

Along with the intensified settlement of coastal areas worldwide over the past century has come a belief that, as coastal geologist Orrin Pilkey and his colleagues put it, "human ingenuity could tame any natural force," protecting human settlements from the forces of climate and the oceans. Consequently, people have been inclined to build closer and closer to the ocean, investing billions of dollars in homes and seaside resorts and responding to danger by confrontation (Anonymous, 1985).

Nowhere in the world is the battle against the sea more actively engaged than in the Netherlands. Hundreds of kilometers of carefully maintained dikes and natural dunes keep the part of the country that is now well below sea level -- more than half the total -- from being flooded. As Dutch engineers know, the ocean doesn't relinquish land easily. In early 1953, a storm surge that hit the delta region caused an unprecedented disaster. More than 160 kilometers of dikes were breached, leading to the inundation of 1,000 square kilometers of land and more than 1,800 deaths. In response, the government put together the Delta Plan, a massive public works project that took two decades and the equivalent of 6 percent of the country's gross national product each year until finally completed in 1986 (Goemans and Vellinga, 1987; UNEP, 1988).

The Dutch continue to spend heavily to keep their extensive system of dikes and pumps in shape, and are now protected against storms up to those with a probability of occurring once in 10,000 years. But the prospect of accelerated sea level rise implies that maintaining this level of safety may require additional investments of up to U.S. $10 billion by 2040 (Goemans and Vellinga, 1987; UNEP, 1988).

Although these expenditures are large, they are trivial compared with what the United States, with more than 30,000 kilometers (19,000 miles) of coastline, would have to spend to protect Cape Cod, Long Island, North Carolina's Outer Banks, most of Florida, the Bayous of Louisiana, the Texas gulf coast, the San Francisco Bay area, and the Maryland, Massachusetts, and New Jersey shores (The Times Atlas of the World, 1985).

Preliminary EPA estimates of the total bill for holding the sea back from U.S. shores -- including costs to build bulkheads and levees, raise barrier islands, and pump sand, but not including the money needed for replacing or repairing infrastructure such as roads, sewers, water mains, and buried cables -- range from U.S. $32 to U.S. $309 billion for a one-half to two-meter rise in sea level. (A one-meter rise would cost U.S. $73 to U.S. $111 billion.) Extending the projections to impoverished coastal areas of Africa, Asia, and South America underscores the futility of such an approach under a scenario of rapidly rising seas (Titus, 1989).

Nevertheless, in most industrial countries at least, property owners in coastal areas have become a powerful interest group supportive of defenses that will save their land, even if only for the short term. Many countries have made vast investments reclaiming land from the sea for use by large coastal populations: witness the efforts in Singapore, Hong Kong, and Tokyo. In most cases, governments have encouraged and continued to support this constituency.

Problem Identification

Heavy investments in roads, sewers, and other public services and insurance against disasters have largely been subsidized by taxpayers living far from any coast.

Political pressures to maintain these lands through dikes, dams, and the like will be high. "The manner in which societies respond to the impact of rising sea levels," observes G.P. Hekstra, "will be determined by a mix of conditions [including] the vested interests that are threatened, the availability of finance ... employment opportunities, political responsibilities and national prestige." Eric Bird of Australia argues, for example, that state capitals and other seaside towns there and resorts in Africa and Asia will probably be maintained by beach nourishment programs -- literally "feeding" the beach with sand transported from elsewhere -- no matter the cost (Hekstra, 1989; Bird, 1986).

Political support for subsidizing coastal areas may be undercut by competing fiscal demands over the long run. In the United States, where a burgeoning budget deficit has vastly reduced expenditures on repairs and construction of bridges and roads, for example, the Federal Highway Administration estimates that bringing the nation's highway system up to "minimum engineering standards" would cost a mind-boggling U.S. $565 to U.S. $655 billion over the next 20 years. Today, that agency's budget is a meager U.S. $13 billion, and fiscal paralysis keeps it from growing any larger. With increasing competition for scarce tax dollars, property owners in the year 2050 may find the general public reluctant to foot the bill for seawalls (Yoo, 1989).

Moreover, what may seem like protection often turns out to be only a temporary palliative. While concrete structures may divert the ocean's energies from one beach, they usually displace it onto another. And by changing the dynamics of coastal currents and sediment flow, these hard structures interrupt the natural processes that allow wetlands and beaches to reestablish upland, causing them to deteriorate and in many cases disappear (Pilkey and Wright, 1989; Dean, 1988).

Beach nourishment is a relatively benign defensive strategy that can work in some cases. Comparing the costs and benefits illustrates that it is not usually as prohibitively expensive as other approaches. Sand or beach nourishment, for example, can cost U.S. $1 million per mile (U.S. $500,000 per kilometer), but these costs are often justified by economic and recreational use of the areas. A recent study of Ocean City, Maryland, found it would cost about 25¢ per visitor to rebuild beaches to cope with a 30-centimeter rise, less than 1 percent of the average cost of a trip to the beach. A more rapid rate of sea level rise would, of course, raise the ante. The fact remains that most beach replenishment is temporary at best, indicating the need for continuous investment (Pilkey and Wright, 1989; Dean, 1988).

Advocates of coastal environmental protection strategies argue convincingly that coastal development should be limited. Most assert, for example, that future disasters may be prevented or the harm done by them lessened if highly vulnerable areas were protected. In recent years, the tide of public opinion in several states regarding conserving wetlands has tended to support the view that some property should be allowed to return to its natural state, although attitudes may changes as today's property owners face becoming tomorrow's proprietors of marshes and bogs.

The legal definitions of private property and of who is responsible for compensation in the event of natural disasters are already coming into question. As sea level rise accelerates, pushing up the costs of adaptation, these issues will most likely become part of an increasingly acrimonious debate over property rights and individual interests versus those of society at large.

Enforcement of the coastal protection law in South Carolina in the aftermath of the recent Hurricane Hugo is a good example of the types of conflicts that can arise. On September 21, 1989, Hurricane Hugo came ashore at Charleston one day after it ravaged several islands in the Caribbean. The storm, creating an ocean surge that reached 20 feet at its highest point, killed 29 people on the mainland and caused an estimated U.S. $4 billion worth of damage in the United States. It also sparked a controversy over South Carolina's new beachfront protection law. The statute completely prohibits any new seawalls from being built and regulates commercial and residential construction in a setback area along the coast. Because the storm ate up so much of the existing beach, 159 plots of land, on which houses were destroyed, all became part of the "dead zone" where new buildings are prohibited. Several homeowners have filed suit against the state for "taking property without just compensation." The States of Maine, Maryland, North Carolina, and Texas also have enacted coastal protection laws (see Klarin and Hershman, this volume; Smith, 1989; Griffiths, 1989; Titus, 1989).

Site-specific studies of several towns in the United States suggest that incorporating projections of sea level rise into land-use planning can save money in the long run. Projections of costs in Charleston, South Carolina, show that a strategy that fails to anticipate and plan for the greenhouse world can be expensive. Depending on the zoning and development policies followed, including the amount of land lost and the costs of protective structures built, the costs of a three-meter sea level rise would exceed U.S. $1.9 billion by 2075 -- an amount equal to 26 percent of total current economic activity in this area. If land-use policies and building codes are modified to anticipate rising sea levels, this figure could be reduced by more than 60 percent. Similar studies of Galveston, Texas, show that economic impacts could be lowered from U.S. $965 to U.S. $550 million through advanced planning (Titus, 1987a).

Obviously, heavily developed areas, such as the island of Manhattan, much of which is less than two meters above high tide, will not be left to be swallowed by the sea. An accounting method is needed to establish priorities and assess the costs and benefits of protection strategies versus the costs of inundation. Several analysts are attempting to develop such a model. Gary Yohe, an economist at Wesleyan University in Connecticut, is developing a method of comparing the costs of not holding back the sea with those of protecting coasts on a year-to-year basis. His economic model is a first step toward "measuring the current value of real sources of ... wealth that might be threatened ... if a decision to forego any protection from rising seas were made." In his preliminary analysis, using Long Beach Island, New Jersey, as a case study, Yohe focuses on estimating the market price of threatened structures, the worth of threatened property, and the social value of threatened coastline.

A truly representative model should account for all the costs and benefits -- economic, ecological, and social -- of protection against other options. One cost not explored in Yohe's assessment is the loss in coastal ecological wealth as a side effect of protection. In keeping with the figures for the United States as a whole, for example, researchers have estimated that a 1.5-meter rise would eliminate about 80 percent of Charleston's wetlands with current barriers in place. If additional developed areas are protected by bulkheads and levees, a 90 percent loss is envisioned. The South Carolina beachfront protection law seeks to prevent this large-scale destruction, but its political viability is still in question (Titus, 1987a).

Protecting wetlands requires a trade-off as well. Taking shore and wetland conservation measures basically implies a willingness to relinquish to the sea some land area now in use or potentially available for social activities, such as farming and home building. A study of coastal land loss in Massachusetts by Graham Giese and David Aubrey of Woods Hole Oceanographic Institution illustrates these processes and estimates the amount of land likely to be lost in Massachusetts under three scenarios (Giese and Aubrey, 1987, 1989).

Giese and Aubrey distinguish between upland (relatively dry terrain that is landward of wetland and not altered much by waves and tides), and wetland itself, including coastal bluffs, dunes, beaches, and marshes that are affected by these forces. Wetlands replace uplands as they migrate landward, resulting in loss of total upland area. Where wetlands are protected by law (as they are in Massachusetts) against being drained or filled, they gain at the expense of uplands, essentially protecting the ecological over the purely economic value of the land (Geise and Aubrey, 1987, 1989).

Relative sea level in Massachusetts has been rising some three millimeters annually since 1950. Under the first scenario in Giese and Aubrey's study, which assumes a continuation of current trends from 1980 through 2025, the sea along Massachusetts' coasts would rise 36 centimeters. The state would therefore lose 0.23 square kilometers a year, or nearly 12 square kilometers over that period. The second scenario assumes a higher global average rise by 2025 (EPA's low to mid-range estimate), which when combined with subsidence leads to a total land loss in Massachusetts of some 30 square kilometers by 2025. Finally, the third case, assuming a rise of 48 centimeters, costs Massachusetts nearly 42 square kilometers of upland, or commercially usable, area (Geise and Aubrey, 1987, 1989).

Whatever the strategy, industrial countries are in a far better financial position to react than are developing nations. Bangladesh, for example, cannot afford to match the Dutch kilometer for kilometer in seawalls. But its danger is no less real. Debates over land loss may be a moot point in poorer countries like Bangladesh, where evacuation and abandonment of coastal land may be the only option when submergence and erosion take their toll and when soil and water salinity increase. As millions of people displaced by rising seas move inland, competition with those already living there for scarce food, water, and land may spur regional clashes. Ongoing land tenure and equity disputes within countries will worsen. Existing international tensions, such as those between Bangladesh and its large neighbor to the west, India, are likely to heighten as the trickle of environmental refugees from the nation that is awash becomes a torrent.

PLANNING AHEAD

The threats posed by rapidly increasing sea level raise questions that governments and individuals must grapple with today. If the world moves quickly onto a sustainable path, the effects of global warming and sea level rise can be mitigated. Minimizing the impacts of climate change will require that a number of strategies be put in place right away. An unprecedented level of international cooperation on agricultural, energy, forestry, and land-use policies will be required. Most important, perhaps, is to develop a method for comparing the costs of measures to avert global warming and its consequences against the costs of adaptation. But for now, preparing to experience some degree of global and regional changes in sea level is a rational response.

How can the world move away from the seemingly universal human tendency to react in the face of disaster but to ignore cumulative, long-term developments? An active public debate on coastal development policies is needed, extending from the obvious issues of the here and now -- beach erosion, river damming and diversion, subsidence, wetland loss -- to the uncertainties of how changes in sea level in a greenhouse world will make matters far worse. Raising public awareness on the forthcoming changes, developing assessments that account for all future and present costs, and devising sustainable strategies based on those costs are all essential.

Taking action now to safeguard coastal areas will have immediate benefits while preventing losses from soaring higher in the event of an accelerated sea level rise. Limiting coastal development is a first step, although strategies to accomplish this will differ in every country. Governments may begin by ensuring that private property owners bear more the costs of settling in coastal areas. A more systematic assessment is needed of the value of creating dead zones to be left in their natural state versus the economic and ecological costs that ongoing development and the subsequent need for large-scale protection will entail.

A new concept of property rights will have to be developed. Unbridled development of rivers and settlement of vulnerable coasts and low-lying deltas mean that more and more people and property will be exposed to land loss and potential disasters arising from storm surges and the like. Governments that plan over the long term to limit development of endangered coasts and deltas can save not only money, but resources as well. Wherever wetlands and beaches are not bordered by permanent structures, they will be able to migrate and reestablish farther upland, allowing society to reap the intangible ecological benefits of biodiversity.

Of course, protection strategies will inevitably be carried out where the value of capital investments outweighs other considerations. But again the key is to plan ahead. As the Dutch discovered, more money can be saved over the long term if dikes and drainage systems are planned for before rather than after sea levels have risen considerably.

A reassessment of dam-building and river diversion projects in large deltas could lead to a lessening of the ongoing destruction of wetland areas and prevent further reductions in sedimentation, thereby minimizing subsidence as well. It is unlikely that the damage done by large-scale dams, like the Aswan, can be remedied. As with past projects, however, analyses of many dams now in the pipeline do not reflect the often massive present and future environmental or external costs. Better water management and increased irrigation efficiencies can both increase crop yields and save water. Exploring the potential gains from conservation may preclude the need for many more large-scale dams. The same can be said of curtailing development of additional dams for hydropower by encouraging energy efficiency and conservation.

Additional money is needed to do more research on sea level globally and regionally. Funds are needed to support studies of beach and wetland dynamics, as well as investigations of likely regional impacts; to take more frequent and widespread measurements of global and regional sea level; and to design cost-effective, environmentally benign methods of coping with coastal inundation.

The majority of developing nations most vulnerable to sea level rise can do little about global warming independently. But they have a clear stake in reducing pressures on coastal areas by taking immediate actions. Among the most important of these is slowing population growth and, where necessary, changing inequitable patterns of land tenure in interior regions that promote coastal settlement of endangered areas. Furthermore, the governments of Bangladesh, China, Egypt, India, and Indonesia, to name just a few, are currently promoting river development projects that will harm delta ecosystems in the short term and hasten the date they are lost permanently to rising seas.

The issue of how to share the costs of adaptation equitably may well be among the hardest to resolve. Industrial countries are responsible for by far the largest share of the greenhouse gases emitted into the atmosphere. And no matter what strategies poorer nations adopt to deal with sea level rise, they will need financial assistance to carry them out. Problems with coastal protection, environmental refugees, changes in land and water allocation, and a hose of other issues will plague poor coastal nations. The way industrial countries come to terms with their own liability in the face of accelerated sea level rise will play a significant role in the evolution of international cooperation during the second half of the 21st century.

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ASSESSING THE IMPACTS OF CLIMATE: THE ISSUE OF WINNERS AND LOSERS IN A GLOBAL CLIMATE CHANGE CONTEXT

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INTRODUCTION

Although most reviews of the greenhouse problem begin with the 1890s works of Swedish scientist Arrhenius, the processes have been well known for more than a century. Interest in the possible impacts on climate of CO_2 emissions have waxed and waned since that time with interest reaching temporary peaks appearing in the mid-1930s (Callendar, 1938), the mid-1950s (Revelle and Suess, 1957), and again in the late 1970s (e.g., Kellog, 1977).

Today, we are inundated by assessments of the prospects of a global warming and its possible impacts on society and the environment. Discussions of such a prospect have steadily increased during the past fifteen years, reaching amazing levels in the past year or so. In the United States, about three dozen bills related to the global warming issue were submitted during the last congressional session.

The century-long interest in this issue has been interrupted partly by other more pressing and urgent historical events such as two World Wars, a worldwide depression, decolonization, the Cold War, and a temporary global cooling; and partly by the fact that the impacts of a temporary CO_2-induced global warming were originally believed to be beneficial to society. For example, Callendar (1938) suggested that a greenhouse warming would help to thwart the emergence of an apparently imminent ice age. Scientific evidence suggested that the Earth was coming to the end of an interglacial period and that at any decade, the ice age process could begin.

From about 1940 to the late 1960s, the Earth underwent an unexplained cooling. Discussions in the scientific community about the possibility of a global cooling were widespread. Scientists provided anecdotal (but nonetheless

[1]The National Center for Atmospheric Research is sponsored by the National Science Foundation.

convincing both to the lay public and segments of the scientific community) evidence to support the belief that the Earth was possibly on the threshold of an ice age: the growing season in England had been shortened by two weeks, fish species formerly caught off the northern coast of Iceland began appearing only off its southern coast; sea ice in the North Atlantic had increased in extent in the early 1970s and was appearing in normally ice-free shipping lanes; and hay production in Iceland had declined by 25% as a result of less hospitable weather. In the United States, the fact that the armadillo, which had migrated as far north as Kansas in warmer decades, was starting to retreat toward the south was also used as evidence to support the ice age hypothesis. Geologic records were invoked as well to show that an ice age was near.

During the brief period of concern regarding a global cooling, one issue widely considered was how it might affect the relative economic and political positions of different countries. Even the U.S. Central Intelligence Agency undertook studies to show how the cooling might affect the U.S.S.R.'s agriculture (CIA, 1976). *The Ecologist* examined the potential impacts of a few degrees of cooling on agriculture in the Canadian Prairies (Goldsmith, 1977).

Some books and articles on the topic went so far as to identify specific countries that would become climate-related world powers in the event of a cooling. For example, Ponte (1976) suggested that "adapting to a cooler climate in the north latitudes, and to a drier climate nearer the equator, will require vast resources and almost unlimited energy.... A few countries, such as equatorial Brazil, Zaire, and Indonesia, could emerge as climate-created superpowers." He also suggested that "We can say with high probability today that the global monsoon rainfall will be below average for the remainder of the century."

Another book on the possibility of a global cooling (The Impact Team, 1977) suggested that with a cooling "...there would be broad belts of excess and deficit rainfall in the middle latitudes; more frequent failure of the monsoons that dominate the Indian subcontinent, south China and western Africa; shorter growing seasons for Canada, northern Russia, and north China. Europe could expect to be cooler and wetter. Of the main grain-growing regions, only the United States and Argentina would escape adverse effects." There was no reluctance whatsoever to discuss who might win and who might lose or to identify specific countries or specific economic sectors within a country as winners and as losers.

A striking difference between the scientific and political responses in the 1970s (to a potential cooling) and those of today (to a warming) is that today there is a strong opposition within scientific as well as policymaking circles to recognize the existence of, let alone identify, specific winners and losers, especially winners. U.S. Senator Albert Gore, for example, argues that there will be no winners in the event of a global warming, a view that apparently is also held by the U.S. EPA. Soviet scientist Mikhail Budyko, in contrast, asserts that everyone will benefit from a global warming. Perhaps the comments that U.S. Senator Tsongas made about diametrically opposing views on the energy crisis of the 1970s and 1980s apply to Gore and Budyko: "Both of these approaches are equally absurd, equally rhetorical, and equally successful. When talking to the convinced, they are very powerful. And that is basically how most people address the issue: we are awash in rhetoric, not to mention hypocrisy, when what we need is a careful sorting and weighing of the facts and values involved in making -- or not making -- a decision."

Many people believe discussing winners and losers will be divisive and undermine efforts to put together a global coalition to combat global warming. Opposition to the open recognition of winners and losers was recently highlighted when Barber Conable, President of the World Bank, suggested in a speech that there might be winners with a warmer atmosphere. Environmental groups, which have been marching lock-step on this particular issue, opposed his public comments. As a result of his speech, some U.S. Congressmen even suggested the need for a closer scrutiny of the World Bank's activities and budget. For example, The Washington Post (12 September 1989) reported, "In a letter to Conable, Senator Kasten wrote, 'The bank's failure to be on the front lines of efforts to fight global warming threatens the bank's long-term financial support from Congress.'"

A similar argument was raised with respect to preventive versus adaptive strategies. When the U.S. EPA released two reports in 1983 suggesting that global warming was inevitable (Seidel and Keyes, 1983) and, as a result, people should plan for rising sea level (Hoffman et al., 1983), the Friends of the Earth publication "Not Man Apart" denounced the Agency for "throwing in the towel," while at the same time, the President's science advisor denounced the reports as "alarmist." There was a feeling that "premature" discussions about adaptive strategies with respect to global warming would break down the development of a united effort to support the enactment of preventive strategies. Proponents of preventive strategies wanted attention to focus on prevention as the best way to cope with global warming.

There is, however, one projected impact of global warming for which one is allowed to identify specific winners and losers -- sea level rise. This is probably because it is the one impact of a global warming for which there may be no obvious winners at the national level. No one is reluctant to identify specific losers associated with sea level rise (papers have identified winners at the subnational level, such as coastal engineering firms and people who would have beachfront property as a result of a neighbor's misfortune). In this regard, one could argue that the sea level rise problem is similar to the stratospheric ozone depletion problem -- no readily apparent national winners can be identified. Such would probably not be the case for changes in rainfall distribution, water resources availability, agricultural production, fisheries productivity, and energy production and consumption.

In this paper, it is my intention to consider problems associated with the process of labeling winners and losers. What factors, for example, must be taken into account in labeling a region, an activity, or a country a winner or a loser? How do perceptions compare with reality? Can wins and losses be objectively identified? What are the costs and benefits of not addressing this issue as opposed to addressing it openly?

Problem Identification

My intention is not to label specific countries as winners or losers. To do that, one could simply use any of the GCM-generated scenarios, the scenarios generated by paleoecological reconstructions, or assessments of recent environmental changes and label specific countries and regions within countries accordingly.

I realize that there is a risk associated with such an identification. If winners and losers are identified with some degree of reliability, the potential for unified action against the global warming will be reduced. Winners will not necessarily want to relinquish any portion of their benefits to losers in order to mitigate the impacts of their losses. On the other hand, there is also a risk in not making such a distinction between winners and losers. While scientists and policymakers formally discuss only losses associated with a global warming, others may perceive that there will be positive benefits as well. The result is that the proponents for action on global warming could be likened to the fable about the emperor's new clothes, professing there are not winners, while everyone agrees with them in public but privately believes the opposite. This could sharply reduce the credibility of the proponents.

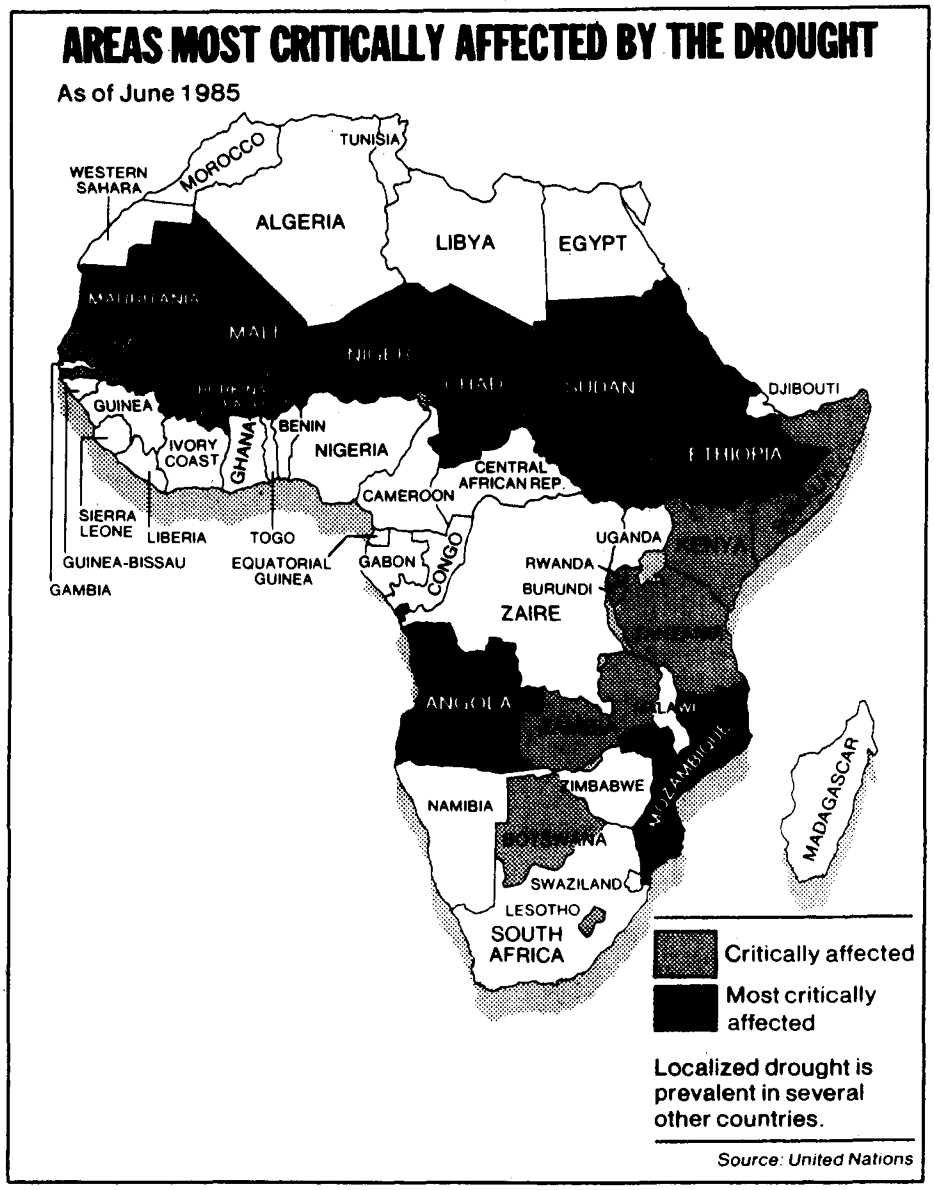
SCENARIOS OF WINNERS AND LOSERS

In the following section, the notion of winners and losers is discussed in terms of climatic conditions. These conditions include today's global climate regime, an altered climate regime, and varying rates of change.

Winners and Losers With Today's Global Climate Regime

It seems obvious that, say fifty years hence, there will be some societies that benefit from whatever climate exists at that time. After all, with today's climate, we can identify climate-related winners and losers. The following map (Figure 1) shows drought-prone regions in sub-Saharan Africa, some of which could be considered climate-related losers. Such maps, depicting drought-prone (and flood-prone) areas, exist for other regions around the globe.

One could argue, however, that there has been little sustained (or effective) effort to date by climate-related winners to assist those who might be considered climate-related losers. Such a statement, of course, calls into question how foreign aid from the international donor community has been distributed. We have seen, for example, that in the past several decades foreign assistance has been frequently tied to political considerations (e.g., aid to Cambodia and South Vietnam in the 1960s and 1970s, or to Ethiopia in the 1980s). Examples that justify such low expectations about adequate, apolitical assistance from the industrialized countries are not difficult to find. In the early 1970s when there were widespread droughts throughout the world (except in the United States), then-Secretary of Agriculture Earl Butz spoke about how food exports from the United States would be a new tool in the nation's foreign policy negotiating kit. Despite statements to the contrary, few leaders in countries chronically affected by the adverse impacts of today's climate believe that they can rely on assistance from those favored by today's global climate.



New York Times, 8/20/85

Figure 1. Areas most critically affected by the drought.

The Colorado River Compact of 1922 provides an example of a recent "climate change" in which winners and losers have been identified. The Colorado River Basin was divided into two parts, the Upper and Lower Basins. The flow in the system was estimated at about 15 million acre-feet (maf) based on the record for the previous 20-year period. The representatives of the various states in the basin agreed to divide in absolute terms 15 maf average annual flow equally between the two basins: 7.5 maf for each basin (75 maf over a 10-year period). However, because the Upper Basin states thought that there was, in fact, more water in the system than 15 maf, they agreed to provide the lower basin states with 7.5 maf, thinking that they would benefit from any surplus that might exist (for further details, see Brown, 1988).

Shortly after the agreement was signed, however, the Colorado River entered a period of low streamflow, setting record lows in the 1930s (the Dust Bowl decade). (Today, the average annual streamflow is estimated at about 13.5 maf.) The loss of streamflow has to be absorbed by the Upper Basin. Thus, in this situation, one can identify winners and losers as a result from what might be considered a climate change that has, to date, lasted about six decades.

Carrying this analysis further, one might ask what those who benefited from the Compact have done to compensate those who have not? What lessons for climate change responses by society might be drawn from this situation? Should future water compacts be based on proportional divisions of a variable resource instead of absolute amounts? What does this case study suggest about when to reach agreement on a variable resource -- before winners and losers are identified or after?

Finally, an important related question that merits attention, but has yet to be addressed among discussions about possible strategic responses to global warming, is the following: Who loses and who wins if no action is taken and the climate remains as it is today? If it could be ascertained that no global warming were to occur, what actions would today's climate-related winners take to alleviate the climate-related problems of today's climate-related losers?

Winners and Losers With an Altered Global Climate Regime

While we do not even know the global let alone regional specifics of the havoc (or windfall) that a climate change will bring, we can assume that there will be winners and losers (however defined) with a global climate warming.

Some researchers and policymakers who are primarily concerned about the regional impacts believe that, compared to the present climate of their region, it is possible that their climate could improve rather than worsen with a global warming. Saudi Arabia is one such example; Ethiopia may be another. Given their current climate, they might consider the risk of change worthwhile. Bandyopadhyaya (1983), an Indian social scientist, as well as Budyko (1988) of the U.S.S.R., have made this argument at length in favor of a climate warming.

Often, when people talk about the possibility of increased rainfall in a given region, a counterargument is raised that ambient temperatures (and, therefore, evaporation rates) will also increase. This would negate any benefits that might come from additional rainfall. Yet, history shows that societies have devised ways to capture rainfall and reduce evaporation, thereby improving the percentage of rainfall that they can effectively use.

Can we find examples of environmental conditions that different societies might have to cope with in the advent of a global warming? Are there existing climate change analogues for most places in the world? In the United States, it has been suggested that Iowa will become hotter and drier. Might Nebraska or Kansas provide a glimpse at Iowa's possible future environmental setting and, therefore, a glimpse of Iowa's future? Attempts to identify climate analogues are not new. The following maps of the U.S.S.R. (CIA, 1974) (Figure 2) and China (Nuttonson, 1947) (Figure 3) depict agro-climate analogues from North America. Similar analogue maps could be created that pertain to climate warming once we have an improved regional picture of the impacts of a global warming.

Winners and Losers and Rates of Change

As we have seen with other environmental changes, it is often not the change itself but the rapid rates of change that are so disruptive of human activities (including the ability to adjust). If changes are slow enough (whatever that means), their impacts may be less disruptive in the short and medium terms than if the rates of change are much faster.

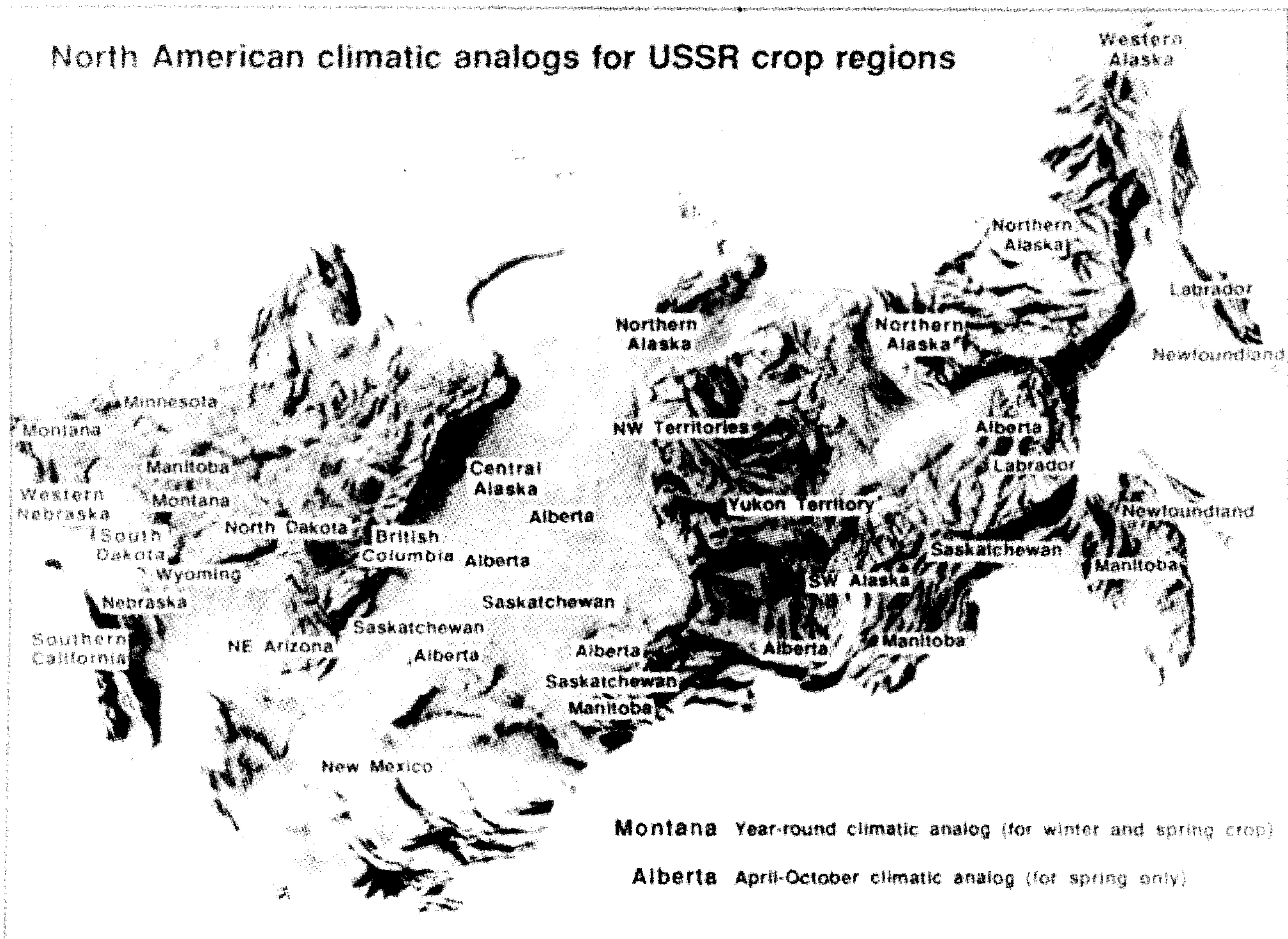


Figure 2. North American climatic analogues for U.S.S.R. crop regions.

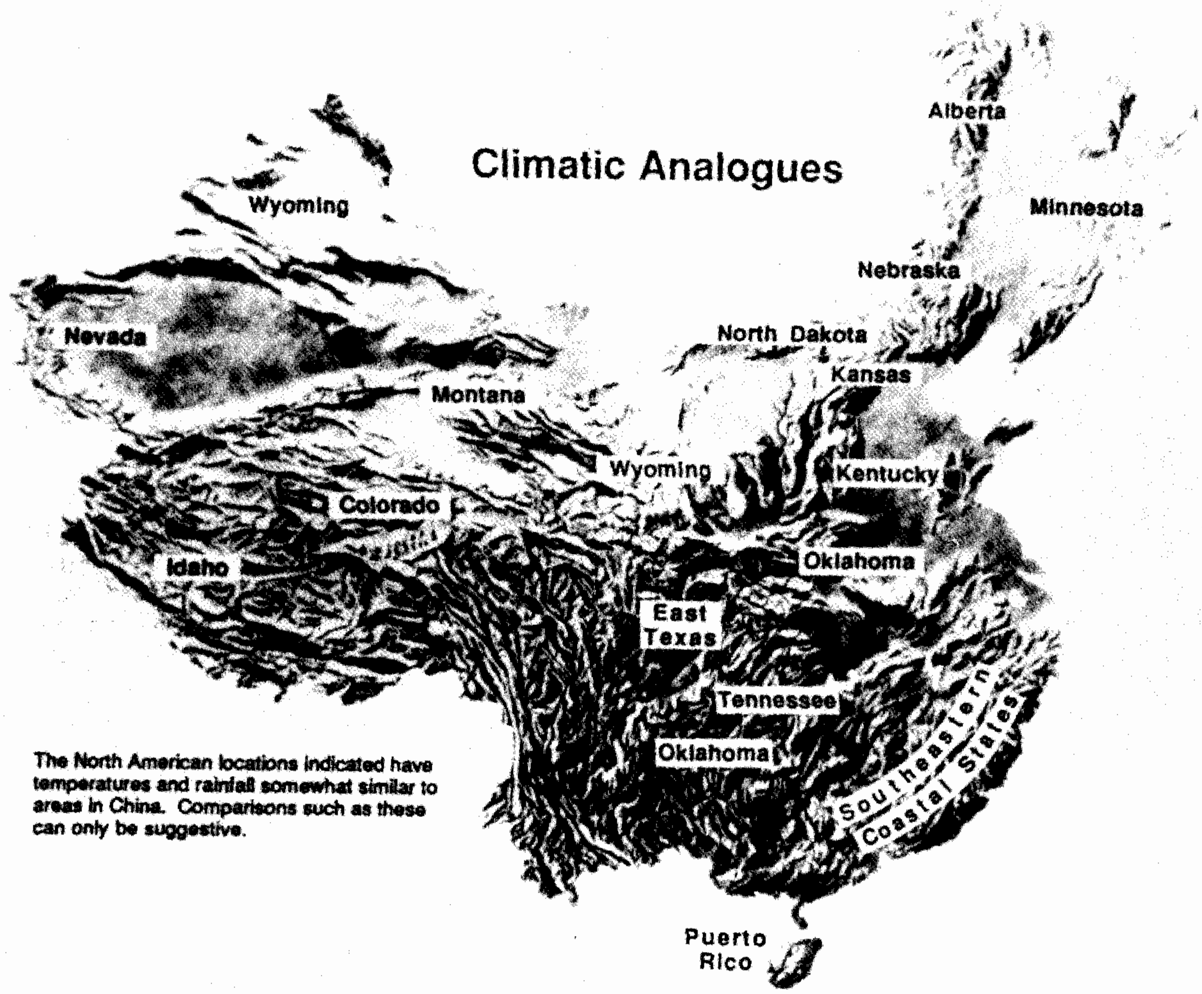


Figure 3. Climatic analogues: comparing China to North America.

One of society's problems in confronting the climate change issue is the absence of a realistic disaster scenario or "dread factor." While attempts have been made in the recent past to identify such scenarios, they have been generally dismissed under closer scrutiny. For example, the possibility of the disintegration of the West Antarctic ice sheet (which would cause sea levels to rise 8 meters) was raised at the end of the 1970s. Upon closer scrutiny of the geophysical mechanisms involved, the probabilities associated with this happening in the next century were sharply reduced. The use of the notion of a doubling of CO_2 from pre-industrial levels was another such attempt. But, as some observers have noted, there was nothing cataclysmic about a doubling itself.

Major environmental and societal impacts could occur before as likely as after the doubling. Interestingly, the time associated with the doubling has been moved closer to the present by different researchers; beginning at first with 2050-2075, to 2020, and even to 2010.

Yet another attempt to identify a dread factor was the article and news release about how the global climate regime might shift abruptly in a steplike manner as opposed to gradually (Broecker, 1988). Steplike changes in global climate would give societies little time to cope with and adjust to the relatively abrupt environmental change that might ensue.

The most recent dread factor appeared in the testimony to Congress of scientist James Hansen during the summer of 1988, in which he stated that the four hottest years on record in North America occurred in the 1980s (U.S. Congress, 1988). He contended that this was proof that the greenhouse effect was in progress and that the especially severe drought of the summer of 1988 was linked to the global warming.[2] Other scientists (e.g., Trenberth et al., 1988), have since shown that the severe drought of 1988 was most likely related to other geophysical aspects and not necessarily to the global warming phenomenon.

Search for a dread factor in order to catalyze action is, in itself, a risky business. Each time a new dread factor has been suggested, evaluated, and challenged, it has failed to stand up under scientific scrutiny, thereby diminishing the reliability and credibility of the global warming proponents. Finally, several of the disaster scenarios cited above relate to rates of climate change. Rates of change can have very significant impacts on society (and therefore are especially important to political decisionmakers). They must be examined and projected with objectivity and care.

RELATED QUESTIONS

Before attempting to identify specific winners and losers that might result from a global warming, there are several "prior" questions that must be addressed. In this section, some of these questions are posed and only briefly discussed to stimulate more critical examination. The following is meant to be suggestive of the kinds of concerns that must be raised when assessing the societal impacts of a global warming. These, among other "prior" questions, will be discussed at an international workshop on assessing winners and losers in a global warming context, tentatively scheduled for late spring 1990 in Malta.

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[2] Editor's note: On the other hand, the Science Times section of the New York Times on January 3 reported that Hansen agreed with Tremberth's analysis and implied that Hansen does not believe the greenhouse effect to be a factor in heat waves and droughts. In a letter to the Times on January 11, 1989, Hansen responded that "as I testified to the Senate during the 1988 heat wave, the greenhouse effect cannot be blamed for a specific drought, but it alters probabilities...climate models indicate that the greenhouse effect is now becoming large enough to compete with natural climate variability."

Problem Identification

What Do We Mean by a Win or a Loss?

It is not sufficient, meaningful, or realistic to equate more rainfall than normal with a win and less rainfall than normal with a loss. In reality, the actual annual amount of rainfall in a given location does not by itself tell much about agricultural production. There are numerous articles about definitions of drought (e.g., Wilhite and Glantz, 1985). Researchers have identified differences between meteorological, agricultural, and hydrologic droughts. If the expected annual amount falls (no meteorological drought) but is distributed throughout the growing season at the wrong time with respect to crop growth and development, a sharp decline in agricultural production (an agricultural drought) could occur.

Defining a win or a loss according to changes in evaporation rates also may not be very useful. If evaporation rates increase, and all else remains the same, then there will be a depletion of water resources. However, as noted earlier, people in many arid and semiarid areas have devised ways to minimize the impacts of high evaporation rates by the way they collect, store, and use their available, often scanty, water resources. Thus, the dependence on a single physical parameter to identify the costs or benefits to a society of a climate change has severe limitations.

How Does One Measure a Win or a Loss?

One might suspect that Canada will be a winner because as temperatures increase and the growing season lengthens, agricultural productivity will improve. But, what will be the impacts on Canadian fisheries, the timing of seasonal snowmelt, or the Canadian ski industry?

Another example of the difficulty associated with measuring wins and losses is provided by historic attempts to augment precipitation in a semiarid part of central Colorado (U.S.A). Cloud seeders were hired to suppress hail, augment rainfall during the growing season, and reduce rainfall during harvest, in order to improve the productivity of hops for beer production. Another group of farmers growing other crops (e.g., lettuce) and ranchers with different moisture requirements in the same valley opposed these cloud seeding activities. The conflict between the two factions became violent and the operation was eventually halted. Thus, even within small areas there can be different responses to changes in rainfall, making an objective determination of a win or a loss exceedingly difficult.

Finally, if one group loses, but loses less than others, should they be considered as absolute loser or relative winner?

Can Wins and Losses Be Aggregated?

While wins and losses can be added together to produce a net figure, one must question the value of that figure. The wins (or losses) are not shared commodities. Those who lose may not benefit in any way from those who win. For example, when the Peruvian anchoveta fishery collapsed, those fishermen who had focused their activities (fishing gear, fishmeal processing factories, etc.) on exploiting anchoveta were not prepared to take advantage of exploiting the sharp increase in shrimp populations that appeared along the Peruvian and Ecuadorian coasts. A country can expect to have both winners and losers within its borders in the event of a climate change. While the winners may be in a position to take care of themselves, **someone** will have to help the losers. Wins and losses cannot be aggregated. A win is a **win** and a loss is a **loss**.

What Is the Relationship Between Perceptions of Wins and Losses and Actual Wins and Losses?

Given the uncertainties surrounding the regional impacts of a global warming, actual winners and losers within and between countries cannot be identified with any degree of confidence. Perhaps, we will learn that in reality everyone will lose with a global warming of the atmosphere. However, as long as some regions or countries **perceive** themselves to be winners, they will act according to this perception. Thus, the issue of winners and losers must be addressed openly, objectively, and scientifically, if we wish to minimize the chance that actions taken in response to a global warming will be based on misperceptions.

How Should One Deal With the Issue of Intergenerational Equity?

Identifying winners and losers spatially, as well as temporally, must become a concern of those dealing with the global warming issue. Arguments about intergenerational equity have been invoked to generate support for taking action now against global warming. We are asked to take actions today to protect future generations from the environmental insults wrought by the present generation. But how can **inter**generational equity generate widespread support for consequences a few generations in the future when we cannot even achieve **intra**generational equity today.

It appears that we have come to believe that any change in the status quo is, by definition, a bad change. But the real answer to this question will depend on who is asked to respond. A Saudi Arabian might believe that any change in the current climate regime will most likely be better for future generations of Saudi Arabians than the existing one. The opposite belief might be held by a farmer in the U.S. Great Plains.

CONCLUSION

Every discipline has dealt with the concept of winners and losers -- biology, political science, sociology, economics, geography, law, ecology, conflict resolution, risk assessment, game theory, and so on. Climate-related impact as a result of global warming is only the latest topic that requires consideration of winners and losers.

There have been conflicting views on whether to identify specific countries as winners or losers in the event of a global warming of the atmosphere. There has also been a reluctance to discuss the possibility that there may be any winners at all. It is time to get beyond that conflict and to ask questions that need to be addressed so that the notion of winners and losers can be assessed on a more objective and realistic level.

There is a calculated risk in such a discussion. Once specific winners have been reliably identified, there may be reluctance on their part to lend support for global action to combat a greenhouse warming. We must take this risk. Many issues must be resolved before we will be in a position to identify with any degree of confidence who those specific winners will be. In the meantime, other issues, such as equity, definition, measurement, and perception vs. reality, must be addressed if we ever hope to identify with some degree of confidence how specific countries, economic sectors, and regions within countries will be affected by climate change in the 21st century.

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OPTIONS FOR ADAPTING TO CHANGING CLIMATE

OPTIONS FOR RESPONDING TO A RISING SEA LEVEL AND OTHER COASTAL IMPACTS OF GLOBAL WARMING

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This chapter focuses on strategies for responding to (1) inundation, erosion and flooding, and (2) saltwater intrusion. As the previous chapters show, these are not the only problems from sea level rise, but they appear to be the most important. Moreover, strategies that successfully addressed these problems would generally take care of the other problems as well.

INUNDATION, EROSION, AND FLOODING

The two fundamental responses to sea level rise are (1) holding back the sea and (2) allowing the shore to retreat. Throughout history, both of these approaches have been applied. For two thousand years the Chinese, and for five hundred years the Dutch have protected low-lying areas with dikes. In other areas of the world, countless coastal towns have been abandoned or moved as the coast eroded; the town of Dunwich (UK) has been steadily moving inland since the time of William the Conqueror, and has rebuilt its church seven times in the last seven centuries.

Holding Back the Sea

Strategies for holding back the sea fall broadly into two categories: dikes and other protective walls and raising the land surface.

Dikes and Other Protective Walls

The coastal engineering profession has developed a wide variety of structures to restrain the sea. To a large degree, the appropriate structure depends on whether inundation, erosion, or flooding is the more serious problem. Generally, dikes are used to protect areas from permanent inundation. To prevent leakage, dikes must be several times as wide as they are long. Thus, their costs include valuable coastal land and perhaps structures that must be abandoned for the dike, as well as the direct construction costs.

Adaptive Options

In most cases, dikes have been built along (or parallel to but inland of) the existing shoreline. However, the Dutch have often found it more economic to build a dike across the narrow part of a bay than around the entire shoreline; because in the former case the dike is much shorter. Doing so can impede shipping, and it converts the upstream part of the estuary to a freshwater lake, which may have undesirable environmental impacts; on the other hand, it can help solve water supply problems, as we discuss below.

In addition to the wall, a means must be devised to remove water from the protected area. For hundreds of years, the Dutch relied on wind-driven pumps; electric and diesel pumps are more common today. For areas that are above low tide, it is possible to rely on gravity drainage by installing tidal gates that open during low tide to let out the water but close at other times to prevent water entering.

Most of the same principals apply to protecting areas threatened by flooding but having sufficient elevation to avoid permanent inundation, but the relative importance of particular factors varies. An important difference is that the problems that discourage one from closing off an estuary permanently do not necessarily make it impractical to close it off temporarily. Hence, Venice, London, Leningrad, and several Japanese cities are or will soon be protected by submersible tidal barriers that remain except during major storms.

Another important difference is that structures that would not prevent inundation may be able to stop flooding. Narrow walls would eventually leak if flooded all the time, but may be adequate for a flood that lasts a day or so.

The differences between flood- and inundation-protection strategies would be transitory. Areas that require flood protection in the near term would require inundation protection in the long run. Thus, the design of any flood protection system should consider the eventual needs as sea level rises. A concrete floodwall that is cheaper than a dike may not be a wise long-term investment if it will eventually have to be replaced with a dike. On the other hand, the designers of the Venice flood barrier have explicitly considered this issue; the barriers have been designed to eventually be retrofit with navigation locks should be necessary to keep them permanently closed.

Different structures may be necessary where waves and erosion are a problem. Breakwaters and many types of seawalls do not prevent flooding but provide important protection against by deflecting storm wave energy. For preventing erosion of areas above sea level, bulkheads and revetments are common along calm-water areas, while seawalls, breakwaters, and rubble are used on the open coast. In all of these cases, the principle is to prevent waves from attacking the shore by interposing an energy-absorbing structure.

One of the greatest advantages of protecting land with walls is that existing land uses need not be threatened, except for the areas taken up by the dikes. Because they can be erected in a couple of decades, there is not need to erect such structures today if an area will not require protection for 50 years. This does not imply, however, that decision makers should delay consideration of responses to sea level rise. The cost and adverse environmental impacts of dikes suggests that this solution will not be appropriate everywhere; because the other options require a greater lead time, delay consideration of sea level rise could foreclose these options and leave future generations only with the option of building a dike.

Raising Land Surfaces

Land surfaces can be raised by (1) artificially transporting fill material from navigation channels, offshore, or land-based sources; (2) trapping sand as it moves along the shore; or (3) restoring or artificially enhancing natural land building processes. The former practice is already commonplace along beach resorts throughout the world, and fill has been used to raise the land in areas experiencing rapid subsidence.

An even older practice is the construction of groins to trap sand moving along the shore. An important limitation of this approach is that erosion protection in one area is often at the expense of increased erosion elsewhere; hence groins are most appropriate for protecting developed areas that are adjacent to undeveloped areas where increased erosion would be acceptable.

Restoration of natural processes could be applied to barrier islands, river deltas, and possibly, coral atolls. The natural overwash process can enable barrier islands to keep pace with sea level by migrating landward. Although developed barrier islands do not migrate landward, an engineered retreat in which the bay sides are filled as the ocean side erodes would often be far less expensive than raising an island in place (Titus 1990).

River deltas in the natural state can keep pace with sea level rise, at least up to a point. However, dams and river dikes prevent sediment from reaching the Mississippi, Nile, Niger, and many other deltas (LWPP 1987; El Raey 1990; Ibe and Awosika 1990), and these deltas are currently losing land with even a slow rate of sea level rise. As a result, officials in the United States are developing numerous plans to restore deltaic processes by selectively dismantling dikes that cause the problem. As sea level rises, officials in other nations may choose to reevaluate whether the benefits of dams and dikes outweigh the cost of losing deltaic lands, although this will be difficult. Nevertheless, the prospect of sea level rise provides a strong impetus for Bangladesh (Commonwealth 1989) and other nations (Broadus et al. 1986) with deltas that still flood to avoid constructing dikes along the rivers.

Many people suspect, but no one has established, that coral atolls islands can keep pace with at least a slowly rising sea. There is little doubt that the coral grows with the sea, but the fate of the islands is not as clear. Some suggest that the islands are only created during periods of stable or falling sea level; others suggest that islands are created and destroyed with a slowly rising sea. But even if islands can not keep pace with sea level on their own, there is little doubt that protecting the surrounding reefs is important because they provide both protection from waves and a source of sand that could be artificially placed on the islands.

Adaptive Options

Raising land surfaces has many advantages over protective walls. Most importantly, the character is the land remains largely unchanged, which can be important environmentally and aesthetically. In addition, this approach can be applied incrementally, as the sea rises. Moreover, this approach can be implemented on a decentralized basis, in which property owners raise their own properties whenever they choose. Nevertheless, some planning is necessary so that buildings do not end up below ground level; however, in many areas flood regulations already require buildings to be elevated 2-3 meters above the ground. Along San Francisco Bay, local authorities require all newly reclaimed land to be elevated an additional 30-50 centimeters to account for future sea level rise.

Retreating from the Shore

Abandonment of coastal settlements has occurred throughout the ages, because people either lacked the means to hold back the sea or found it more burdensome than rebuilding farther inland. In the 20th century, a new rationale has emerged: environmental protection. Particularly in Australia and the United States, many local officials are promoting policies to prevent development from blocking the landward migration of beaches and wetlands. Because buildings often last one hundred years and infrastructure can determine development patterns for centuries, planning a retreat requires much greater lead times than policies to hold back the sea.

There are three ways to foster a retreat: (1) limit development in areas likely to be flooded; (2) allow development subject to the requirement that it will eventually be removed (presumed mobility) and (3) do nothing about the problem today and eventually require developed areas to be abandoned.

Limit Development

These efforts generally involve either the purchase of land or regulations that restrict construction. Buying coastal property and creating parks can be desireable even without sea level rise, but it would be expensive to apply it on more than a limited scale.

Regulations that restrict construction save the public money, but in many countries it would be unconstitutional to prohibit development in every area likely to be flooded by sea level rise without compensation -- and even where it would be legal it would probably not be politically feasible. Nevertheless, it might be possible to implement this approach for areas likely to be flooded in the next few decades. Several states in the U.S. and Australia (?VERIFY) already require construction to be set back from the shore a distance equal to 30-60 years of annual erosion (assuming current sea level trends), and along the Chesapeake Bay (USA), only one house per 8 hectares is permitted within 300 meters of the shore. India prohibits new construction within 500 meters of the ocean coast. Coastal scientists in Nigeria, Argentina, and the United Kingdom are advocating setbacks for their nations as well.

The chief disadvantages of this approach is that it says nothing about areas that are already developed. Moreover, it does not perform well under uncertainty. The restrictions have to be based on a particular amount of sea level rise, the uncertainty of which is exceeded only by the difference in opinion regarding how far into the future we should protect our descendants and the environment. If the sea rises less than anticipated, property is needlessly withdrawn from development; if it rises more than expected, the policy eventually fails. Moreover, even if there is an accurate projection, after the sea rises to that point the policy fails. Finally, it is not always wise to prohibit construction of a waterfront building simply because it would eventually have to be abandoned.

<u>Presumed Mobility</u>

Unlike limiting development, these policies well under uncertainty and can be applied to areas that are already developed. Although they do not alter the ability of governments to control development in response to current concerns, they limit it s role in sea level rise to laying out the "rules of the game," -- the need to eventually allow the sea to come in. Investors and real estate markets, which are accustomed to uncertainty, decide whether development should proceed given that constraint.

The most widely discussed approaches to presumed mobility are (1) prohibiting private shore protection structures and (2) long-term and conditional leases. In the United States, Maine regulations explicitly state that bulkheads cannot be built to prevent natural systems from migrating inland; and the owners of large buildings that would interfere with wetlands and dunes given a one-meter rise must submit a demolition plan before starting construction. Several U.S. and Australian states limit bulkheads to protect wetlands.

The greatest limitation with this approach is that there is a large risk of "backsliding," that is, that officials 50-100 years from now will be unable to resist pleas from property that it is unfair to protect the environment at the expense of their homes.

Leases that expire at a particular date or whenever sea level rises a particular amount may be less vulnerable to backsliding, particularly in societies that take contractual obligations more seriously than government regulations. Conversion of ownership to leases would often require compensations, but with the effective date in the remote future, the present discounted value of the loss to the property owner -- and hence the fair compensation -- would be small.

In the United States, coastal property is under long-term leases in many areas. Although conditional leases that expire when sea level rise a particular amount have not yet been implemented, the National Park Service has used conditional leases that expire under other conditions, such as the owner's death.

The major drawback of presumed mobility is that it takes more political will to abandon an existing area than to block development of a vacant area. However, if people agree to an eventual abandonment many decades in advance, political leaders can at least appeal to the need to live up to one's part of the bargain.

Do Nothing Today

In cases where people will not have the money to hold back the sea anyway, it may be reasonable to face the problem later and do nothing today, particularly in areas where the population pressure is so great that the area would probably be developed even if abandonment was certain to be necessary. However, this approach leaves open the risk that private and public organizations will make substantial investments in areas that must eventually be lost to the sea.

This approach is particularly unsuited to nations such as Australia and the United States, which would be likely to retreat for the sake of environmental protection. In spite of the difficulties of planning an abandonment today, retreating later without a plan would be much more difficult. Deferring action 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.

SALTWATER INTRUSION

As with responses to flooding and inundation, society can respond with either structural measures to counteract salinity increases, or by accepting and adapting to the landward penetration of saltwater. Many of the relevant measures have already been applied in response to droughts or increased consumption.

Preventing Salinity Increases

Because salinity increases in the coastal zone result from either increases in seawater head (pressure) or from decreases in freshwater head, they can be counteracted by changing the head of either water body. Increasing freshwater pressure has been applied more often. These measures affect both human and ecological impacts from sea level rise.

Increasing Freshwater Pressure

In the United States, dams have been constructed to protect water supplies by maintaining sufficient flows of freshwater into Delaware and San Francisco Bays. Along the Mississippi River, structures are being built to divert freshwater into wetlands threatened by excessive salinity (caused by past river modifications that had blocked the flow of freshwater).

Planning for future saltwater intrusion may be warranted long before a crisis occurs. For example, some water authorities release fresh water from reservoirs when salinity levels increase. Sea level rise may require more reservoirs in the future. While there is no need to build those dams today, now is the time to identify the locations where they would be built if needed. Otherwise such sites may be developed for other uses precluding the options by which future generations can address the problem.

Increased freshwater recharge has also been used to prevent salinity increases in groundwater. For example, although the large network of freshwater canals in southern Florida was designed to drain the land of surface water, some canals are now used to maintain pressure along the freshwater/saltwater interface of Biscayne aquifer. In the Netherlands, numerous man made freshwater lakes such as the Iselmer help to maintain freshwater pressure in the shallow aquifers. The Maldives is modifying roadways so that rainfall will seep into groundwater aquifers rather than run off or collect in puddles and evaporate.

<u>Decreasing Saltwater Pressure</u>

Barriers to saltwater penetration have been used less frequently. Nevertheless, during the drought of 1988, the U.S. Army Corps of Engineers designed a barrier across the bottom of the Mississippi River to prevent saltwater from penetrating upstream to New Orleans. (Because freshwater floats on top of saltwater, the barrier prevents saltwater from encroaching without blocking the outward flow of freshwater.) To curtail the loss of freshwater wetlands, gates and sluices are also used in Louisiana, to permit the outward flow of freshwater through wetlands during a falling tide, while preventing saltwater from invading when the tide is rising. Groundwater can also be protected through the use of physical barriers, but this has rarely (never?) been done.

Adapting to Salinity Increases

In the absence of physical measures to prevent salinity increases, society can move intakes inland, shift to alternate supplies, decrease consumption, or use saltier water. On the other hand, aquatic species respond by moving upstream although, in some cases, habitat will be reduced because the upstream segments of the estuary are narrowed or polluted.

<u>Move Inland</u>

Sea level rise by itself does not decrease the amount of freshwater flowing into rivers and groundwater, it merely moves the interface of fresh and saltwater. Thus, relocating intakes and wells inland may be a viable response to sea level rise, just as moving development inland is a viable response to erosion and flooding.

<u>Shift to Alternate Supplies</u>

In some cases, it may be practical to develop a new source. Along the U.S. Atlantic coastal plain, many barrier islands have shifted to deeper aquifers as the unconfined aquifers became salty due to overpumping. Long ago, New York City realized that the Hudson river would not supply enough water and began taking water from the Delaware River as well. Nevertheless, this option is becoming less viable as coastal communities frequently find that all available aquifers and rivers are being exploited already.

Decrease Consumption

Decreased consumption can be viewed as a response to salinity increases or as a measure for preventing them, since less freshwater is withdrawn. The major premise behind conservation is that by avoiding non-essential uses, freshwater will be preserved for essential uses. Many major metropolitan areas have used regulations to curb outdoor (evaporative) consumption; officials in some regions are contemplating restrictions on withdrawals from groundwater for agriculture.

Pump Saltier Water

Finally, consumers may simply draw saltier water and either send it to a desalination plant or tolerate saltier end use. While the United States, Canada, and Northern Europe generally take for granted that public water supplies are safe for drinking, much of the developing world and even some cities in the developed countries use municipal supplies for cleaning but drink only bottled water or rainwater stored in small tanks. For some industrial uses, it may be practical to tolerate salty water.

RELATIONSHIP AMONG RESPONSES TO SALTWATER INTRUSION AND INUNDATION, EROSION AND FLOODING

Although the freshwater supply and shoreline retreat/flooding issues are conceptually very different, in some cases, the responses will have to be considered in concert, largely because of the impact of shore protection strategies on water supplies.

Perhaps the most important interrelationship concerns the impact of levee and pumping systems on groundwater. Freshwater floats atop saltwater in a typical coastal aquifer. If an island or mainland area were to be raised by the amount of sea level rise, the freshwater table will tend to rise as well. However, because land masses will not rise isostatically by an amount equivalent to global sea level rise, the area must instead be protected with levees, and it will be necessary to pump water out. Because the land surface will be below sea level, areas near the coast could lose the entire freshwater table. For cities with alternate supplies, this may not be a major concern. For more lightly developed areas, deltas, agricultural regions, and coral atolls, however, the potential loss of the freshwater table may be a critical concern.

The management of river deltas is another case where land protection and salinity control are interdependent, Diversion of rivers has reduced freshwater and sediment reaching many deltas, making them doubly vulnerable to sea level rise. Rediverting the flow of water through deltaic wetlands can help to restore the ability of the delta to keep pace with sea level, but perhaps at the expense of the water supply for the areas to which the water is currently diverted.

INTERRELATIONSHIPS OF SEA LEVEL RISE WITH OTHER IMPACTS OF GLOBAL WARMING

Coastal Defense

Sea level rise is likely to be the dominant impact of global warming requiring a coastal defense (or retreat) response. Although increased hurricane frequency would make areas more difficult to defend, even a doubling of hurricane frequency would have a smaller impact on beach erosion than a 30-centimeter rise in sea level, and the impact on sheltered shorelines would be relatively small. Changes in storm frequency could have important impacts on flooding in some areas, but the changes would have to be great to change substantially the basic strategy for responding to sea level rise.

Water Supplies

By contrast, changes in climate could completely dwarf the impact of sea level rise on water supplies. Unlike sea level rise, changes in climate could increase or decrease the amount of available freshwater (rather than merely shifting the fresh/saline interface inland). If droughts become less severe, the response measures discussed above for sea level rise might not be necessary. On the other hand, if droughts became significantly more severe and precipitation generally decreased, some of the options might be ineffective. For example, increased reservoir capacity would accomplish little if there was not enough rainfall to fill them; moving intake pipes upstream would not solve the problem if the total flow of freshwater into the river is less than the requirements of surrounding municipalities.

INTEGRATED STRATEGIES

Except for cases in which one particular response is the unequivocal choice, an integrated strategy must contain a decisionmaking process for deciding what options to implement when, where, and by whom, as well as an inventory of the response measures themselves.

The goal of a response to sea level rise is to enable future generations to avoid adverse economic and environmental costs, without undertaking expenditures today that, in retrospect, would have accomplished more if allocated elsewhere. Because future climate change and sea level rise -- and to a large degree, even the impacts of various response options -- are uncertain, there is a risk that any action employed (as well as no action) will subsequently prove to have been ill-advised.

Although it is desirable to minimize the risk of adverse consequences, such a goal can take many forms. For example, investors in common stocks generally seek to maximize the expected return, while bondholders seek to minimize the probability of a default. A public works official might be willing to take the chance that sea level rise will require modifications of a project, because the tradeoff is between an investment today and the possibility of a larger cost in the future; on the other hand, an environmental official might not be willing to take the risk because once an ecosystem is lost it may not be possible to bring it back.

Strategies to address sea level rise can be either comprehensive or opportunistic. Comprehensive strategies have been rare in coastal issues, because responsibility and authority tend to be distributed among many governmental bodies. Moreover, comprehensive approaches require a complete picture of all the interrelationships of an issue. The advantage of such an approach is that it guards against inconsistent approaches being implemented by various parties; the disadvantage is that the desire for consistency may prevent anything from getting done until there is a consensus of the need for action.

Opportunistic strategies simply assume that if an action is urgent and worthwhile, it should be implemented. In some cases, the benefits of implementing a measure outweigh the costs so greatly that even a low probability of a significant rise in sea level justifies implementation; in other cases, the costs may be great enough to justify action only if a large sea level rise is fairly well established.

These two approaches are not mutually exclusive. The first step in any comprehensive response should be to survey the possible impacts and responses and determine which are rational given a low probability of sea level rise, and which would require a higher probability to justify implementation. Of those that are justified with a low probability, one can then ask whether they would be rendered less effective if delayed. If so, they satisfy the criteria for urgency and should be implemented as soon as possible.

To a large degree, decisions will be based on available information about the risks. However, large nations have the ability to improve this information by supporting efforts to more precisely forecast future trends in sea level. Such efforts include better climate models, monitoring sea level trends, and improved ocean and glacial process models. Any comprehensive long-term strategy should realistically consider the opportunities for improving available information, and determine which decisions can be made with current information and which can be safely deferred.

COASTAL ENGINEERING OPTIONS BY WHICH A HYPOTHETICAL COMMUNITY MIGHT ADAPT TO CHANGING CLIMATE

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ABSTRACT

Projected climate change scenarios suggest that both global sea level rise and changes in storm patterns will affect coastal processes, erosion, and flooding. The functional and structural performance of existing coastal navigation, and of flood and erosion control projects and other coastal facilities and infrastructure, will be modified and most likely degraded as natural factors exceed the conditions for which the infrastructure and facilities were designed.

Adaptive options are needed to modify or maintain existing works. In addition, new projects should plan for a more severe and evolving environment. Inlet relocation, changed dredging practices, incorporation of sand management techniques, and structural modification are potential adaptive options for coastal navigation projects. The effectiveness of existing flood control projects -- such as sea walls, surge barrier gates, dune fields, and levees/dikes -- and of the routing of storm surge waters will be reduced, and new food-control projects will be required in response to sea level rise and storm-induced flooding. There will be increased pressure for coastal armoring and dune construction. Many "hard" (e.g., revetments, seawalls, groins, breakwaters) and "soft" (e.g., beach fill) erosion control devices will have reduced effectiveness and higher maintenance requirements. Increased erosion rates will promote more public interest in beach renourishment. However, the effectiveness of unprotected beach fills will decrease, suggesting that combinations of hard and soft approaches may be the only cost-effective solution. An array of coastal engineering options is reviewed as applicable in response to the various site-specific impacts associated with global climate change.

INTRODUCTION

Global climate models imply that the greenhouse effect will cause the world's coastal environment and communities to experience significant impacts over the next century. Many cultural, commercial, and recreational resources are endangered by both sea level rise and changes in storm patterns. Although the level of impact is difficult to quantify, it is appropriate to review the adaptive options that are current engineering practices and explore other more innovative concepts. In addition, long-term coastal management strategies need to be developed, and research needs to be conducted to better define the impacts of global climate change and to develop responses.

The projected impacts of global climate change to the coast include a eustatic sea level rise of 0.5 to 1.5 meters by the year 2100 due to melting of the polar ice caps (National Research Council, 1987). In addition, global warming implies a rise in the average sea surface temperature of 2 to 4°C (World Meteorological Association, 1986). It has been hypothesized that this warming will lead to changes in the world's tropical storm patterns. Hurricane seasons are likely to be longer, with an increased occurrence of higher-intensity storms and more storms in higher latitudes. For coastal areas, this may mean more and higher storm surges accompanied by higher waves. Current coastal land-use practices and protective structures are at risk as coastal processes are modified, causing accelerated shoreline erosion and more frequent and severe coastal flooding.

IMPACTS ON COASTAL PROJECTS

Coastal wave theory demonstrates that higher sea level and higher storm surges mean larger waves will reach coastal structures and unprotected shorelines. Waves will exceed the design conditions of existing protective works and infrastructure, and new projects will need to consider more severe conditions. Erosion rates will increase and there will be more frequent and severe flooding of coastal lands and estuaries, higher waves in "protected" navigation channels and mooring areas, and reduced efficiencies for existing seawalls and revetments. Beaches will narrow and dune fields will be breached. Because estuaries will be wider, tidal prisms will increase; this process can lead to channel scour (endangering structures), stronger currents, development of multiple inlet systems, and faster rates of inlet migration toward land. Therefore, impacts to coastal navigation may include changes in channel shoaling and scour patterns, reduced durability of structures, shifts in inlet dimensions and locations, reduced channel and harbor navigability, and increased damages in mooring areas.

Erosion rates will increase and many of the "hard" (e.g., revetments, seawalls, groin fields, breakwaters) and "soft" (e.g., beach fill) erosion control devices be less effective and will require more maintenance. Toe scour and higher inshore waves can damage seawalls and revetments. Groin fields and detached breakwaters may experience increased structural damage, and become less effective in retaining the desired beach widths.

Other coastal facilities and infrastructure may also experience impacts. Cross-sectional change at inlets may cause scour around the pilings of bridges and damages where the bridges connect to land. Shoreline recession can endanger coastal roads and facilities such as septic systems, buildings, and utilities.

Increased rates of alongshore (sediment) transport can shoal the intakes for power plants. Damages to docks and wharves will increase as higher waves propagate farther into the harbor.

THE SCENARIO OF RISING SEA

There are many international examples of the variety of impacts we can expect global climate change to cause on the world's coastal areas. Although caused by other factors, the subsidence of Venice and the Louisiana coastal plain, the dramatic erosion of the Nile delta, the land reclamation efforts in the Netherlands and Germany, the 15-year high-water-level cycle in the Great Lakes (1972-1986), and the recent Hurricane Hugo all contribute to our understanding of what sea level rise and increased tropical storm activity can mean.

Many great cities are at risk from a change in the world's climate. However, to illustrate the quantitative level of impact that communities are likely to experience, we use a fictional coastal area, which we call the town of Rising Sea (Figure 1). The magnitude of impacts to this coastal community were computed for a rise in mean sea level or storm tides or increased storm surges of 0.3, 0.6, and 0.9 m (Table 1). The effects of sea level rise on the Rising Sea area were calculated using the Automated Coastal Engineering System (ACES) package of computer programs developed at the Coastal Engineering Research Center (Leenknecht and Szuwalski, in press) and analytic methods presented in the Shore Protection Manual (SPM, 1984).

A rubble mound breakwater protects boats moored in the harbor. The harbor shore is a narrow beach backed by a revetment, which protects the town from flooding. South of the revetment is the city dock and a bridge over the south end of a tidal marsh. The bridge leads to a resort community protected by a seawall. On the north side of the inlet is a natural beach and dune area.

The breakwater was designed to afford adequate protection for a stillwater depth of 4.6 m at the toe of the breakwater, which is a typical multiple-layer stone rubble mound structure. The armor stone was sized assuming that the waves reaching it were depth-limited to 3.6 m by the 4.6-m water depth at the toe. The calculated stable armor size is a 7.6-M stone. When hit by 3.6-m, 9-second waves, the breakwater transmits 0.8-m waves to the harbor.

The 0.8-m waves propagate across the harbor toward the revetment, inflicting minimal damage to the moored fleet. The 305-m-long revetment is 1.8 m from toe to crest and has a toe buried 0.6 m below grade. Under present design sea level, there is 0.6 m of water over the toe of the revetment. The 0.5-m depth-limited breaking wave requires a computed stone size of 18 kg. However, to prevent users of the area from possibly dislodging the stone, the revetment is made of a 45-kg stone, although there will be no overtopping. Undoubtedly, the winds accompanying a design storm will blow considerable spray into the town. Fortunately, existing drainage systems can easily handle this water. The city docks are 0.9 m above mean sea level, and waves can pass under them without causing damage.

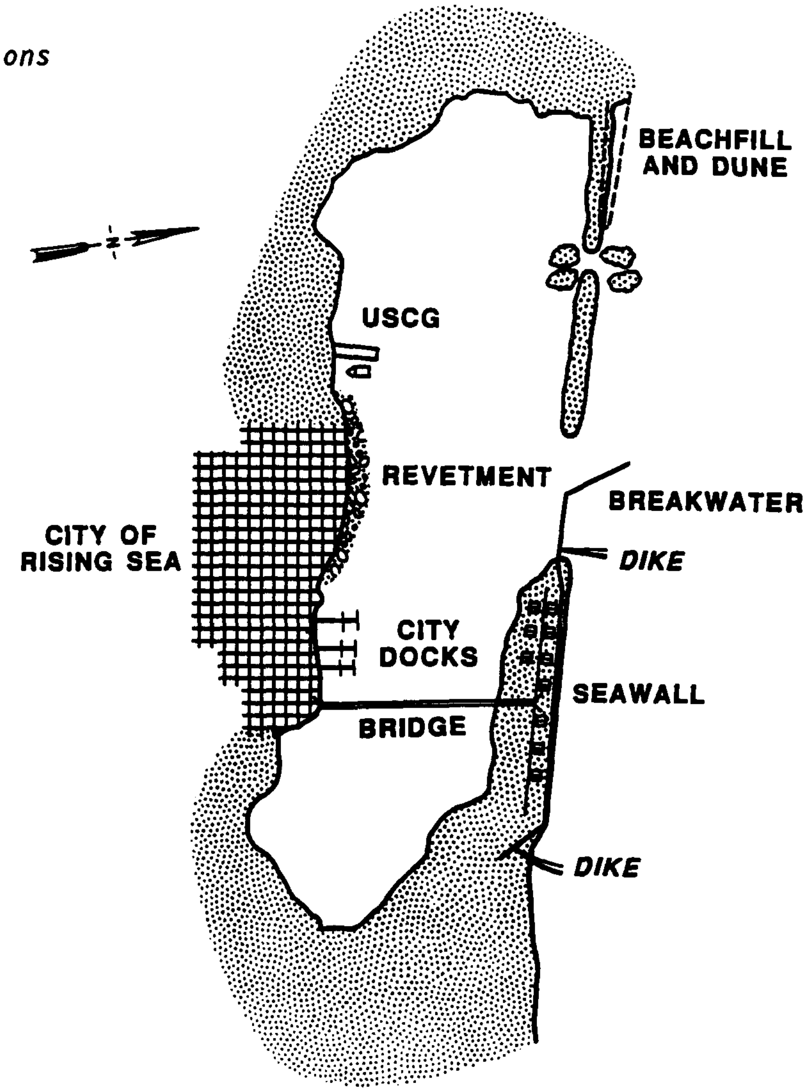

Figure 1. Fictional coastal setting and the community of Rising Sea.

A 0.3-m sea level rise will result in 4.9 m of water at the breakwater toe. A depth-limited wave of 3.8 m will now affect the breakwater. Stable armor stone size requirements are now 9.1 M, rather than 7.6 M. The loss of rubble mound reduces the structure's height as armor stone is displaced. If the breakwater does not lose crest elevation, the transmitted wave will be 1.1 m, but if it fails only 0.2 m, the transmitted wave will be 1.3 m, and will increase damage to the moored fleet. The revetment now has 0.9 m of water on it and is subjected to a 0.7-m breaking wave, which requires a 61-kg rock. Assuming the structure survives with no major damage, 0.0024 cubic meters per second of water is delivered to the town center by overtopping. For the 305-m waterfront, this is 2,700 cubic meters per hour, which may tax the existing drainage system. Wave crests will be about even with the pier deck and will start to cause damage.

For the scenarios of 0.6- and 0.9-m sea level rise, the situation becomes progressively worse. With a 0.9-m rise, there is 5.5 m of water on the breakwater toe, and a proper design would require 13.2 M stone for the resulting

Table 1. Effect of Sea Level Rise on City of Rising Sea

Sea Level Rise	0	+0.3	+0.6	+0.9 m
Breakwater				
Depth limit wave	3.57	3.78	4.02	4.27 m
Armor stone size	7.62	9.07	10.98	13.15 M
Transmitted wave	0.85	1.10	1.34	1.71 m
Settlement		0.15	0.30	0.61 m
Transmitted wave After settlement		1.28	1.59	1.95 m
Revetment				
Depth limit wave	0.49	0.70	0.94	1.19 m
Armor stone size	18	61	145	282 kg
Overtopping (m^3/s)	0	0.0024	0.035	0.14
hectare m per hr per 303 m revetment	0	0.27	3.91	15.54
Docks				
Wave crest height	0.61	1.16	1.77	2.46 m
Tidal Prism				
Upriver of bridge	70,792	82,544	95,145	108,595 m^3
Seawall				
Wave impact force	429	617	846	1083 N/m

4.3-m breaking wave. The 7.6 M stone used in the original construction is only a little over half the required weight and would be easily dislodged by wave forces. An estimated 0.6 m of crest loss or 20% damage to the breakwater may be optimistic. Boats would no longer be safe at their moorings in the resultant 2-m seas. Since wave energy is proportional to the height squared, the 2-m wave would have almost 5-1/2 times the energy of the 0.8-m wave. If given notice, the fleet would head for a safer port. In these situations, people often leave too late, resulting in loss of lives and boats. The revetment, which is constructed of 45-kg stone, would be severely underdesigned, with the 1.2-m breaking wave requiring a 282-kg stone. In the unlikely event the revetment did not fail, the town would receive 155,000 cubic meters of water per hour, which would result in extensive flooding. If the revetment did fail the flooding would be much worse. The docks would most likely be destroyed by wave crests over 1.5 m above the pier decks and by excessive forces on the pilings. Depth-limited wave forces on the seawall, as calculated by the Minikin formula, would be over twice what they would be before the 0.9 m of sea level rise. Overtopping for the town revetment and flooding near the seawall would be severe.

The marsh south of the bridge was 150 m by 300 m before sea level rise. If the land adjacent to the marsh slopes upward at 1:30 on the east and west sides and 1:100 on the south side, the water surface and thus the tidal prism will increase as sea level rises. This could result in increased current velocities and sediment movement. In this case, the channel under the bridge was 4.6 m wide and 1.8 m deep before sea level rise. The rise in sea level would increase the cross-sectional area of the channel as the tidal prism increased. With the expected 16% increase in cross-sectional area, there would probably not be any significant scour around the bridge pilings for this bridge located in the back of the estuary, a small comfort compared to all the other calamities this community would face.

ADAPTIVE OPTIONS

Coastal response options for the impacts of global climate change fall into three main categories: retreat, soft structures, and hard structures. Retreat is primarily a planning approach, which involves manipulating human activities rather than the natural environment. Soft or "dynamic" structures attempt to modify the natural processes through management of the physical system and maintenance practices. Hard or "static" structures involve the construction of some permanent devices. Hard structures tend to represent the more traditional coastal engineering approach. Table 2 summarizes the range of coastal response adaptive options, including some new and relatively untried approaches.

Retreat options summarized in Table 2 include not only abandonment but also the concept of restricted development and government-controlled land use. Through zoning practices, local communities can gradually influence the complexion of a coastal development. Strong zoning codes may force an area to be abandoned gradually or to migrate inland (roll-over communities). Flood insurance programs that allow for rebuilding of damaged properties or unrestricted zoning may promote a laissez-faire development, prompting significant government investment in the construction of protective works. Retreat may be an adaptive option for currently semi-developed or planned developments, but there are many coastal communities where the human and financial commitment is so great that retreat is not feasible.

Soft options listed in Table 2 include sediment transport and hydraulic flow management procedures, which rely on maintenance and operation practices to manipulate the natural environment. The rebuilding of beaches and dunes using sandy material from inland or offshore sources is a fairly traditional practice. Other, more innovative sources of material to rebuild or maintain the beach and dune system include the bypassing of sand from around inlets to maintain the natural longshore sediment supply (Dean, 1988), the scraping of the offshore portion of the active profile after a significant storm to enhance the natural beach response (e.g., South Carolina after Hurricane Hugo), and the placement

Table 2. Coastal Engineering Adaptive Options

Option	Approach/structure
Retreat options	Abandon to nature Limit development Laissez faire Roll-over communities Evacuation routes
Soft options	Beach fill Dunes Beach scraping Nearshore berms Dredging Sand bypassing Vegetative plantings Channel relocation Hydraulic modification
Hard options	Flood gates Dikes Levees Seawalls Bulkheads Revetments Breakwaters Jetties Groins Detached breakwaters Sediment weirs Perched beaches Floating breakwaters

of sandy dredged material on the offshore portion of the profile in the form of an underwater berm or bar (McLellan, in press). The use of dredged material to maintain wetlands is also a realistic option. Vegetative plantings can be used to help stabilize dunes, protect the shores in relatively quiet waters, and trap sediments to enhance wetland development.

A highly promising soft approach for adapting to climate change may be to modify the hydraulic processes of the inlet and estuary system based on an improved understanding of the development and exchange of the tidal prism. Such activities could include modifying the exchange cross-section and location between the estuary and the sea via inlet opening and closing, and channel relocation. In addition, it may be feasible to control the tidal prism volume and distribution via wetland enhancement, dikes, and modification of flow patterns. However, these approaches require a greater understanding of the relationship between wetland flow, tidal hydraulics, inlet processes, and the behavior of multiple inlet systems.

Hard options listed in Table 2 include structures used in navigation, flood control, and beach erosion control projects. Seawalls, bulkheads, revetments, levees, and dikes that attempt to "draw a line," stopping shoreline recession and limiting flooding. The construction of a wide-toe berm can help extend the life of these structures. However, as sea level rises and the offshore profile steepens, these structures must be enlarged or abandoned and replaced by new more landward structures. Navigation structures such as breakwaters and jetties can also be modified via higher crests, larger armor stone, or additional length to reduce damage to the structure and improve the navigability of the harbor. In cases where channel scour has over-steepened the toe of the structure, threatening the structure's stability, stone aprons, training dikes, or coarse-grained material in filling have been successfully used.

Several structural options are designed to trap the littoral sediment and enhance the inshore. These include groins, which block the longshore moving material; perched beaches, which capture the onshore transported material; and sediment weirs, which are used mainly at inlets as part of navigation projects. Some breakwater-type structures attenuate the wave energy, causing an inshore wave sheltering. Floating breakwaters have been incorporated into navigation projects to reduce wave action within the harbor (Hales, 1981). Detached, permeable, and headland breakwaters have been used to maintain a beach width and profile along receding shores (Pope and Dean 1986, Pope 1989).

For most situations, a combination of hard, soft, and retreat adaptive options will be needed. Limited development enhanced by beach scraping or the placement of dredged material in a nearshore berm; rehabilitation of navigational structures, accompanied by sediment bypassing; and the construction of breakwaters to ensure longer residence for beach fill operations are proven combination activities that could be used in response to a rise in sea level or increased storm severity. Each situation will be different, and the appropriate adaptive option will need to be carefully considered.

SUMMARY

Adaptive options to potential sea level rise include relocating inlets, modifying dredging practices, incorporating sand management techniques, and structurally modifying navigational systems. There will be increased pressure for coastal armoring in response to coastal erosion. At existing project sites, structural modification, supplemental works, or coastal evacuation routes may be appropriate options. Increased erosion rates will promote more public interest in beach renourishment. However, the effectiveness of unprotected beach fills will decrease over time, suggesting that combinations of hard and soft approaches may be the only cost-effective solutions.

Our fictional coastal town of Rising Sea could adapt to the impacts associated with global climate change by modifying existing works and installing of new works. The town could use "band-aid" approaches and simply treat the local problem as it evolves, putting in heavier armor stone and increasing structure heights on an as-needed basis. However, the financial commitment with this approach will escalate rapidly, and the local quality of life could deteriorate. Or the town could evaluate and project the nature of the process and problem and develop long-term alternative options, such as an advance measure maintenance and operation strategy. In the end, the community might develop a multi-action plan that incorporates the assistance of the federal and state governments and private industry. Dredging practices could be modified to recycle material onto the beaches and inshore, several developed zones could be converted into undeveloped public access areas, mooring patterns could be changed and an interior structure added for additional protection, wetland enhancement programs could be developed, some existing structures could be modified, and the drainage system could be upgraded. Through the development of a long-term policy and coastal management plan that is based both on a clear understanding of the process and impacts of sea level rise and on an evaluation of all the rational response options, the town of Rising Sea may make it into 22nd century.

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THE ROLE OF COASTAL ZONE MANAGEMENT IN SEA LEVEL RISE RESPONSE

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ABSTRACT

Successful adaptation to the effects of sea level rise will require a comprehensive approach to the management of the affected coastal area and its resources. A nation's response to sea level rise is likely to be a combination of structural and nonstructural responses.

Nonstructural adaptive responses are likely to be the most economic approach to sea level rise in most areas, particularly those with low population density and minimal infrastructure investment. Nonstructural adaptive responses to sea level rise can have other values, such as resource protection, which can mitigate the uncertainty facing policy makers and planners. The success of nonstructural adaptive responses will require the cooperation of the affected populations. This cooperation can best be achieved through education, resulting in increased public awareness of the problem and the potential solutions and their accompanying costs, and early involvement in the decision-making process.

INTRODUCTION

The potential rise in sea level resulting from global warming will present coastal nations with a myriad of problems, and will require governments, the private sector, and coastal residents to make some very difficult choices. In responding to the loss of existing land and resources, policymakers will have to balance competing demands for resources and preserve existing social and cultural values, without overtaxing the national economy. Any significant rise in sea level will require consideration of both the impacts of a given policy choice on diverse resources, and the interrelationship of those resources and those choices.

Any successful response to sea level rise will need to rely on a <u>comprehensive</u> approach to the management of coastal areas: comprehensive in terms of both viewing the coast as a whole and taking into account all of the impacts of any chosen response option. (For an opposing viewpoint, see the paper in this section by Titus.)

IMPACTS OF SEA LEVEL RISE

Rising sea level will inundate low-lying lands immediately adjacent to the coast as well as lands along rivers flowing into the sea. Beach areas will be eroded, and existing wetlands will be submerged. Shorelands consisting of cliffs and bluffs are likely to experience increased erosion and undermining, resulting in the collapse of the bluffs. The configuration of the coastal lands may also change (e.g., through new inlet formation) owing to changing physical forces.

Sedimentation and Increasing Salinity

Changing land forms and water volumes caused by sea level rise will alter coastal water movements and resulting sedimentation patterns. Estuarine areas and rivers flowing into the coast will experience increased salinity. Coastal aquifers will experience increased saltwater intrusion from rising seas and possible loss of freshwater recharge areas as a result of the coastal inundation.

Loss of Wetlands and Breeding Sites

The alteration of the coastal shorelands will also significantly affect the living resources that dwell in these areas or that depend on resident species. The potential loss of beach areas for breeding sites for turtles and some shorebirds could be the final blow for many species already endangered or severely stressed. The impact of the loss of wetlands, which are critical to the life cycle of many fish species of importance to human as a food source, will be seen in reduced fishing harvests.

Residential and Commercial Losses

Residential and commercial development immediately along the coast may be threatened by inundation and may be susceptible to increased damages from the more frequent and severe coastal storms. These changes may present particular problems for some industries. For example, coastal electricity-generating or industrial facilities that depend on fresh riverine waters for cooling or manufacturing processes will face abandonment of operations or retooling to use now brackish waters. As mentioned before, port operations will also require adjustment to the changing physical conditions. The limitations on fresh groundwater caused by saltwater intrusion may serve as a limiting factor for all forms of future land development.

Other Losses

Uses such as recreation, tourism, and fishing, which are important to the social, cultural, and economic well-being of coastal communities, also will be affected by the physical changes to the beaches and wetlands.

RESPONSES TO SEA LEVEL RISE

Three basic management approaches can be taken in response to sea level rise: (1) do nothing and suffer the consequences; (2) resist the rising waters through various forms of hard and soft structures; or (3) gradually retreat. The choice of which to do in any given circumstance will depend on a number of factors including the following:

- the magnitude and rate of sea level rise;
- the geology and elevation of coastal land;
- the value and importance of the particular resource both to its owner and to the economic, physical, and social health of the nation;
- the likelihood that a particular response would be successful;
- the availability of viable alternatives;
- the costs -- including economic, environmental, social, cultural, and safety -- of the chosen response.

Structural Response

While a structural response to sea level rise is almost always possible, it may not always be reasonable, given the economic costs involved or the adverse environmental impacts. For example, bulkheads eventually cause the loss of natural shorelines, which can hurt recreation, tourism, and environmental quality (see the section on Environmental Implications of Response Strategies). Moreover, hard structures can foreclose the retreat option (such as allowing the migration of wetlands or barrier islands) and can commit a coastal area to an expensive course of resistance. Nevertheless, hard structures will most likely be the chosen response for major population centers, industrial complexes, ports, and in some nations, agricultural land as well.

Nonstructural Responses

The following is a brief discussion of some possible non-structural responses in light of some of the more readily apparent impacts of rising sea level.

<u>Abandonment of High-Risk Areas and Relocation of Coastal Structures</u>

In the face of coastal inundation and increasing erosion, existing structures can be abandoned or moved. Erosion and inundation of coastal lands are a constant process along the coasts of many countries. Even without the prospect of a significant rise in sea level, coastal structures and populations are vulnerable to natural storm and erosion processes. The impacts of these storms and erosion are costly to the individuals involved as well as national economies. Therefore, relocation of populations from areas susceptible to these natural hazards can benefit a nation, even if the extent of water rise from global warming is less than is currently projected. In addition to reducing the vulnerability of people and property at risk, relocation of coastal structures can have other benefits, such as the preservation of natural areas like wetlands and their beneficial value for fisheries, water quality, and storm protection.

Adaptive Options

Gradual Retreat

In areas with small populations and little investment, retreat in the face of rising waters may be the most effective and economic response to sea level rise. This is particularly true when retreat is viewed as a long term process that can be implemented as part of a program of land use control, and with the recognition of the other benefits associated with these land use decisions. Among these benefits are protection of coastal resources and the uses that are based on them. Retreat can also be seen as a way of mitigating the extent and cost of eventually maintaining and rebuilding hard structures.

In many areas, the value of a gradual retreat from the shoreline has been recognized, and several mechanisms for implementing that choice are being tried. In the United States, approximately one-third of coastal states require new structures to be set back from the shore. The State of South Carolina, for example, requires houses to be inland of the primary sand dune (where the primary sand dune would be if the coastline had not been altered), a distance equal to 40 times the long-term annual erosion rate. This determination reflects an attempt to protect coastal construction through its projected effective life. The Beach Management Act also places severe restrictions on armoring the coastline and on rebuilding structures damaged by storms or chronic erosion.

<u>Landward Migration of Wetlands</u>

Given a gradual rise in sea level, wetland areas can retreat. However, this retreat will be possible only if inland areas do not contain barriers such as manmade structures, and if sediment flows to these areas are not interrupted. The decisions to allow landward migration of wetland areas to protect their ecological values will require modification of human activities to respond to these concerns.

THE MECHANISMS OF RETREAT

In choosing retreat, one will seek to gradually relocate the existing population at risk to other areas, and to establish programs to prevent population increases in areas at risk. Incentives can be established to encourage affected populations to relocate elsewhere. For example, industry can be encouraged to locate in safe areas through the provision of special tax incentives for relocation and subsequent preferential hiring to individuals from the areas impacted by the sea level rise.

Another approach would be to establish as national policy that areas likely to be at risk in the future should be used for economic activities that do not require major investments for infrastructure or whose loss will have minimal social and economic impacts. For example, areas immediately adjacent to the coast can be made primary areas for parks and other recreation that involve little investment. Agriculture or silviculture uses could be emphasized in areas that are still able to support these uses, but that are known to be susceptible to inundation in the 25- to 50-year period.

Allocation of increasingly limited safe oceanfront areas will also need to give priority consideration to coastal-dependent uses that cannot readily be located elsewhere (e.g., fisheries).

Negative incentives to encourage existing populations to relocate and to discourage new settlement in threatened areas can be based on public policies to limit economic loss to the country as a whole by refusing to make new public investment in infrastructure in areas at risk, and to not repair, replace, or improve infrastructure damaged by sea level rise or by coastal storms.

IMPLEMENTATION OF THE RETREAT OPTION

Basic to the adoption of any retreat option will be an understanding of the existing coastline, its vulnerability to sea level rise, and the existing use of these areas. An assessment of vulnerability also needs to be placed in a time frame to make planning realistic while not unnecessarily foreclosing options for development.

Limitations on freshwater will be a significant determinant of the type and extent of coastal development. A number of strategies can be implemented to deal with the damage to coastal aquifers:

- reduction in consumption either through regulation or pricing structures;
- construction of additional reservoirs or development of procedures for interbasin water transfers (these two options have the disadvantage of being costly, of having significant environmental impacts, and of transferring a significant burden of the support of coastal development to inland areas); and
- desalinization and innovative methods for recycling wastewaters (the latter option could have the additional benefit of enhancing the protection of coastal water quality).

Unlike holding back the sea, which primarily involves the decision to commit the economic resources to undertake the activity, the implementation of a retreat option will require broad support among the affected populations. To achieve this support, individuals and private-sector representatives in the affected areas should be involved early in the decisionmaking process. Part of this involvement must be an intensive education program directed toward increasing the general understanding of the extent and impact of sea level rise, and the possible response options and their impacts. Another mechanism for achieving cooperation is technical assistance in the planning for uses and structures in the coastal area. Sea level rise should required to be considered in infrastructure development and land use planning.

Adaptive Options

Once a decision is made to retreat, it will be necessary to clearly define the role of each level of government and the private sector in the retreat plan. While the national government most likely will be responsible for the broad policy decisions, actual implementation or enforcement of the retreat plan may best be done at the lowest level of government with enforcement authority. The advantage of concentrating implementation at the local level is that this level is closest to the problem and the population affected, and, therefore, is more likely to be effective at persuasion as well as enforcement. Because of the inherent problems with enforcement, there should be some governmental override to ensure national strategy implementation.

A WORLDWIDE OVERVIEW OF NEAR-FUTURE DREDGING PROJECTS PLANNED IN THE COASTAL ZONE

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INTRODUCTION

One of the goals of the Coastal Zone Management Subcommittee of the IPCC Response Strategy Working Group is "to provide information and recommendations to national and international policy centers, enabling decision making on coastal zone management strategies for the next 10-20 years" (IPCC-PLANNED-CZM Meeting, Geneva, May 9, 1989). Raising the level of awareness about the possible impacts of sea level rise and changes in storm frequencies/intensities on projects planned in the coastal areas of the world is therefore considered to be an IPCC-PLANNED task.

The land-use projects planned in the coastal zones include harbor construction, land reclamation, and urbanization, with lifetimes of 50-200 years. Such civil engineering projects generally attract other large-scale investments and lead to further exploitation of the coastal zone (for example, an increase in the number of fisheries and in tourism, other commercial activities, and groundwater and oil/gas extractions). This large increase of capital investment and gross domestic production in the coastal zones will have to be safeguarded in the future.

Careful technical and economic studies carried out during the planning phase of specific coastal zone projects might reveal that extra spending now, in anticipation of climate change, will pay off in the future.

Additional funds might be expended for the following response measures: additional coastal defense; shifting of project locations to higher ground, farther away from the present coastline; incorporating into construction plans the extra space needed to accommodate sea level rise (in the case of harbour planning, providing extra space for roll-on/roll-off operations, cargo flow, and port management activities).

Problem Identification

Before such response measures can be implemented, two conditions must be met:

1. Local, national, and international policy makers and coastal management organizations must acknowledge the importance of long-term planning; and

2. The IPCC must agree on scenarios of sea level rise and storm changes.

In general, coastal engineering development is characterized by three types of activities, which are accomplished in the following order: 1) dredging activities; 2) construction of harbour quays and docks, and preparation for urbanization and land reclamation; and 3) construction of harbor installations, cities, industrial areas and other infrastructure. Major civil engineering projects in the coastal areas are usually accompanied by dredging activities. The economic value of the dredging activities is, to a large extent, indicative of the cost of the subsequent projects to be executed. To better understand the nature and extent of the human activities anticipated in the coastal zones and the magnitude of the associated future capital investments, a global inventory of future dredging projects was undertaken.

METHOD OF DATA COLLECTION

To obtain data on near-future dredging projects planned in coastal areas, the authors consulted the world's largest dredging company, which is based in the Netherlands and has a worldwide network of agencies and long-term experience. Only projects having work valued at $20 million or more (U.S. dollars) were considered. These near-future dredging projects (scheduled to occur between now and 5 years from now) were grouped into four categories:

1. coastal protection;

2. port extension/construction;

3. industrial land reclamation; and

4. urbanization.

Each dredging project was determined to be in one of four different stages: prospective, budgeted, pending, and executed.

RESULTS OF THE NEAR-FUTURE DREDGING PROJECT INVENTORY

This inventory covers 62 near-future dredging projects located in 36 coastal countries (Figure 1) The worldwide coverage of near-future dredging projects is about 85%, excluding the U.S. and U.S.S.R. dredging activities. The total value of the 62 dredging projects is about $4 billion (U.S. dollars). Dredging projects whose budgets are smaller than $20 million constitute about another $4 billion. Those small-scale dredging projects, although large in number, involve

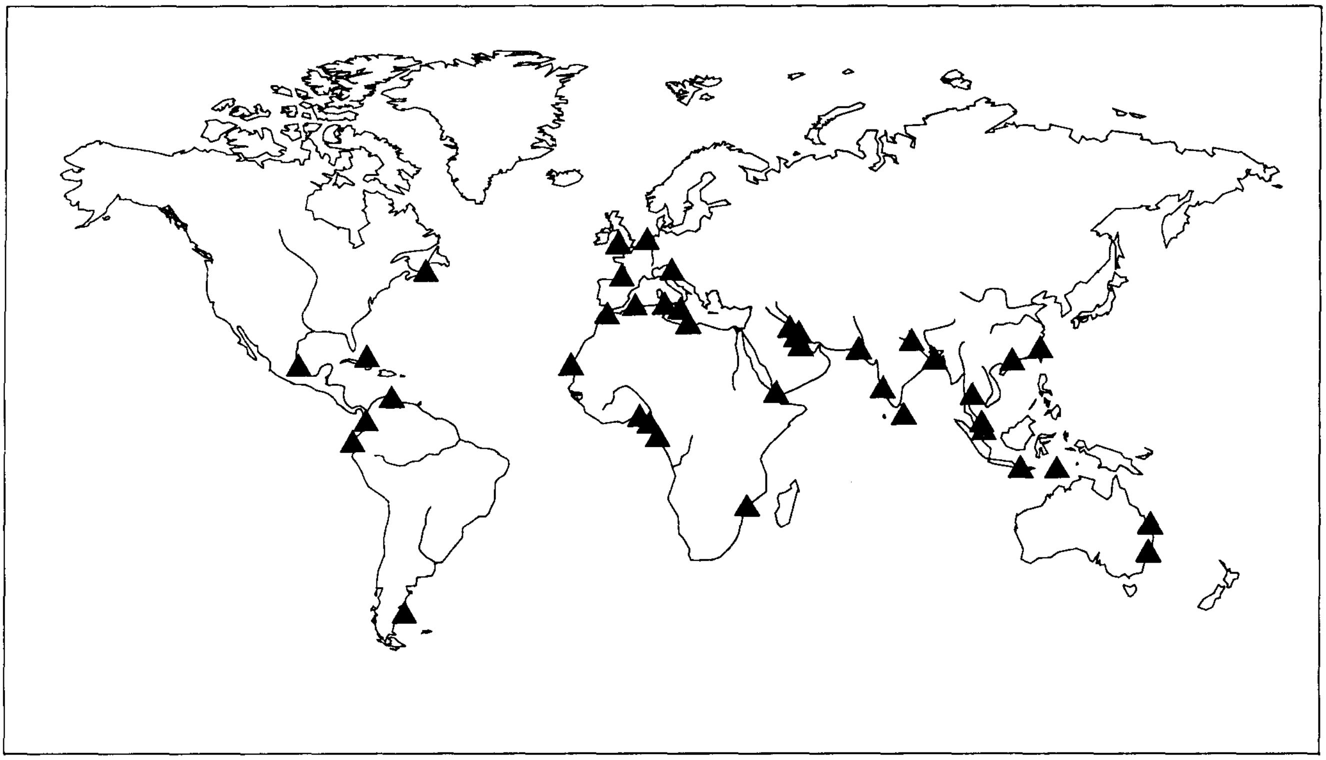

Figure 1. Locations of the major near-future dredging projects.

much smaller capital investments. The preliminary results of a similar survey covering the dredging projects executed during the last five years reveal a total expenditure of about $3 billion.

The percentage of capital allocated to these dredging projects can be broken down by stage of project and by category:

Stage	(%)	Category	(%)
prospective	60	coastal protection	20
budgeted	17	port extension/ construction	30
pending	10	industrial land reclamation	40
executed	13	urbanization	10

The dredging projects reviewed here are mainly planned in combination with port extensions, urbanization, and land reclamation projects. Activities related exclusively to shore protection cover only 20% of the dredging projects considered in this inventory.

Problem Identification

Figure 2 shows the regional distribution of the major dredging projects by project stage and by category of dredging activity.

Figure 3 shows the regional distribution of the total cost for these dredging projects; 70% of the total will be spent in Asia and in the Arabian Gulf States. The land-use projects (e.g., land reclamation and port extension) are predominant in Asia. In the Arabian Gulf States, the amount of capital allocated or spent on port extension/construction, land reclamation, and urbanization is more or less equal.

As previously stated, dredging activities provide an indication of the future level of capital investments in the coastal zone. Experience shows that the capital investments in coastal areas are about 5 to 15 times the dredging costs. This means that a rough estimate of the near-future capital investments in the coastal zones of the world might range between $20 and $60 billion. Other types of large-scale projects, such as capital-intensive, near-future agricultural projects, are not included here.

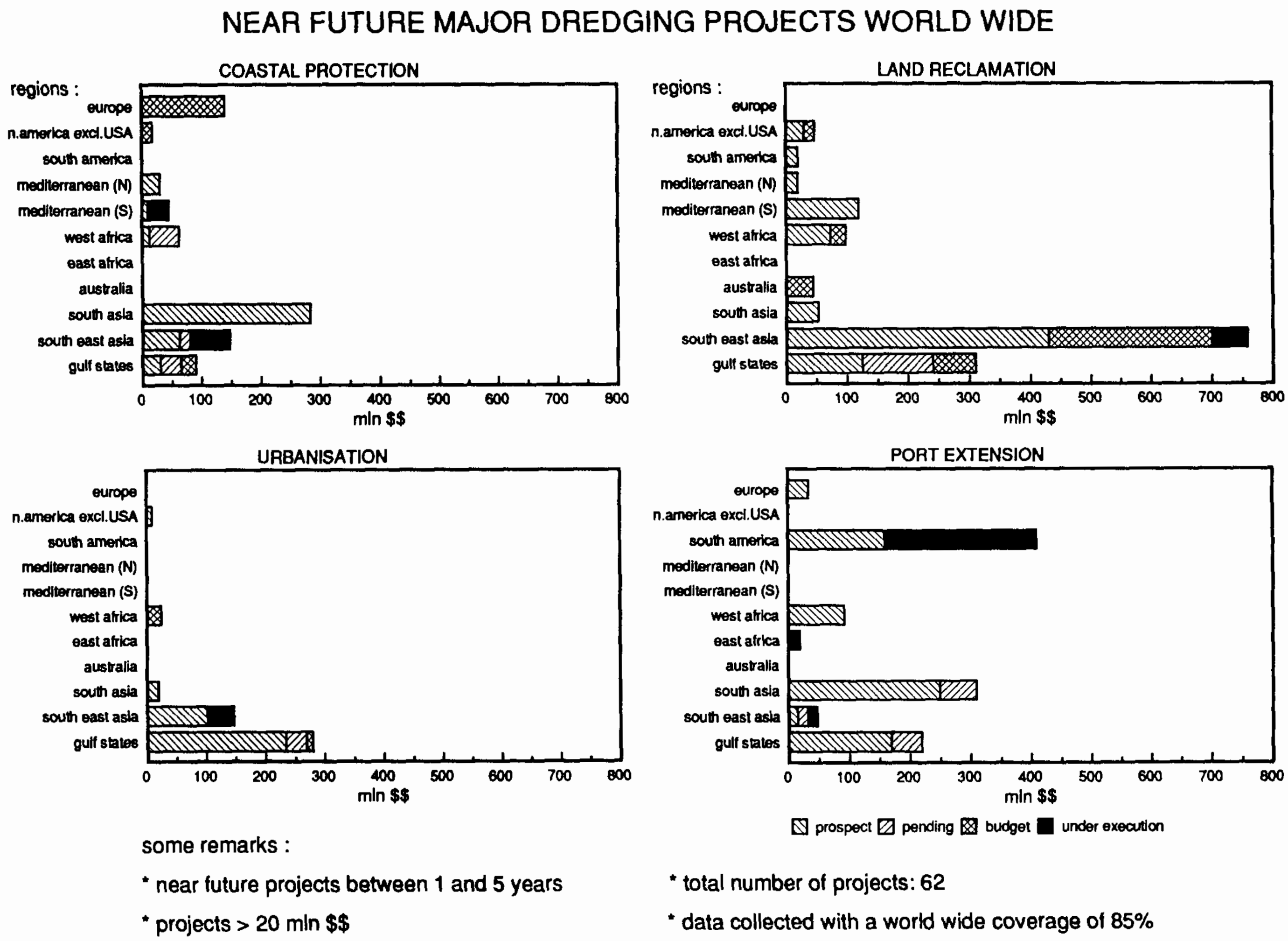

Figure 2. Regional distribution of major near-future dredging projects by stage and category of activity.

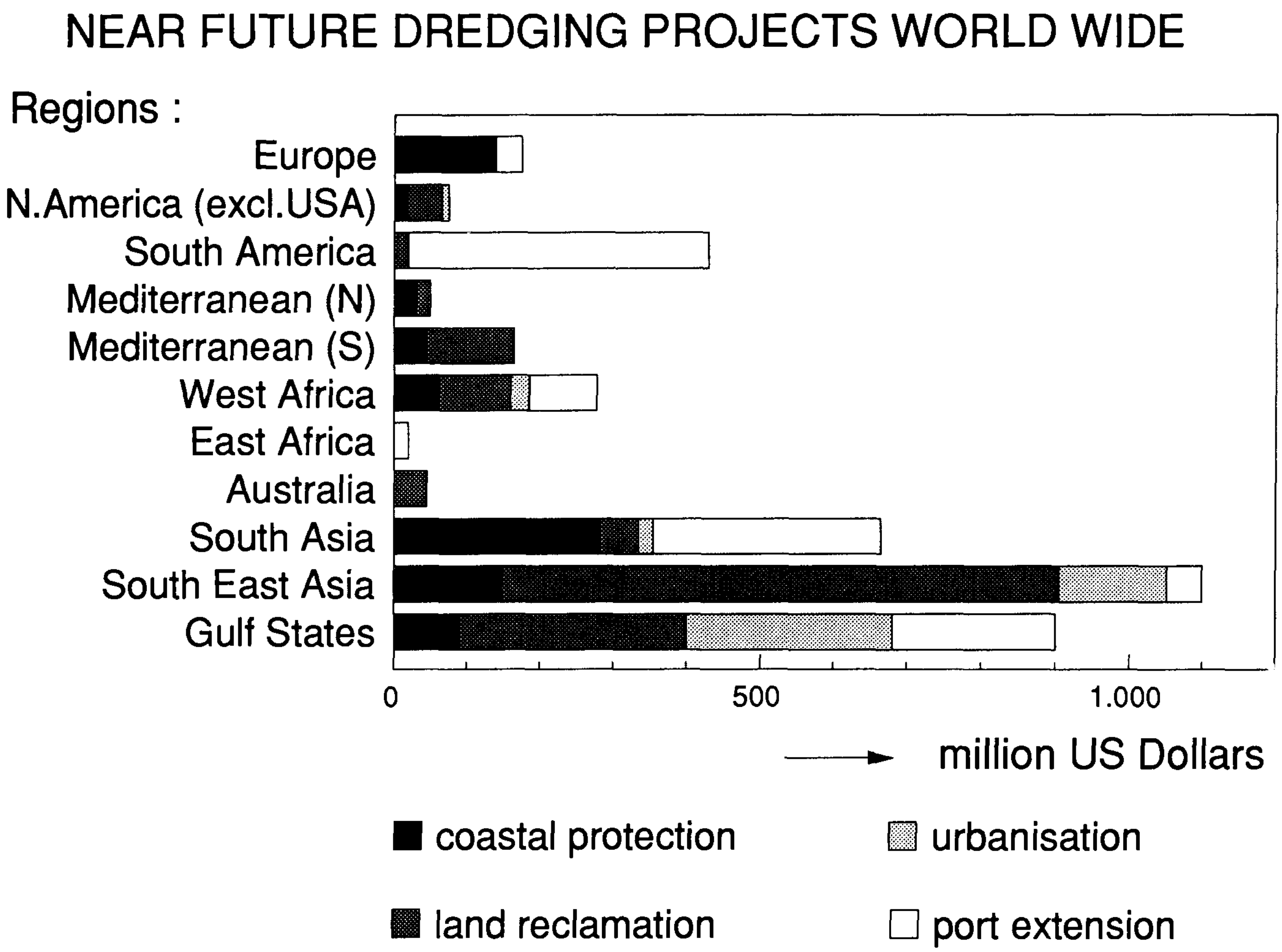

Figure 3. Regional distribution of total cost of near-future dredging projects. considering the possible impact of sea level rise (and climate change) during the planning phase of coastal projects.

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions can be drawn, based on the global inventory presented above:

1. Future capital investments in the coastal zones could range between $20 and $60 billion (U.S. dollars). This sum emphasizes the importance of

2. South Asia, Southeast Asia, the Arabian Gulf States, and to a smaller degree, South America will be heavily investing in future land use

projects, such as port extensions, (industrial) land reclamation, and urbanization projects.

3. It appears that relatively large investments are planned for land-use projects and that there will be relatively small investments in shore-protection measures on vulnerable coasts. To find out whether this is indeed the case, a global inventory of planned shore-protection construction should be conducted.

4. To obtain more complete information on the investments in the coastal zones, additional inventories should be taken of plans for capital-intensive agricultural activities (enpolderment of lagoons, irrigation/drainage projects), freshwater management projects, and construction of infrastructure (bridges, sluices, airports). Such research should be conducted within the framework of IPCC working groups.

ECONOMIC, ENVIRONMENTAL, LEGAL, AND INSTITUTIONAL IMPLICATIONS OF RESPONSE STRATEGIES

Editor's Note:

The organizers of the Miami Conference intended to have a session on the social and cultural implications of response options, but no such papers were received. The conference preserved the time slot by accepting papers addressing the social implications of climate change. In this report, those papers have been placed in the other sections.

SOCIOECONOMIC, LEGAL, INSTITUTIONAL, CULTURAL, AND ENVIRONMENTAL ASPECTS OF MEASURES FOR THE ADAPTATION OF COASTAL ZONES AT RISK TO SEA LEVEL RISE

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ABSTRACT

In response to the consequences of climate change, in particular sea level rise, the Coastal Zone Management report addresses adaptive policy strategies for the coastal zones at risk. This paper investigates the effectiveness and implementability of response strategies and formulates recommendations for adapting to sea level rise. It presents a worldwide overview of the major problems raised by adaptation to sea level rise.

A second purpose of this paper is to present a methodological framework for the elaboration of response strategies. This framework may serve as a reference for the preparation of more detailed response plans on a national level.

Criteria for comparing response strategies are defined and evaluated for the world's largest coastal zones at risk. The comparison of strategies is based, as much as possible, on the quantitative information analyzed in this paper. The present situation is used as a reference for all considerations in this study.

INTRODUCTION

As indicated by the Science Working Group, there is great uncertainty concerning the degree to which sea level is expected to rise in the next century. As a working hypothesis, a rise of 1 m will be considered. Information on other

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[1]This was prepared by the Netherlands' Delegation as information for the Coastal Zone Management report of RSWG of the IPCC. This paper was written to stimulate discussions of the CZM subgroup at the Miami workshop held in November 1989. As such, it presents preliminary views only. It does not constitute the policy of the Dutch government.

climate change effects, such as alteration in the frequency and intensity of storms, is insufficient to be dealt with in this study.

The impacts of different sea level rise scenarios on coastal zones at risk if no adaptive measures are taken have been investigated by the Impact Working Group. These impact predictions form the basis for the response strategies considered in this paper.

Basically, two policy response options can be distinguished: limitation and adaptation. This study deals only with adaptation, for which two strategies can be followed: land-use adaptation and coastal protection. Which one will be best depends on criteria referring to the effectiveness and the implementability of these strategies.

Carrying out the policy options requires "technical" measures (for example, the execution of shore protection works, the institution of a coastal survey system) and the creation of appropriate conditions for implementation by legal, social, economic, financial, and institutional measures. These "implementation" measures are necessary to overcome barriers that prevent technical measures from being taken or from being effective, such as insufficient financing, lack of technical and management know-how, legal opposition, inefficient administration, social rejection, cultural traditions, and adverse concessions.

Elaboration of the optimal policy choice for all coastal regions at risk in the world, including the most appropriate technical and implementation measures, is an enormous task. It requires detailed investigations that cannot be accomplished within the limited time available. Furthermore, the choice of a response strategy involves the sovereignty of each concerned country, and detailed plans are, therefore, the responsibility of local authorities.

For these reasons, the approach chosen here avoids a detailed elaboration of strategies for each country. A set of parameters is defined and then related to the economic, social, institutional, cultural, and environmental aspects of various measures. They are chosen in such a manner that simply evaluating just the order of magnitude yields an impression of the effectiveness and the implementability of different types of measures. Thus, these parameters act as "indicative" criteria. They do not serve to optimize a response strategy, but rather to indicate the problems that are raised by that response strategy.

Finally, it should be noted that policies to protect the coastal zone against storm events may be linked to policies regarding other (natural) disasters: hurricanes, earthquakes, avalanches, fires, and droughts.

MEASURES

Limitation and adaptation are the main policies in combating sea level rise in coastal zones. There is also the possibility of doing nothing. One then has to face the consequences, which are described in Chapter 2 of the Coastal Zone Management report: "Impacts." A brief outline of different policies follows.

This paper emphasizes adaptation. It considers two different adaptive strategies: land-use adaptation and coastal protection. In practice, not just one type of policy will be followed. It would be most efficient to follow some policies simultaneously, with regional differentiations.

Limitation

If the accumulation of greenhouse gases in the atmosphere continues at the present rate, the heat budget of our planet will be strongly disturbed. The consequences are hard to predict, but a sea level rise on the order of 6 m in the long run cannot be ruled out. Adaptation to such a sea level rise implies enormous loss of land and economic and cultural values. Limitation measures, therefore, need to be considered. The impacts of prevention strategies are investigated in other subgroups of the RSWG and will not be considered here.

Limitation aims at limiting the concentrations of greenhouse gases in the atmosphere in order to fight the causes of climate change and sea level rise. Even if limitation measures are taken, the concentration of greenhouse gases in the atmosphere will most likely increase during the next century. This brings about the risk of an additional rise in sea level, which may amount to 1 m or even more. Therefore, it will also be necessary to consider adaptive measures in low-lying coastal areas.

Land-Use Adaptation

If the coastal zone at risk is used freely for living and working, the safety of people could be permanently in danger, and valuable infrastructure could be lost. The risks can be limited, however, by regulating the activities in the coastal zone. Incidental flooding could be accepted, for example, if it were sufficiently controlled so that the zone's people and most valuable investments would remain safe.

Land-use planning in general is a powerful instrument for adaptation to the risk of disastrous events, especially if these events are frequent and protection is difficult. In many countries, land use is already subject to regulation. This planning is often based on socioeconomic arguments, with risk limitation playing a minor role. Examples of risk-limiting land-use planning are:

- no activities that may cause subsidence (extraction of gas, oil, water; lowering of the soil water level, etc.);
- restriction of urban development;
- no vulnerable industries with pollution risks;
- no vulnerable investments close to the seashore.

The adapted land-use strategy requires a large number of adaptive measures:

Implications of Response Strategies

Technical Measures

Construction works should be considered to create locations (mounds) where the population can flee the water in case of inundation. Drainage systems are necessary for the discharge of water when the sea level decreases after inundation. In addition, an early warning system will be necessary to limit the loss of lives by timely evacuation of the population to safe locations. A service with appropriate skills and equipment should be created to assist damaged regions.

Implementation Measures

Legal adaptation will be necessary to support changes in coastal marine boundaries and land-use planning. In high-risk areas (for example, earthquake areas) regulations often exist, mainly referring to construction rules for buildings. One might also consider the establishment of legal requirements for the construction of houses in regions with risk of inundation. In many coastal zones at risk, houses are already built on poles, but legislation exists in only a few countries. Legal adaptation requires the creation of new institutions.

Legal requirements should also exist to clarify who will carry the costs of land-use adaptation. Such costs include the following:

- relocation of property,
- creation of employment in other parts of the country,
- loss of property and income due to inundation, and
- adaptation of infrastructure.

Regions at risk need a high degree of organization to respond to natural disasters with a minimum of damage and loss of lives. A coastal zone administration should be charged with planning and putting into effect adapted land use, control, coastal survey, early warning, and rapid intervention. Educating the population in the coastal zone is also an important concern.

Coastal Protection

Technical Measures

Protection against natural disasters can, in principle, be offered by civil engineering works (see Chapter 4 of the CZM report). Limitation of natural hazards by such construction works is essentially a matter of striking a long-term economic balance between costs and benefits.

The starting point for the protective measures considered here is maintaining the present protection level of human beings and infrastructure in the coastal zone at risk. (As an example, the above-formulated starting point implies that in a region protected by dikes -- assuming that other conditions remain the same -- the dikes should be raised to a level that is approximately equal to the height of the rise in sea level). This starting point often does not coincide with optimal coastal protection, and may even leave some coastal regions with too low a level of protection. This is the case, in particular, for coastal zones which at present are insufficiently protected owing, for example, to recent land occupation or subsidence. These situations require a solution, but in principle this is independent of sea level rise.

Protective measures can be divided into "hard" and "soft" measures. Hard measures include raising dikes (protecting lowlands), constructing storm surge barriers (protecting cities) or closure dams (shortening coastline), and polder building (land reclamation). Examples of soft measures are shore face and beach nourishment, landfill, and environmental restoration.

In many cases, the original shape and floral cover of regions at risk offer an inexpensive and efficient means to diminish the risk and the extent of storm surge disasters. The original environment, however, has in some cases been strongly altered to enhance the exploitation of resources in regions at risk. In those cases, restoration of the natural environment should be considered.

Sea level rise will cause an increase of seepage. Infrastructural works for water drainage are, therefore, necessary, and operational costs (pumping, etc.) have to be considered. An overview of available techniques is given by the U.S. delegation of the Climate Zone Management subgroup.

<u>Implementation Measures</u>

- An adaptive response strategy based on shore protection works is effective only if additional implementation measures are taken.
- An economically and socially acceptable funding mechanism for protective works has to be elaborated. Legislation has to be reviewed and eventually revised to ensure that it is clear who owns the rights to coastal property and who has the responsibility to protect it.
- For the construction, planning, operation, and maintenance of shore protection works and for water management, an appropriate organization ("Coastal Works Administration") is necessary. Such an organization should consist of an intensive and sufficiently trained staff. The creation of training programs and the attraction of technical know-how are, therefore, important prerequisites for the success of a protection strategy.

IDENTIFICATION OF CRITERIA

Each of the two adaptive strategies consists of a set of technical and implementation measures. As mentioned in the introduction, the regional optimalization of response strategies requires a detailed quantitative impact evaluation, which is beyond the scope of this study. Instead, specific criteria will be identified for use in evaluating the effectiveness and the implementability of the adaptive strategies.

Effectiveness

Effectiveness refers to the capability of strategies to save lives and to save economic and environmental values, taking into account the expenses of all measures involved. As mentioned in the previous section, this study addresses only the problem of sea level rise. Presently existing problems of insufficient coastal protection are, in principle, left out of consideration. Consequently, the coastal protection strategy does not go farther than maintaining the present level of protection against inundation. Such a strategy, thus, is not very effective in saving lives and economic values in coastal zones that at present suffer from frequent disastrous inundations.

If in those coastal zones the choice is made for a coastal protection strategy to respond to sea level rise, then an additional effort is required to improve the present situation. The existence of a low coastal protection level influences the choice of a coastal protection strategy in a negative way, as it brings about an increase of costs.

Capability of Maintaining Safety

- Coastal protection works, provided they are properly constructed and maintained, may guarantee the safety of lives at the present level. Land-use adaptation can, in principle, offer the same safety only if a substantial part of the population is displaced. Massive displacements are, however, difficult to deal with. Therefore, in countries where the coastal zone population constitutes a significant part of the total population, a coastal protection strategy is likely to be more effective in protecting lives than a land-use adaptation strategy. The fraction of the population living in the coastal zone at risk is a relevant parameter for assessing the effectiveness of land-use adaptation in maintaining safety.

Capability of Protecting Economic Values

- Sea level rise increases the risk of loss of economic values (capital investments, production capacity) by inundation. This risk of loss can be diminished by land-use adaptation measures. However, certain loss of capital investments and potential production capacity will always exist.

  Coastal protection measures can prevent the risk of an increase in economic losses, but may bring about costs that exceed the benefits. The cost-benefit ratio is a relevant parameter for assessing the economic effectiveness of a shore protection strategy. Without detailed studies, only a very rough estimate can be given of this parameter. A firm conclusion can be drawn only if the ratio is either a multiple or a small fraction of one. In the first case, the economic values in the coastal zone at risk must be small, making land-use adaptation the most appropriate option. In the second case, coastal protection probably is the most effective strategy.

Capability of Protecting Environmental Values

- Sea level rise inevitably affects the coastal environment, as will any adaptive measures. The impact on the environment depends on the type of measures considered. For example, the impact of closure dams will, in general, be greater than the impact of raising dikes.

  A great environmental impact, however, does not necessarily imply a net loss of environmental values. Environmentally valuable new conditions may be created. Adaptive response strategies should aim as much as possible at creating conditions for the maintenance or development of sustainable ecosystems with a high biological diversity.

  Which strategy is most effective -- coastal protection or land-use adaptation -- cannot be decided without detailed studies and requires optimizing of the technical measures. Therefore, within the limited scope of this study, no indication can be given with respect to the environmental effectiveness of adaptive strategies.

Capability of Protecting Cultural Values

- In general, a coastal protection strategy offers more possibilities to protect cultural values in the coastal zone at risk than a land-use adaptation strategy. The effectiveness of protection can be assessed only on the basis of elaborate studies and plans. This criterion, therefore, will not be considered in the further quantitative elaboration.

Implementability

Implementability refers to the capability of countries to carry out the adaptive strategies. This capability depends on economic, technical, cultural, social, legal, and institutional conditions.

Economic Implementability

- Implementation of a coastal protection strategy requires the availability of sufficient financial means to afford the realization, maintenance, and operation of coastal protection works. If a high percentage of gross national product (GNP) is necessary for coastal protection, then implementation of this strategy poses problems.

  These problems may be partly solved by international funding. In the long run, however, national economics should be able to afford the maintenance and further reinforcement of coastal works. In that respect, the ratio of costs of protection works (including maintenance and operation) to the GNP is a relevant parameter for assessing implementability.

Land-use adaptation places restrictions on the economic exploitation of the coastal zone at risk. If the major contribution to the GNP originates from the coastal zone at risk, then such restrictions may be economically unacceptable. The fraction of the GNP contributed by the coastal zone at risk, therefore, is a relevant parameter for assessing the economic implementability of a land-use adaptation strategy.

Technical Implementability

- Coastal protection and land-use adaptation strategies both require the execution of technical measures. Coastal protection, however, asks for works of a larger scale and with a higher degree of complexity than land-use adaptation. Both strategies require technical know-how, especially the coastal protection strategy. The availability of sufficient technical know-how is hard to assess. The presence of hydraulic research institutes and the number of university graduates in the country can be considered as indicators.

Social Implementability

- Social acceptance and cooperation are important conditions for implementing adaptive strategies. The coastal zone population is more strongly affected by land-use adaptation than by coastal protection. Coastal protection, however, requires economic sacrifices of the entire population on behalf of protecting the population in the coastal zone. Participation of the most concerned population groups in the decisions concerning the strategy to be followed favors social acceptance and cooperation. This is possible only if the population is well informed and well organized socially.

  If the coastal zone population constitutes a large part of the total population, coastal protection measures will be supported in large part by those who are directly concerned. This also favors social acceptance. A land-use adaptation strategy that involves the migration of the most threatened groups poses social integration problems if the displaced groups are large in comparison to the host population. Thus, the fraction of the population living in the coastal zone at risk is an important assessment parameter: if this fraction is high, social implementability of a shore protection strategy is easier than that for a land-use adaptation strategy.

Legal Implementability

- Adaptive response strategies to sea level rise raise a considerable number of legal questions, some of which have been raised in the previous section. For the successful implementation of adaptive strategies, the relevant legal questions have to be settled in advance. Countries where some form of land-use planning is already practiced may more easily implement a land-use adaptation strategy than countries lacking this experience. Transfer of experience to those countries will be most useful.

Cultural Implementability

- Adaptive response strategies to sea level rise should, as much as possible, prevent the loss of cultural values in the coastal zone at risk and should respect cultural traditions. Generally, cultural values will be better protected by the possibilities inherent in a coastal protection strategy than by those associated with land-use adaptation. The presence of important cultural values in the coastal zone at risk is an argument in favor of a coastal protection strategy. In contrast, coastal zones that have recently been occupied and exploited could be redeserted, as part of a land-use adaptation strategy, without great loss of cultural values.

Institutional Implementability

- Coastal protection requires administering coastal works with a staff of highly trained technical personnel (see also the section "technical implementability"). The effectiveness of such an organization can be enhanced by encouraging the local population to participate in funding and decision making, and by delegating tasks to local authorities. The same holds even more true for a land-use adaptation strategy.

  In this case, a high degree of organization of the entire coastal zone at risk is necessary. Regulation has to take into account the coherence of all social activities based in the coastal zone at risk. High management skills are required. Moreover, the cooperation of the population has to be ensured. Important conditions for success are a sufficient degree of social organization (see also "social implementability"), and a sufficient educational level of the population in the coastal zone at risk. The degree of general education can be considered as an assessment parameter, especially for the implementability of a land-use adaptation strategy.

RESULTS FROM APPLYING THE CRITERIA

The criteria for choosing a policy to adapt to sea level rise and for assigning priorities to certain types of measures are summarized in Table 1. The information necessary to evaluate these criteria for the major coastal zones at risk is displayed in Table 2. The necessary information includes the following:

- National population of countries with major coastal zones at risk;
- Gross national product;

Table 1. Criteria for Policy Selection

Criterion	Strategies	Required for coastal protection	Assessment Parameters	Required for land-use adaptation
<u>Effectiveness</u>		+	Present protection	•
- Safety		•	POP.CZ/POP.N	-
- Economics		+	Benefit/cost	-
- Environment		Dependent on detailed plans		
<u>Implementability</u>				
- Economic		-	Cost/GP.N GP.CZ/GP.N	-
- Technical		+	Experts	o
- Social		•	POP.CZ/POP.N	-
- Legal		•	Planning exists	+
- Cultural		•	Values	-
- Institutional		o	Education	+

CZ = Coastal zone at risk.
POP. = Population.
N = National.
GP. = Gross product.
Cost = Cost of maintaining present level of coastal protection.
Benefit = Increase of economic risk for 1 m sea level rise.
Required: + = high/much
o = medium
- = low/few
• = no requirement

Table 2. Source Data for Policy Selection

Country	POP.N $*10^6$	GP.N $*10^9$ $	Shore-length km	Prot. cost $*10^6$ $	POP.CZ $*10^6$	GP.CZ $*10^9$ $	Benefit $*10^9$ $
Argentina	32	35	2,000	200	3.2	3.5	0.1225
Bangladesh	108	15.3	2,000	200	15.12	2.1	0.0735
Brazil	140	240	2,000	200	1.4	2.5	0.0875
China	1,000	1,500	2,000	200	10	15	0.525
Egypt	50	63	1,800	180	8	10	0.35
Gambia	0.7	0.5	400	40	0.161	0.1	0.0035
Indonesia	180	90	2,000	200	18	9	0.315
Iraq	16	40	100	10	0.96	2.4	0.084
Italy	58	670	400	40	1.74	20	0.7
Maldives	0.2	0.09	400	40	0.2	0.09	0.00315
Mozambique	15	3.9	1,000	100	1.5	0.4	0.014
Netherlands	15	203	700	90	8.1	110	3.85
Nigeria	105	100	2,000	200	10.5	10	0.35
Pakistan	106	40	1,600	160	3.18	1.2	0.042
Senegal	7	4.7	1,000	100	0.98	0.7	0.0245
Surinam	0.4	1	600	60	0.252	0.6	0.021
Thailand	56	40	400	40	7.84	5.6	0.196
U.S.A.	250	6,000	1,600	160	2.5	60	2.1
Vietnam	60	?) 12	1,000	100	6	1.2	0.042
Total	2,199.3	9,058.49	23,000	2,320	99.633	254.39	8.90365

GP = Gross product [$/year]
CZ = Coastal zone
POP = Population
N = National
Cost = Cost of maintaining present level of protection [$/year].
Benefit = Increase of economic risk for 1 m sea level rise [$/year].
Thumb rules:
GP.CZ/GP.N = POP.CZ/POP.N
FREQ = Increase of inundation frequency = 0.01
CAP.INV = Capital investment in CZ = 5* GP.CZ
Benefit = FREQ * (0.5 * CAP.INV + GP.CZ) = 0.035 * GP.CZ
Cost = 100,000 * shore length (km)

Sources: The Europa Yearbook 1988. World Survey, Vol. 1 and 2, Europa Publ. Ltd., 1988, London; Times World Atlas; Criteria for Assessing Vulnerability to Sea Level Rise - A Global Inventory of High Risk Areas. UNEP/Delft Hydraulics, May 1989, Report nr. H838; Dutch Coastal Protection after 1990. Ministry of Transport and Public Works, Rijkswaterstaat, Tidal Water Division, April 1989 (in Dutch).

Implications of Response Strategies

- Shore length (including floodplains and bays) of the coastal zone at risk;
- Cost of maintaining safety at the present level;
- Population of the coastal zones at risk;
- Gross product of the coastal zones at risk; and
- Increase of economic risk (average loss of values due to inundation) at 1 m sea level rise.

The assessment parameters corresponding to the criteria in Table 3 are presented in a number of world maps and summarized for each country and each strategy in Tables 4 and 5. The status of the present information is very preliminary. Some data are obtained by applying rough approximations and only have an indicative value; the workshops of Miami and Perth should provide more complete and reliable data.

For the assessment parameters, only three ranges of values are indicated, with the medium range corresponding more or less to a world average. This qualitative approach is chosen not only because of the uncertainty of the underlying data, but also because of the objective of this study, which is limited to worldwide indications. The assessment parameters and corresponding low, medium, and high ranges are indicated in Table 3.

DISCUSSION

As stated in the introduction, the aim of this study is, to the extent possible, to express policy implications of climate change and sea level rise in measurable quantities. At the present state of this study, the quality and completeness of the input data are insufficient to draw reliable conclusions. The writing of this section should, therefore, be postponed.

However, to test the usefulness of the chosen approach, a preliminary version is drafted. This section, which should be considered mainly as an exercise, will discuss the following subjects:

- Which coastal zones at risk already have an implementable and effective strategy for adapting to sea level rise?

- For which coastal zones at risk is the implementation of an effective strategy a problem that cannot be solved in the short term by national means?

- What actions at a national level can improve the implementability and the effectiveness of adaptive strategies?

- What international actions can assist in the national implementation of adaptive strategies?

Inspection of the set of criteria shown in Table 1 leads to the following conclusions:

Table 3. Assessment Parameters

Parameter	Description	Low	Medium	High
Present protection	(Frequency of inundation) per (year)	< 10	10-100	> 100
POP.CZ/POP.N	Fraction of the population living in the coastal zone at risk.	< 10%	10-50%	> 50%
Benefit/cost	Increase of risk of economic losses at 1 m sea level rise vs. cost of maintaining present level of coastal protection	< 0.5	0.5-2	> 2
Cost/GP.N	Cost of maintaining present level of coastal protection vs. gross national product	< 0.005	0.005-0.05	> 0.05
GP.CZ/GP.N	Fraction of gross national product originating from the coastal zone at risk	< 10%	10-50%	> 50%
Experts	Presence of a hydraulic institute and/or a relative number of graduates superior to the world average	No/No	Yes/No No/Yes	Yes/Yes
Education	Educational level	< 0.5	0.5-1.5	> 1.5
Planning	Land-use planning exists	No		Yes
Values	Important cultural values are present	No		Yes

Table 4. Assessment Parameters for Coastal Protection Strategy

Country	Effectiveness		Implementability	
	Technical: experts	Economic: benefit/cost	Economic: cost/GP.N	Present protection
Required	H	H	L	H
Argentina	--	M	M	--
Bangladesh	--	L	M	--
Brazil	--	L	L	--
China	--	H	L	--
Egypt	--	H	L	--
Gambia	--	L	H	--
Indonesia	--	M	L	--
Iraq	--	H	L	--
Italy	--	H	L	--
Maldives	--	L	H	--
Mozambique	--	L	M	--
Netherlands	--	H	L	--
Nigeria	--	M	L	--
Pakistan	--	L	L	--
Senegal	--	L	M	--
Surinam	--	L	H	--
Thailand	--	H	L	--
USA	--	H	L	--
Vietnam	--	L	M	--

H = High
M = Medium
L = Low
-- = Not yet available.

Table 5. Assessment Parameters for Land-Use Adaptation Strategy

Country	Effectiveness		Implementability				
	Lives POP.CZ/POP.N	Economic benefit/cost	Economic GP.CZ/GP.N	Social POP.CZ/POP.N	Legal planning exists	Cultural values	Insti-tutional education
Required	L	L	L	L	H	L	H
Argentina	L	M	L	L	--	--	M
Bangladesh	M	L	M	M	--	--	L
Brazil	L	L	L	L	--	--	M
China	L	H	L	L	--	--	M
Egypt	M	H	M	M	--	--	M
Gambia	M	L	M	M	--	--	M
Indonesia	L	M	L	L	--	--	M
Iraq	L	H	L	L	--	--	M
Italy	L	H	L	L	--	--	H
Maldives	H	L	H	H	--	--	M
Mozambique	L	L	L	L	--	--	L
Netherlands	H	H	H	H	--	--	H
Nigeria	L	M	L	L	--	--	M
Pakistan	L	L	L	L	--	--	L
Senegal	M	L	M	M	--	--	L
Surinam	H	L	H	H	--	--	H
Thailand	M	H	M	M	--	--	M
USA	L	H	L	L	--	--	H
Vietnam	L	L	L	L	--	--	M

H = High
M = Medium
L = Low
-- = Not yet available.

Implications of Response Strategies

1.) Nations with a high GNP:PROTECTION COST ratio and sufficient technical know-how are capable of implementing a coastal protection strategy. For some parts of the coastal zone, a land-use adaptation strategy may be chosen if this is more effective and more easily implemented.

Most of the developed countries are in this position (see Table 4). The implementation and effectiveness of adaptive strategies may be improved by observing national recommendations (see below).

2.) Nations with a medium GNP:PROTECTION COST ratio will hardly be able to afford protection of the entire coastal zone at risk, especially if the present protection level is already (too) low. If, in addition, a high fraction of the population is living in the coastal zone at risk, and if a high fraction of the GNP originates from this area, then the alternative land-use adaptation is hard to implement. Nations facing such a problem are Bangladesh and, to a lesser degree, Senegal. In these countries, the conditions for institutional implementation are also unfavorable because of the population's low educational level. The latter problem may also impede the implementation of a land-use adaptation strategy in Mozambique (see Table 5).

3.) Nations with a low GNP:PROTECTION COST ratio can hardly afford any coastal protection. If a high fraction of the population lives in the coastal zone at risk and provides a substantial part of the national income, then the alternative of land-use adaptation strategy also is hardly practical. Nations in this position are the Maldives, Surinam and, to a lesser degree, Gambia (see Table 5). With the present national means, these nations cannot adapt to sea level rise in an effective and implementable manner. Therefore, a considerable fraction of the population, prosperity, and cultural values will be subject to high risk if no international assistance is provided.

The above conclusions should lead to actions on national and international levels.

National Actions

Recommendations for action at a national level mainly follow from the conditions for effectiveness and implementability. Tables 4 and 5 show that a number of these conditions are better satisfied in some countries than in others. The list of recommendations may, however, be used as a checklist for actions that should eventually be undertaken. The actions are listed in the approximate order in which they have to be taken.

<u>National Policy Analysis of the Sea Level Rise Issue</u>

Such an analysis may follow the lines of this study, but should be more detailed. It should prepare a policy decision for the optimal strategy to be followed and it should yield insight into the actions to be undertaken. It should be clear whether the present situation can be considered as a reference, or whether a higher protection level is needed.

Detection of Activities or Construction Detrimental to Coastal Safety

Examples are human-induced subsidence or diversion of sediment from eroding parts of the coast. Measures to stop these activities, adapt construction, or diminish the negative effects should be considered. In principle, the emission of greenhouse gases also falls into this category of actions.

Collection of Knowledge of Coastal Zone Management

Countries that are in similar situations should be encouraged to exchange information on how to deal with coastal problems. Coastal zone management staff members should participate in training programs.

Administration

The responsibilities of coastal defense should be clearly established, along with the proprietorship of the shore zone and coastal protection structures. Planning, construction, maintenance, and operation of coastal infrastructure, regulation and control, information, early warning, intervention, and assistance are tasks that need to be carried out. Participation of the coastal population in decision making and funding should be considered. Executive tasks can be delegated to local authorities.

Land-Use Planning

Any new developments in the coastal zone at risk should be examined with respect to their sensitivity to sea level rise. Risk-limiting regulations are necessary for the installation of new activities. Space for coastal retreat or for protection works should be reserved. Environmental values in the coastal zone need protection. When land-use planning is implemented, indemnity of expropriation should be regulated.

Coastal Survey and Early Warning

Regular inspection of coastal protection structures is necessary to detect shore retreat and a diminished capability of the protective structures to resist storm surges. A service should be established to take charge of short-term prediction of storm surges and early warning of potential danger.

Environmental Restoration

In many cases, the natural environment contributes to the safety of the coastal zone against inundation. Restoration should be considered in those regions where the coastal environment has been altered by human activities.

Education

The population of the coastal zone at risk must become aware of the potential danger of flooding to better understand and obey risk-limiting regulations. Information programs for the population should be organized.

Implications of Response Strategies

Attention should be given to the importance of birth control in densely populated coastal zones at risk.

Funding

In national financial planning, funds should be reserved for coastal protection. An equitable cost sharing should be devised between the population of the coastal zone at risk and the rest of the nation, and between different categories of the population.

Technical Measures

Technical measures should be elaborated, estimated, and planned to prepare for the execution of the preferred adaptive strategy. Any existing backlog of coastal protection has to be addressed by reinforcement of coastal protection works, creation of high-water flight areas, etc.

International Actions

The international community can assist coastal zones at risk to adapt to sea level rise in essentially three areas.

Technological Assistance

The United Nations can establish a service of experts in adaptive measures, who would be available to assist any country with a coastal zone at risk. A paper on this subject has been prepared by the IPCC-RSWG as part of its Task B activities.

Financial Assistance

For the nations with medium or low GNP:PROTECTION COST ratio, funding is one of the major problems in adapting to sea level rise. Possible funding mechanisms will be discussed in more detail in the chapter prepared by the delegation of New Zealand.

Relocation

Some nations may encounter unsolvable problems in the implementation of both a coastal protection strategy and a land-use adaptation strategy. This may be the case for certain atoll islands (for example, the Maldives). With a sea level rise of 2 m or more, these nations will disappear entirely. Appropriate technical protection measures are hardly available. Certain islands will have to be abandoned.

International assistance will be necessary to facilitate the integration of these populations into other countries. The eventual disappearance of certain nations poses problems that deserve the attention of the international community. The United Nations should designate a special commission to prepare possible solutions for relocation problems. Such a commission might address the problem of "environmental refugees" due to global changes in a broader sense.

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ENVIRONMENTAL IMPLICATIONS

ENVIRONMENTAL IMPLICATIONS OF SHORE PROTECTION STRATEGIES ALONG OPEN COASTS (WITH A FOCUS ON THE UNITED STATES)

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INTRODUCTION

Land loss is a major problem along the U.S. coasts (Figure 1). Erosion was first identified along the New Jersey coast where some of the earliest beachfront development of hotels and cottages occurred. Almost every conceivable form of shore protection has been attempted in northern New Jersey, including construction of seawalls, groins, and jetties as well as beach nourishment. Sea level rise induces coastal erosion, and the accelerated rate of rise due to global warming will only exacerbate the present problems.

SHORE STABILIZATION

Shore stabilization measures can be divided into two categories: rigid and nonrigid (U.S. Army Corps of Engineers, 1984). The former often involves the emplacement of seawalls, bulkheads and breakwaters (shore-parallel structures), and jetties and groins (shore-perpendicular structures). Each of these structures has been shown to induce adverse effects in particular settings. For instance, the Ocean City inlet jetties have caused sand blockage along the Maryland coast for 50 years; the result has been the downdrift erosion of northern Assateague Island (a national seashore) at a rate of 10 meters per year. Sea Bright, New Jersey, is protected by a massive seawall, but at the expense of the recreational beach.

Elsewhere, groins have been shown to cause extensive damage to downdrift beaches, the most infamous case perhaps being Westhampton Beach at Long Island, New York.

Figure 1. Continuing shore erosion threatens this parking lot at Coast Guard Beach, Cape Cod, Massachusetts. This is a national problem as best estimates are that about 90 percent of the U.S. sandy beaches are experiencing erosion.

The nonrigid approaches of beach nourishment and dune building are generally preferred by coastal communities because the soft interface of a sandy beach is preserved for recreational pursuits, and yet storm protection can be gained if adequate sand quantities are available. This approach has the least environmental impact of any approach, but care still must be exercised. Possible problems involve both the dredging and placement of sand. Biologically productive sandy shores must be delineated, and they must not be disturbed. Also, adjacent declinate ecosystems, such as coral reefs, must be carefully guarded to protect them during dredging operations. Actual placement of the offshore sand on the beach will obviously kill any of the marine organisms in the dredged material as well as bury the beach invertebrates (e.g., ghost and mole crabs). Studies have shown, however, that the beach ecosystem recovers in a few years because organisms living in such a dynamic environment are adjusted to severe perturbations from storms and can repopulate the nourished beach.

Shore-Parallel Structures

Shore-parallel rigid engineering structures can be further subdivided into onshore (seawalls, bulkheads, and revetments) and offshore (breakwaters) approaches. The Galveston seawall along the north Texas coast is probably the most important such structure in the United States. On September 8, 1900, Galveston was demolished by a major hurricane, and 6,000 people were killed. A seawall constructed after this disaster successfully protected the residents and buildings from direct storm assault on the city (Figure 2). The seawall was constructed approximately 100 meters landward of the shoreline in 1904, but the beach had completely disappeared three decades later (National Research Council, 1987). While the seawall has functioned well, the recreational beach has been lost along this eroding shore. Additional riprap and groins have been emplaced to protect the seawall toe and to prevent failure by undermining during a severe storm.

Seawalls are constructed to protect the upland areas at the expense of the beach along retreating coasts. Most likely the seawall would not have been built if the beaches had been stable or accreting. It is easy to understand why the beach will be pinched out of existence with the confluence of a migrating shoreline and a static structure.

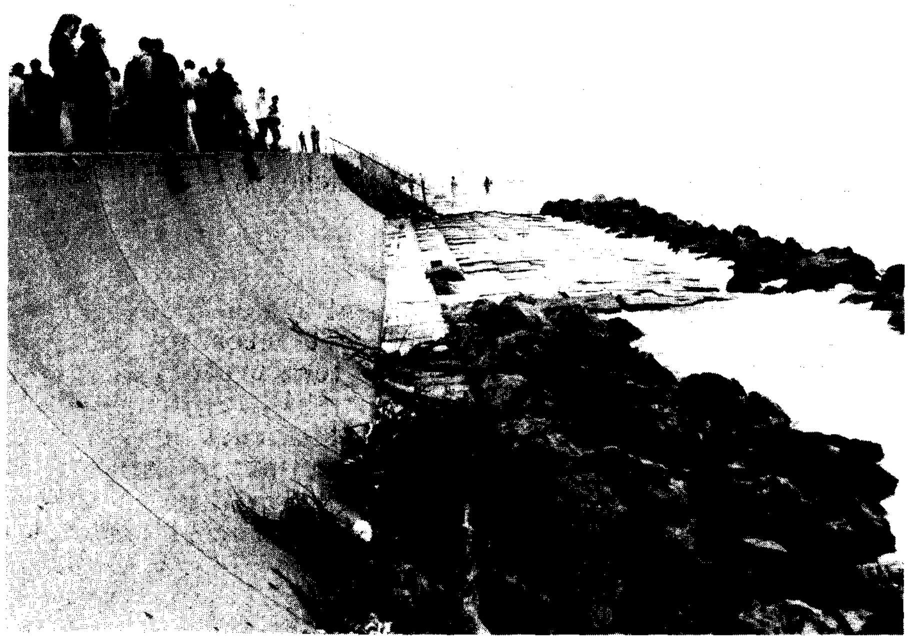


Figure 2. The Galveston seawall has been effective in protecting the city from certain hurricane destruction but at the expense of the recreational beach.

Environmental Implications

There is much conjecture that seawalls actually accelerate erosion of beaches by reflecting a portion of the incident wave energy and increasing turbulence at least locally. While it is clear that a certain portion of the wave energy can "rebound" off the frontal face of the seawall, it has not been proven scientifically that seawalls actually increase beach erosion despite all the rhetoric to the contrary by environmental zealots. This issue needs to be thoroughly researched by laboratory studies and, especially, by quantitative field studies.

Some coastal states have banned further seawall construction, notably North Carolina and Maine. Their position is that the shore should be allowed to naturally retreat and still maintain the recreational beaches. Because incessant beach erosion will eventually result in destruction of human development without protection, the rhetorical question here is, "Do you want bedrooms or beaches?" No new major seawalls are presently being planned in the United States, largely because of their huge expense and the public's preference for "soft" solutions.

It should also be kept in mind that seawalls and bulkheads do not always work. These structures can be destroyed in a storm or simply overtopped by a very high storm surge as happened during Hurricane Hugo along Folly Island, South Carolina (Leatherman and Moller, 1990).

Breakwaters are emplaced offshore to break down the waves, reducing the wave energy and longshore currents. Unfortunately, these massive structures are often too effective in this regard, causing severe erosion of downdrift beaches such as at Santa Monica, California. This breakwater did not work correctly (i.e., as designed) until it was subsequently damaged in a 1950s storm to allow some wave energy to pass through and prevent the building of a beach tombolbo (Weigel, 1964).

The classic case of the adverse environmental impacts of breakwaters is illustrated by the one built in Santa Barbara, California. This breakwater was constructed during 1927-28 to provide safe anchorage for recreational boats (Figure 3). The implications were not immediately evident even as the downdrift beaches experienced severe erosion and storm destruction of buildings and infrastructure. The cause and effect relationship was only later realized; attention was drawn to the adverse impacts of these coastal engineering structures when the littoral drift system was interrupted. Breakwaters are expensive to build and maintain, and they have found little utility along the U.S. coasts.

Shore-Perpendicular Structures

The two common types of coastal engineering structures built perpendicular to the shore are groins and jetties. Groins are the most widely used structures in the coastal zone, but they are also perhaps the least understood in terms of their engineering design. Groin design is considered both an art and a science in terms of their length, spacing, height, and permeability.

Figure 3. The Santa Barbara breakwater and harbor represent a classic case of interruption of the longshore sediment transport system with updrift accumulation of sand as a spit and severe erosion of adjacent, downdrift beaches.

The current debate and dilemma surrounding the Westhampton Beach groin field epitomizes the problem for downdrift property owners (Figure 4). The affected parties are lodging a $200 million lawsuit against the county, state, and federal governments for the loss of their beach and now their houses. It should be noted that this groin field was not built to engineering specifications with respect to completion of the entire field or sand emplacement requirements. This case illustrates the "politics of shore erosion" (Tanski and Bokuniewicz, 1989).

Groins essentially "rob Peter to pay Paul" as no new sand is created, just redistributed across the beach profile. This question of "sand rights" in the coastal zone could be considered as akin to riparian (water) rights in the U.S. Southwest. It should also be remembered that groins do not always work. For example, Hurricane Hugo swept over Folly Beach and the existing groins seemed to play little role (negative or beneficial).

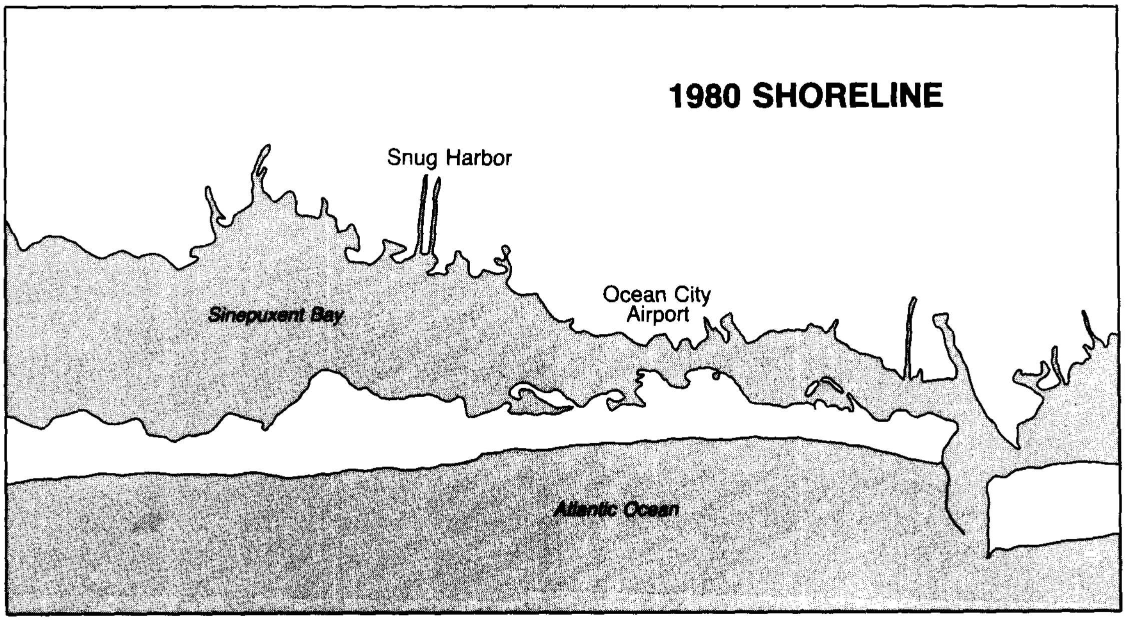
Figure 4. The effects of groins on the shoreline at Westhampton Beach, Long Island, New York, are obvious. While some property owners have greatly benefited from the emplacement of these shore-perpendicular structures, the downdrift beaches are quickly retreating and the sea is actively claiming residences.

Jetties are constructed at entrances to tidal inlets to maintain an open channel for navigational purposes. Jetties often serve as total littoral barriers to longshore sediment transport, and therefore these large, rigid structures can result in extreme starvation of downdrift beaches.

Ocean City, Maryland, serves as a good case study of the impacts of jetties on the adjacent shorelines (Figure 5). A severe hurricane in August 1933 opened this inlet, and it was consequently stabilized by the Corps of Engineers during 1934-35. As the updrift shoreline accreted, the Ocean City fishing pier had to be lengthened twice. The jetties filled to capacity in the 1950s, capturing all the sand possible updrift of the jetties. Since this time, the sand has been shunted offshore to form an immense ebb tidal shoal.

Figure 5. Ocean City Inlet divides the Maryland coast into Fenwick Island (site of Ocean City) and Assateague Island National Seashore. Prior to inlet breaching and subsequent inlet stabilization, this shoreline was relatively straight. The large-scale offset at the inlet and arc of erosion along northern Assateague Island are visible from space.

The jetties have completely blocked the sediment moving southward along the coast at an annual net rate of 114,000 cubic meters per year so that northern Assateague Island has been sand starved, rapidly retreating landward with an average erosion rate of 11 meters per year (Leatherman, 1984). During the past 50 years, since inlet stabilization, the northern end of the island has already migrated landward more than its width into the adjacent bay. It is expected that this will result in the next few decades in a 3-kilometer-wide breach in the barrier island continuity along the Maryland shore (Figure 6). Installation of a sand bypassing system, which is critically needed, is not expected because of the initial large expense, high operating costs, and problems elsewhere with reliability.



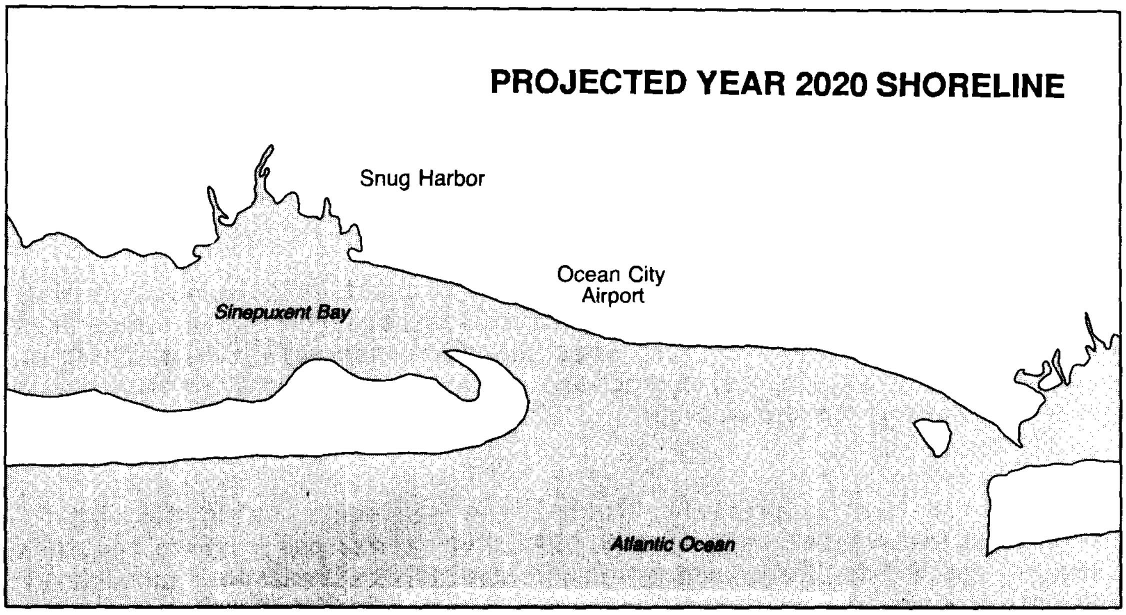


Figure 6. A large breach in northern Assateague Island is predicted based on an extrapolation of historical shoreline changes. Ocean City citizens and Maryland politicians do not seem alarmed about this eventuality because "ponies don't vote."

Some jetties have been designed on insufficient information or on erroneous analysis of existing data. A case in point is the east pass of Coctawhatchee Bay, where the weir section was placed on the wrong side of the channel (Leatherman, 1989). The long-term, net direction of longshore sediment transport had not been correctly determined, resulting in design failure of this engineering work.

Beach Nourishment

There has been a shift from rigid or hard engineering structures to nonrigid or soft engineering solutions in the past few decades. By placing sand from outside the nearshore sand-sharing system, it is possible to build back the beach and maintain this soft interface. Beach nourishment is the method of choice for most U.S. coastal communities as a means of providing recreational beaches and storm buffers.

Sand nourishment involves dredging material from a source area and dumping it on the nearshore area to create or augment an existing beach. In both areas, care must be exercised to avoid environmental problems. The source material must be compatible with the existing beach material in terms of grain size and chemical qualities (e.g., not polluted). In earlier times, material was dredged from the bays and lagoons and pumped onto the adjacent beaches. While inexpensive per volume extracted, much of the material was too fine to remain on the open-coast beach. Perhaps more important, highly productive estuarine sediments were disturbed, resulting in mass mortality of endemic species. This practice has ceased along the U.S. coasts because of its environmental implications and ineffectiveness.

Sand for beach nourishment is now largely obtained from offshore shoals that are sufficiently far out to ensure that their removal does not accelerate erosion (Figure 7). Environmental inventories are necessary to evaluate and avoid highly productive offshore shellfish beds, especially clams. Also, the dredgers should avoid excavating deep holes in the seabed that will change wave refraction patterns, perhaps concentrating wave energy on one part of the shore. In Florida, special care was taken because the sand was being dredged from between coral reefs, which are susceptible to high water turbidity. While the Miami Beach project was well planned and executed, the anchor lines on the dredge ships were moved across the tops of the reefs by currents, scraping off the living organisms.

Water turbidity can also be a problem with sand emplacement unless the material is devoid of fine-grained sediments. In any case, the beach invertebrates (e.g., ghost and mole crabs on the U.S. Atlantic coast) will be buried and killed by sand pumping and burial. Fortunately, these populations can recover quickly, and species numbers can be back to normal within a few years following beach nourishment.

Figure 7. Beach nourishment along the Florida Atlantic coast is the preferred response to mitigate erosional problems and to maintain a wide recreational beach.

SUMMARY

Beach nourishment is considered the most environmentally sensible and compatible form of shore protection. Some people also argue that if the sand filling is a mistake, then much less damage has been done to the coastal environment than with emplacement of hard engineering structures. After all, nature can take care of the problem by washing the sand away. By contrast, hard engineering structures rarely have been removed once emplaced regardless of the adverse consequences. The environmental implications and the long-term economic costs have often been underestimated in the continuing process to "shore-up" the coast.

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IMPLICATIONS OF RESPONSE STRATEGIES FOR WATER QUALITY

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ABSTRACT

Human responses to projected climate changes and associated sea level rise will affect water quality in many ways. In many areas, allowing natural shoreline retreat and inundation will have an adverse effect on water quality. Erosion of wetlands will increase turbidity. Saltwater will migrate upstream in estuaries, endangering water supplies. Reduced discharge from upstream impoundments will aggravate estuarine circulation problems and will enhance saltwater intrusion. Some coastal areas, however, will benefit from increased circulation of coastal waters. In many areas, rising water tables will inundate septic tanks and leach into fields and hazardous waste sites, causing health and eutrophication problems.

In most areas, holding back the sea will have an adverse effect on water quality. Dredge and fill may create noxious conditions as dredged areas stagnate. Dikes and levees will isolate wetlands and water bodies from adjacent estuaries and will affect sedimentation rates and salinities. Tidal barriers will enclose estuaries for increasing periods of time, thus impeding natural circulation; estuarine salinities will be significantly affected, and residence times for pollution will increase drastically.

INTRODUCTION

Responses to sea level rise can range from planned retreat from coastal areas to increasingly more costly engineering solutions, including dredge and fill, emplacement of tidal barriers, and construction of dikes and levees. Retreat can leave natural terrains and pollutant sources exposed to leaching and erosion, resulting in degradation of water quality. Ironically, many engineering structures intended to protect against the ravages of the sea will cause problems in water quality by modifying mixing and discharge rates.

RETREAT

The option of doing nothing in response to sea level rise will undoubtedly be exercised in many areas of the world. In a few instances water quality will improve compared to present conditions, but in most cases water quality will suffer as a result.

EROSION OF WETLANDS AND LOWLANDS

Erosion of extensive wetlands will create additional turbidity in some areas, with adverse effects on marine flora and fauna. For example, simulation of conditions in Key Largo and the Everglades of southeastern Florida indicates that a large area of mangrove swamp and freshwater marsh would be inundated and eroded by a one-meter rise in sea level by the year 2100 (Figure 1). Even very conservative estimates of erosion and transport of wetland soils suggest that high turbidity would result, excluding seagrass from all but the shallowest

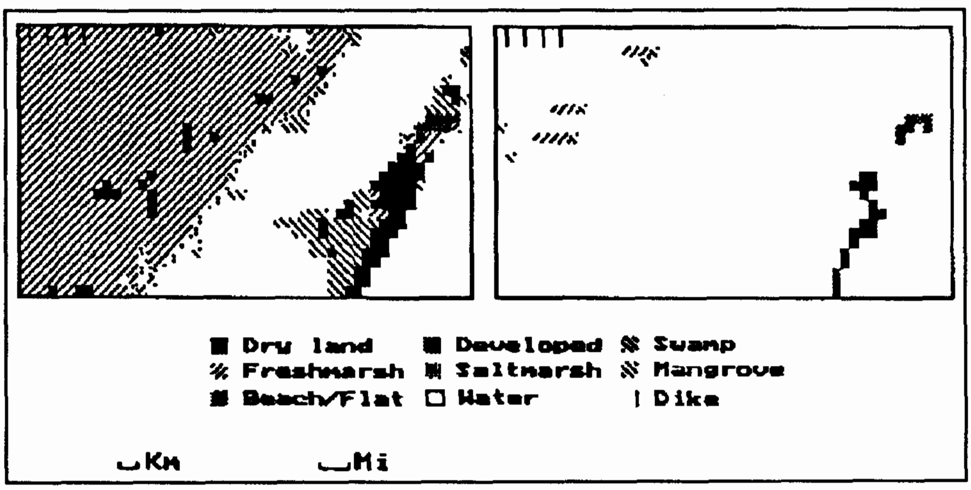


Figure 1. Key Largo and the Everglades, southeastern Florida; present conditions and predicted conditions with a one-meter sea level rise by the year 2100, with residential and commercial developments protected (Park et al. 1989).

waters and killing the coral reefs. Cessation of reef-building along the Florida coast during the postglacial sea level rise probably occurred as a result of similar erosion of soils on inundated lowlands (Lighty et al., 1978).

Many waste disposal sites will also be subject to erosion, especially if they have been constructed above ground level (Flynn et al., 1984). Unless these facilities are protected or moved, erosion will release toxic chemicals and other hazardous materials into the coastal environment.

IMPACTS ON ESTUARIES

Salinity

In response to sea level rise, saltwater in estuaries will migrate upstream (Figure 2). This saltwater intrusion will displace coastal fisheries and ecosystems, perhaps increasing shellfish grounds (Hekstra, 1986) but also introducing predators (such as the oyster drill) that are excluded by lower salinities (deSylva, 1986). It also will endanger municipal water intakes (Hull and Titus, 1986). The problems will be aggravated by decreased average discharge that can be expected for many rivers under conditions of climate change. However, upstream saltwater intrusion may be ameliorated by adjusting river channels to higher sea level by means of sedimentation (Goemans, 1986).

Upstream reservoirs could cause further problems with saltwater migration by decreasing freshwater discharge. However, controlled releases of fresh water to coincide with high tide levels, as practiced now by many water basin authorities, could help alleviate the problem. Trapping of sediments in reservoirs also will prevent adjustment of channels and adjacent wetlands to sea level rise, thereby perpetuating both saltwater migration and inundation (Broadus et al., 1986).

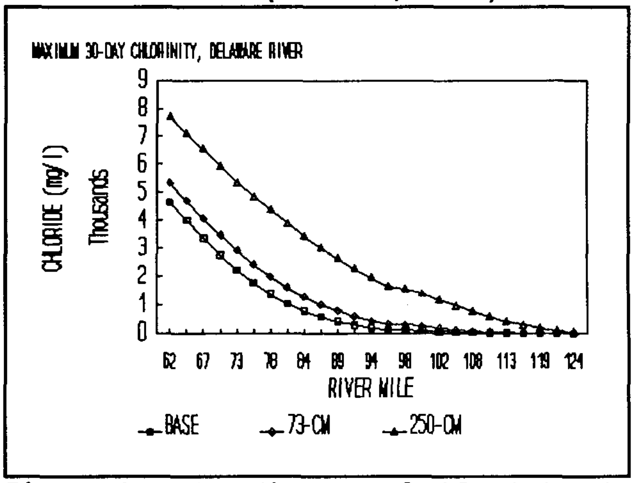


Figure 2. Distribution of chlorinity in the Delaware River, U.S.A., at present and as a function of sea level rise (Hull and Titus 1986).

Some coastal areas that now have higher or lower salinities due to restricted exchange with the open ocean will benefit from more normal marine salinities as tidal prisms increase and as barrier islands and fringing reefs are breached and inundated.

Turbidity and Sedimentation

Only a small fraction of sediment transported into estuaries reaches the Continental Shelf. For example, 91% of the sediment transported into the upper Chesapeake Bay is retained there (Meade, 1972a). Most of the coarser bed load is deposited near the toe of the salt wedge that extends upstream beneath the less dense freshwater wedge; sea level rise would cause this material to be deposited farther upstream. Sedimentation of suspended particles occurs initially near the turbidity maximum, which is just downstream from the toe of the salt wedge (Meade, 1972b). The turbidity maximum would also move upstream with sea level rise.

Environmental Implications

Increased Stagnation at Depth in Restricted Areas

In well-stratified coastal waters, deepening conditions may increase the potential for stagnation of bottom waters and development of anoxic conditions.

IMPACTS ON GROUNDWATER

As of 1977, 21 coastal states in the United States had problems with saltwater intrusion into aquifers, because of excessive pumping (Newport, 1977). Saltwater intrusion will become a greater problem with sea level rise, especially if coastal communities and farms are forced to rely more on groundwater as surface water supplies become saline.

The Ghyben-Herzberg principle has been used to estimate the extent of saltwater intrusion into unconfined aquifers as a result of sea level rise (Kana et al., 1984). The saltwater-freshwater interface below sea level is 40 times the freshwater head above sea level, and the interface and head are assumed to shift accordingly with sea level rise (Figure 3). The horizontal displacement has two components: x, which is a function of the slope, and y, which is a function of sea level rise. However, the principle assumes equilibrium conditions, which may not be attained with substantial groundwater discharge and with rapid sea level rise; the result is usually a worst-case estimate. For example, the saltwater front in the Biscayne aquifer extends several miles seaward past where the Ghyben-Herzberg principle predicts it should be (Lee and Cheng, 1974).

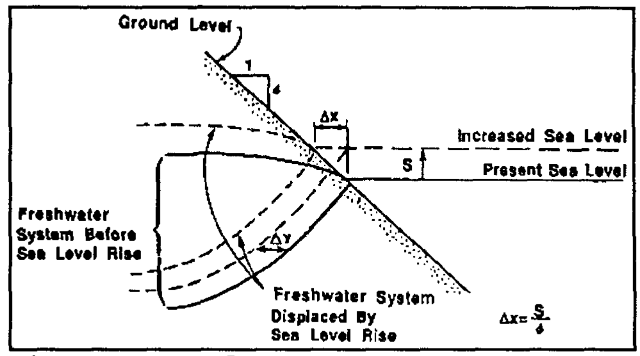


Figure 3. Saltwater intrusion into an unconfined coastal aquifer as a function of sea level rise (modified from Mehta and Cushman 1989).

DREDGE AND FILL

One response that can be undertaken by individual property owners is to dredge canals and use the dredge fill to raise individual properties. However, these finger-fill canals can become anoxic with deepening water conditions. To promote adequate mixing and aeration, the U.S. Environmental Protection Agency (1975) has recommended that canal depth not exceed 1.2 to 1.8 m. If 4.0 mg/L dissolved oxygen is taken as the minimum desirable concentration, even a 0.5-m rise in sea level will cause a significant water quality problem (Figure 4).

DIKES AND LEVEES

Dikes and levees are earthen embankments constructed to prevent flooding of lowland areas. By isolating wetlands and water bodies from normal exchange with estuaries and rivers, they reduce sedimentation rates and alter salinities. They also prevent natural flushing of pollutants. As the hydraulic head increases with rising sea level, water tables will rise and seepage of saltwater will increase in areas below sea level. This problem is already affecting Dutch agricultural lands (Goemans, 1986; van Dam, 1986), and substantial sea level rise would aggravate the problem further (Figure 5).

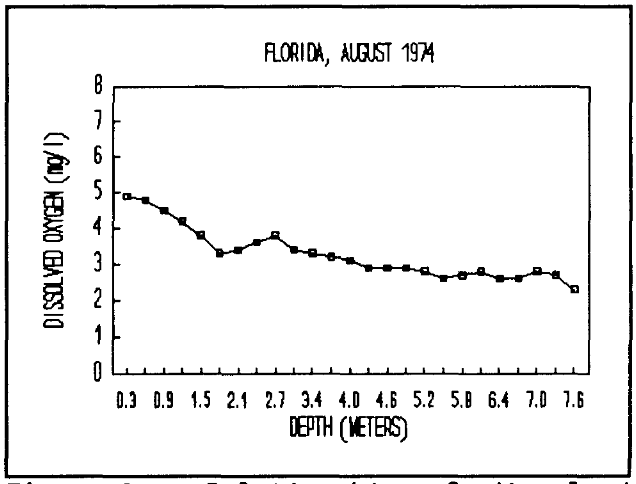
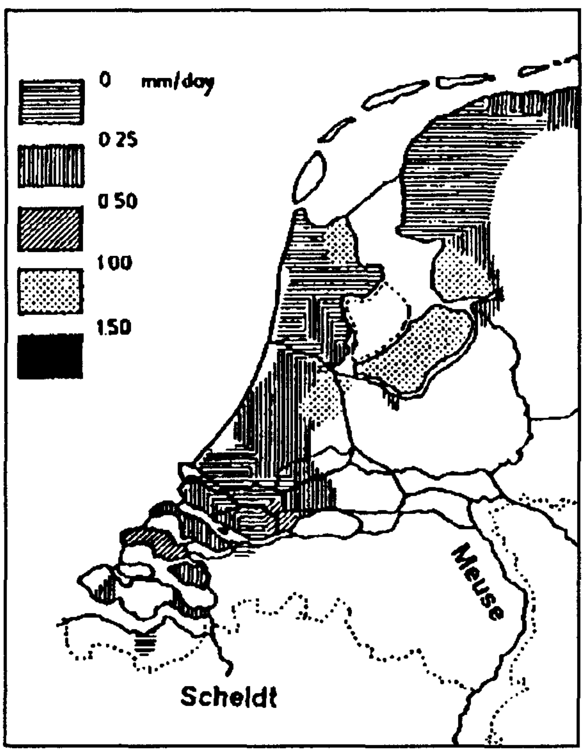
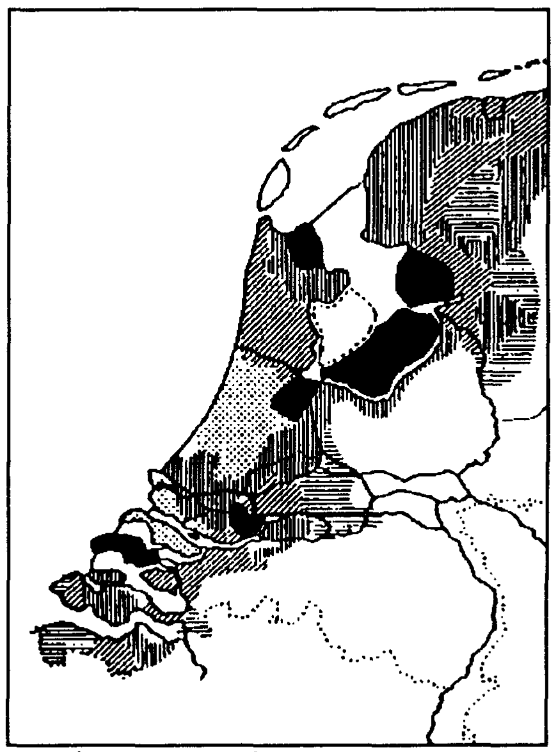


Figure 4. Relationship of dissolved oxygen to depth of fingerfill canals in Florida (U.S. Environmental Protection Agency 1975).



A Present



B Five-meter rise

Figure 5. Change in seepage of saltwater in the Netherlands with a five-meter sea level rise (DeRonde, 1989).

Environmental Implications

TIDAL BARRIERS

Movable barriers are constructed across estuaries to prevent storm surges from moving upstream; they also can be designed to ameliorate the effects of tidal flooding associated with higher sea level. Barriers have been installed to protect areas such as London, England; Osaka, Japan; Providence, Rhoda Island (U.S.); and the Rhine Delta, the Netherlands. Barriers are currently being planned to protect Venice, Italy, by sealing off the tidal inlets to Venice Lagoon (Carter, 1987; Pirazzoli, 1987). The problem with such barriers is that they impede circulation, thus affecting salinities and trapping pollutants. Extensive studies of Venice Lagoon (Figures 6 and 7) have shown that water quality would be much worse under more limited exchange through the tidal inlets; algal blooms would increase due to eutrophication, and residence times of toxic pollutants would also increase. However, the surface of the lagoon is inclined to the southwest with the persistent Bora wind, which causes about a quarter of the floods (Pirazzoli, 1987), and barriers could be operated to enhance circulation due to that difference (Kej, personal communication, 1989).

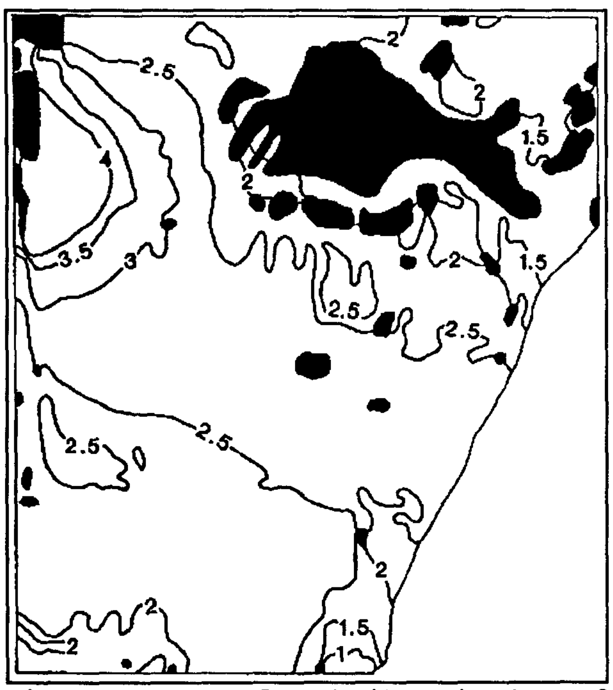


Figure 6. Simulated distribution of ammonia in Venice Lagoon with tidal exchange with the Adriatic Sea (Dejak et al., 1987).

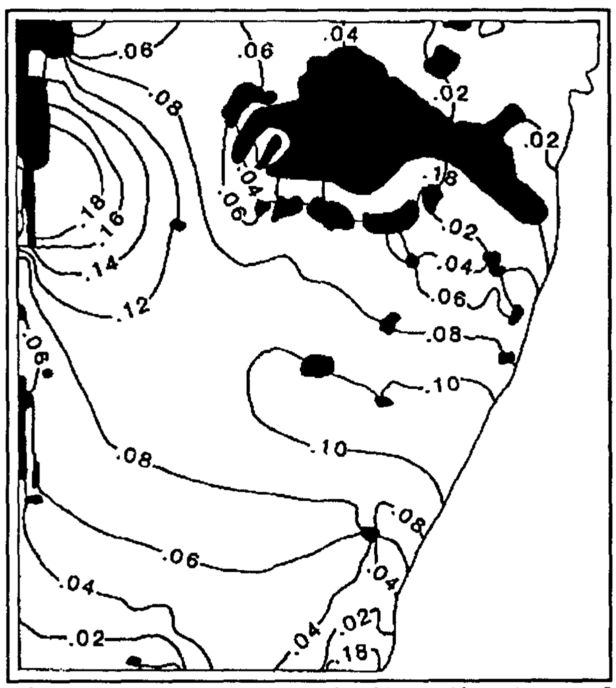


Figure 7. Simulated distribution of phytoplankton in Venice Lagoon with tidal exchange with the Adriatic Sea (Dejak et al., 1987).

CONCLUSIONS

If response strategies are ignored, water pollution is generally viewed as a minor impact of sea level rise, compared with inundation, erosion, and flooding. But strategies to protect dryland would have important impacts on water quality. When viewed in conjunction with potential loss of natural shorelines, one could conclude that the environmental implications of sea level rise ultimately may, prove to be more important than the more obvious economic impacts.

ACKNOWLEDGMENTS

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COASTAL MARINE FISHERY OPTIONS IN THE EVENT OF A WORLDWIDE RISE IN SEA LEVEL

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INTRODUCTION

Many stocks of marine finfish and shellfish throughout the world depend on fertile coastal marsh and estuarine areas for either part or all of their life cycle. With a worldwide rise of sea level of 0.5 to 1.0 meters by the year 2050 (as assumed in this paper), these areas may undergo considerable change and may eventually be replaced by new environmental regimes. Living marine resources indigenous to these areas will have to adapt to the changing conditions, migrate to more suitable waters, or simply die.

During these changes, the socioeconomic and perhaps political fabric dependent on the harvest of these resources will also be in jeopardy. With these possibilities in mind, governments will have to decide either to attempt to protect important fisheries or to allow nature to take its course. If the protection course is chosen, then options and strategies must be developed for its implementation.

Habitats Threatened by Sea Level Rise

In the United States, about 70 percent of our fisheries depend on estuaries for their existence (National Marine Fisheries Service Archives, 1989a). Worldwide, this figure is probably smaller but certainly significant. There are, of course, regional variations. In the southeastern United States, for example, about 90 percent of the fisheries are estuary dependent. In this region, we have the most important U.S. fishery in terms of value -- shrimp (Penaeus spp., $506 million) -- and in terms of volume -- menhaden (Brevoortia spp., 946 million metric tons) (National Marine Fisheries Service, 1989b). The sea level rise problem in the Southeast is complicated by subsidence of the land in a large portion of the region. We are experiencing now the problems that may occur on a more general basis around the world with a rise in sea level. Those of us involved in a custodial role with living marine resources have several concerns.

Environmental Implications

Marshes and Shallows for Habitat and Nutrition

A multitude of commercially and recreationally important species use the fringing marshes and shallow waters for critical parts of their life cycle (including reproduction, shelter, and foraging). We are becoming increasingly aware of the great significance of these areas to marine resources. Many species live in rather narrow bands along and through these coastal areas. If sea level rise is rapid, new habitats will not be created by natural processes in the quantities required to maintain healthy populations of many species (Gardner, 1990).

Wetlands That Interact With the Marine Habitat

Further inland from the marshes are the wetlands and their rich and diverse life, all of which interact with the marshes (Figure 1). Nutrients, animal life, and waters are exchanged in an endless pattern. The health of the wetlands is crucial to the health of the marine side of the equation. As sea level rises, the areas occupied by the wetlands will be the primary source of new marshes and shallow-water habitat.

Turtle-Nesting Beaches

Many species of sea turtles are recognized throughout the world as being endangered or threatened with extinction (Endangered Species Act of 1973 (P.L. 93-205), as amended in 1988 (P.L. 100-478)). Many of their nesting beaches have attributes that are also sought by mankind. As a result, many of the existing beaches are fringed with buildings of various types. Many of these structures represent significant economic investments. In addition, roads throughout much of the world are built just landward of these beaches. With even a small rise in sea level, significant additional stress will be placed on turtle populations.

Haul Out and Pupping Beaches for Pinnipeds

Most pinnipeds are heavy users of beaches (Figure 2). As in the case of turtles, there are often human investments just landward of the present beaches. In addition, sea level rise will inundate some important habitats. A very gradual rise in sea level probably would not present a major problem. Perhaps the case involving pinnipeds is more regionally differentiated than any of the other problem areas. Some species are quite isolated from interactions with mankind, while others compete quite aggressively with people for beach space.

WINNERS AND LOSERS

Short-Term Impacts

In the short term (10 to 100 years), it is possible to find both winners and losers. As marshes flood, some shrimp will have improved their habitat,

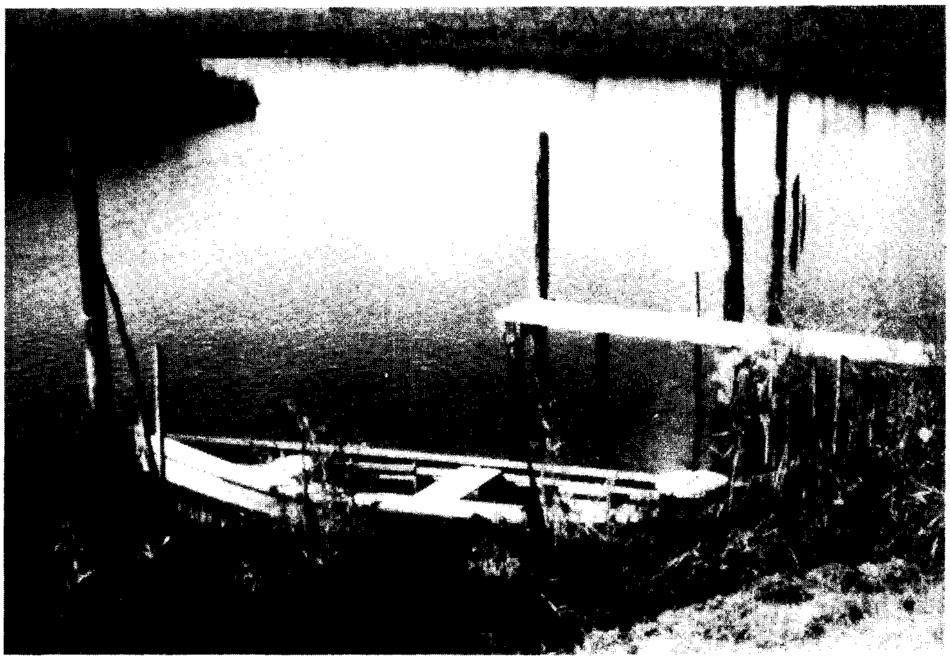

Figure 1. Estuarine channel showing marsh grasses and boat access.

Figure 2. Female California sea lions with pups on a northwest U.S. beach.

and some fish will have more food as the marshes rot (Zimmerman et al., 1989). However, it should be clear that these benefits are very transitory. With a loss of their habitat as the marshes flood and die, the populations of these animals will most likely plummet. These are not inconsequential losses. In the United States, for example, our southeastern shrimp and menhaden fisheries fall into this category.

Some species subsist on a narrow band along the shore. For example, some clams and other shellfish live in quite narrowly defined niches in the marshes and shallows. They will lose their habitats with any but the slowest rates of sea level rise. As noted above, some important species of sea turtles are particularly susceptible to losing their nesting beaches.

Long-Term Impacts

In the long term (beyond 100 years), if sea level rises very slowly and land and property are not protected, there will be little impact on fisheries. However, sea level rise may not be quite so slow, and people will most likely protect their investments in property and farmland that line much of the world's beaches, marshes, and wetlands. Given that significant protection will be attempted to preserve valuable dryland, particularly in the absence in many areas of knowledge of the importance and value of wet habitats, estuarine-dependent species can be expected to suffer. Shrimp, sea turtles, and coastal pelagic finfish may lose the most.

We have been quite unsuccessful in identifying the long-term winners. Perhaps as we learn more about the interactions of fisheries' resources with sea level rise, we will find some. However, we do not envision discovering species that will significantly benefit over the long term.

As custodian of our nation's living marine resources, NOAA/National Marine Fisheries Service argues constantly against those in government and in the private sector who would add to investments in the coastal areas (National Marine Fisheries Service, 1983-1989). We do not do this in anticipation of sea level rise, but rather to slow the rate at which we are losing our coastal wetlands and estuaries. We know that this is a difficult struggle, and we are gravely concerned that those with investments along shores and wetlands will be successful in protecting them regardless of the value of the fisheries affected by protectionist actions. If sea level rises and the natural succession of dryland to wetland, marsh, and shallow water is not allowed to run its course, many fisheries and some endangered species will pay a dear price. This information on the importance of coastal habitats to continued production of fisheries must be brought before coastal planners, engineers, and government officials in as forceful and meaningful a manner as possible. There are many acres of land suitable for farming and for cities. There is relatively little available for coastal and estuarine habitat. This leads us to the following thought:

An acre of farmland is one of many.
An acre of marsh is one of a few.
Protection of farmland will disproportionately hurt fisheries.

FISHERIES OPTIONS

The following options were developed from a review of the current literature, as well as our own thoughts and discussions on the subject, based on the assumption of a 0.5- to 1.0-meter rise in sea level. For purposes of this paper, the options have been placed in three groupings: scientific/technical, economic, and sociological/political.

We also project that human and financial resources (HFR) to address living marine resource (LMR) problems and opportunities throughout the world, resulting from a rise in sea level, will be very scarce. Individual nations may accord higher priority status, and use of scarce HFR, to more pressing needs such as agricultural adjustments, population relocation, disaster relief, transportation, etc. The only practical way to address the protection and conservation of LMRs, many of which are highly mobile and transboundary, is through the international pooling and allocation of HFRs.

To help in deciding how to allocate these fiscal resources, we have ranked the options under each category according to what we consider would be their value to society and the resource. In this regard, options were assigned a value of High (H), Medium (M), or Low (L) according to their importance relating to the protection, conservation, and use of the world's living marine resources. The rankings were developed following discussion and review with several senior fisheries scientists and administrators at the headquarters of the U.S. National Marine Fisheries Service.

Scientific/Technical

(H) Advise decisionmakers engaged in the planning, construction, and maintenance of water barriers about the needs of fisheries. Serious attempts may be made to "Hollandize" certain parts of a country to regain or supplement lost land as a result of flooding. Encourage the concept of providing for new nursery grounds at a level possibly exceeding preflood extent and values.

(H) Improve resource monitoring systems to provide current information on changes in fishery habitats and populations in response to global warming or to some other environmental change that may significantly alter the "stability" of fishery resources. The information must be developed, archived, and made readily accessible.

(H) Encourage development now of biological controls of agricultural pests over chemical means, and promote the use of rapidly degradable crop growth chemicals to reduce land runoff pollution of estuarine, marsh, and coastal areas conducive to fishery resources. Reduced land for agricultural use may trigger efforts to drastically increase agricultural production through more deliberate and extensive use of fertilizers and other growth chemicals. Such development may substantially increase their entry into fishery ecosytems.

(M) Promote the development of realistic models of the inshore, nearshore, and offshore environment to assist in predicting environmental and biological changes in these overlapping zones.

(M) Maintain the diversity of species by establishing preserves of suitable habitat for species being harmed.

(L) Cooperatively develop State/Federal plans addressing anadromous and catadromous fishery resources.

(L) Encourage development now of an early warning system to detect abnormal pathogenic activity among fishery resources that may enter the human food chain. Depending on the rate of change, a worldwide rise in sea level may very well result in biological stress to existing and potentially new fishery resources. Such stress may aggravate existing pathogenic, but in-check or dormant, organisms to explode to epidemic proportions. LMR populations may suffer irrevocable disaster, and some pathogens may find their way into the human food chain. Some thought and prevention planning should be given to this possibility, and early warning systems to detect pathogenic abnormalities should be devised and monitored.

(L) Assist in development of different or new harvesting and processing methods and techniques geared to different stocks and their distribution.

(L) Develop and establish federally funded and supported "Living Marine Resources Banks" designed as repositories (cryogenic gene banks?) for the continuance of species biologically important not only to mankind but also to their own survival and prosperity.

Economic

(H) Constrain further development in the coastal zone to avoid the likelihood of defensive strategies to protect developed areas. The natural succession needed by marine species will depend on an undefended shoreline.

(H) Foster, possibly with economic incentives, mariculture to continue and increase the supply of seafood as well as to supplement wild stocks, and maintain populations of endangered and threatened species (e.g., turtles) that may be affected by changes in nesting habitat, locale, and food supply.

(M) Safeguard existing coastal mariculture capabilities of countries and communities that heavily depend on mariculture for food and export revenues.

(L) Develop and establish a decisionmaking process for the sole purpose of determining which fishery stocks (and support systems) should be and can be "saved," as opposed to those that should be allowed to be at the mercy of natural forces.

Sociological/Political

(H) Encourage and provide for education of the public and government sectors about sea level predictions and how they should respond. It is important that all people understand the situation and receive good advice on proper courses of action.

(H) Continue mediation of potential conflicts between commercial and recreational fishermen. Some problems will exist, but priorities and species of concern may change. There may be more initial commercial demand for fish protein as the supply of agricultural, dairy, and land-produced meat products changes.

(H) Encourage the development, implementation, and enforcement of policies designed to promote holistic commercial and recreational development of newly created marsh, estuarine, and other coastal areas that may serve as resource nursery and feeding grounds.

(H) Promote the concept of "world food security," as defined by the Food and Agriculture Organization, but in terms of world fisheries exemplified by the adequacy of fishery products, stability of fishery products, and especially access by the world's populace to fishery products.

(H) Implement fishery management schemes to protect, conserve, and adequately allocate offshore fishery stocks. There may be a shift from perceived unstable inshore fisheries toward greater utility of more stable offshore fisheries. Such a move would result in greater harvest pressure on offshore stocks, possibly resulting in depletion of such stocks.

(M) Develop new fishery management methods, techniques, and plans to accommodate the potential shift and relocation of fishery stocks in primarily new estuarine and coastal areas. It is also very important to keep stocks healthy so that they can be resilient in times of stress.

(M) Encourage and promote closer ties and alliances among fishery-oriented government groups (domestic and international), private citizenry, and commercial enterprises for the purpose of pooling talent and scarce resources.

(L) Foster appropriate implementation of new regulations and the enactment of new laws as may be necessary to manage the new fisheries regimes.

(L) Assist harvesters, processors, and users in adjusting to different and new species and to the demands made on them.

Environmental Implications

(L) Encourage the streamlining of the current judicial process dealing with environmental and LMR matters so that the focus of resulting litigation will not "wither on the vine."

CONCLUSION

As custodian of our Nation's living marine resources, we are dedicated to the protection, conservation and wise use of the animals that inhabit the marine and estuarine environment, as well as their habitat. Government can help conserve and manage fisheries that are of economic, sociological, and political importance to our planet's inhabitants.

The ability of governments to take these actions depends both on the availability of financing and on the importance these nations attribute to the resources at risk. A cursory examination of the listed options reveals that many of them would require massive expenditure to effect the option. It is also evident that no single government can achieve even adequate protection of its living marine resources and their habitat unless it is willing to sacrifice other substantive resources to do so. Our observations indicate that governments are often neither willing nor able to allocate scarce resources to protect fisheries and their habitat.

We therefore conclude that if governments decide to protect their living marine resources, they must collectively decide on fishery priorities and pool together the scarce, necessary resources to produce the desired effect.

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IMPACT OF RESPONSE STRATEGIES ON DELTAS

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The previous three papers have a common theme: protecting developed areas from inundation and erosion usually upsets the coastal environment. In the case of the open coast, Leatherman shows that seawalls and sea dikes can result in the loss of natural beach and dune ecosystems; groins merely transfer the erosion problem from one area to another; and even the environmentally preferred approach of sand replenishment can hurt life on the inner continental shelf. Along sheltered shores, bulkheads to stop erosion can result in wetlands loss, and Park points out that tidal barriers to prevent flooding can cause pollutants to build up.

In addition, dams built to counteract increased drought could limit the freshwater flowing into estuaries, and thereby exacerbate salinity increases due to sea level rise. Frequently, however, the dams are used to maintain riverflows above a minimum level; hence they would often help to offset the salinity increases. Finally, the construction of dikes and pumping systems to prevent inundation due to sea level rise would cause groundwater to become salty.

The purpose of this note is to highlight the environmental impact of response strategies on deltas, which fit broadly into three categories: river dikes (levees); dams; and sea dikes.

RIVER DIKES

Deltas were created by the sediment washing down from the adjacent rivers. Generally, the flood season brings sediments that elevate existing land and create new land in areas that were formerly shallow water bodies. The size of a delta tends toward an equilibrium equal to the volume of sediment supplied by the river and wetland vegetation divided by the rate of relative sea level rise.[1] Because the recently deposited deltaic muds tend to settle, the relative rate of sea level rise in many deltas is 5 to 10 millimeters per year (compared with the worldwide average of 1 to 2 millimeters per year). Without the sediment supplied by the river, they would gradually disappear even without an accelerated rise in sea level due to the greenhouse effect.

Environmental Implications

In the case of a delta with the equilibrium area and relative sea level rise today of 5 mm per year, a 50-cm rise in sea level by 2100 would imply that the sustainable area of the delta will be cut in half -- assuming that the supplied sediment remains constant. But if sediment supplies are curtailed, the delta could be almost completely lost. As Schroeder (North America, Volume 2) discusses, Louisiana (United States) is losing 100 square kilometers of deltaic wetlands to the sea largely because dikes (levees) along the Mississippi River prevent it from overflowing its banks during floods and from providing sediment to the delta; the sediment washes off the continental shelf instead.

There is a risk that a rise in sea level could encourage additional dikes. Consider Bangladesh, half of which is regularly flooded. If sea level were higher, the water levels in much of the country would be similarly higher, and areas currently outside the floodplain would then be within it. As a result, officials might decide to build dikes to protect a few key areas. The resulting confinement of riverflow, however, would tend to increase the flooding of other areas, which could lead them in turn to demand a dike. If this process continued, large amounts of sediment eventually would be washing into deep waters there as well.

As has already occurred in Louisiana, the dikes would accelerate the conversion of wetlands to water and would lead to the inundation of dryland that would otherwise remain above sea level. Because the annual river flooding provides important nutrients, the dikes would also degrade the fertility of deltaic farmland.

DAMS

Similar impacts could occur if changes in precipitation patterns lead to the construction of more reservoirs. Dams block the sediment flowing down rivers. Although the diversion of water reduces the average annual flow of water, their impact on estuarine salinity during droughts (when it is most critical) depends on whether water managers use the dams to maintain minimum flows for navigation and environmental quality.

The Nile Delta has already seen the consequences of dam construction. The delta has started to erode rapidly, and the sardine fishery was largely lost to saltwater intrusion. Without the annual flooding, soil fertility is dropping as well.

SEA DIKES: THE END OF THE NATURAL DELTA

Whether caused by dams, river dikes, or the natural consequences of sea level rise, erosion and flooding may lead officials to conclude that it is necessary to completely protect the delta with dikes and to place it under artificial drainage. That is, they may decide that it is no longer desirable for the area to be a delta. In many cases, the complete cultivation of an area may have effectively accomplished this transition anyway.

Nevertheless, in Louisiana and other deltas with a mix of natural wetlands and reclaimed lowlands, the environmental implications of such a decision would be profound. Although it would be possible to maintain freshwater wetlands for waterfowl, the saltwater wetlands would be lost, and the fisheries would shrink to a "shell" of their former productivity.

Although coastal protection is expensive, the loss of land may be even more expensive; consequently, even developing nations may be able to raise the necessary funds. But it is an open question whether foreign donors would actually be doing these nations a favor if they provide the necessary assistance.

1. We are referring only to an equilibrium total area. Deltas continually change course, so the shoreline position is never in equilibrium; but apart from the mathematical "catastrophes" of a change in river course, the total area generally tends toward an equilibrium. This argument is analogous to the Bruun rule approach: Continual changes in wave climate prevents the shore profile from ever remaining at equilibrium, the concept of an equilibrium allows one to calculate the average retreat of the shore for a rise in sea level or a given input of sediment to the beach.

ENVIRONMENTAL IMPACTS OF ENCLOSURE DAMS IN THE NETHERLANDS

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INTRODUCTION

A big storm surge in 1916 caused great damage and land losses in the areas around the Zuider Zee. As a result, the longest enclosure dam in the Netherlands, the one enclosing the former Zuider Zee, was built in 1932 (see Figure 1). An even more disastrous storm surge in 1953 was the catalyst for the building of the so-called Delta Works, which were finished in 1986 with the completion of the storm surge barrier of the Eastern Scheldt. During the building of the Delta Works, three other estuaries were cut off from the sea. This paper discusses the impacts of these enclosures.

THE IMPACTS OF THE ENCLOSURE OF THE FORMER ZUIDER ZEE

The enclosure of the former Zuider Zee caused a big change in the tidal and storm conditions in the Wadden Sea area. The tidal range increased by roughly 50% -- e.g., at Harlingen it increased from 1.25 to 1.80 m. In addition, the height of storm surges increased by roughly 20%. This meant that besides building the dam itself, all the dikes in the western part of the Wadden Sea needed raising.

Since the enclosure of the Zuider Zee, the morphological system required about 30 to 40 years to reach more or less a new equilibrium (Misdorp et al., 1989). After these 30 to 40 years, the changes have become smaller. To reach a real equilibrium will probably take more than 100 years. Near the dam, the currents decreased. But in other areas of the Wadden Sea, and especially in the tidal inlets between the islands, the currents and tidal volumes increased, causing an unbalance in the morphology of the area. The tidal gullies near the dam have been filled up by sediments, while the cross-sectional areas of the

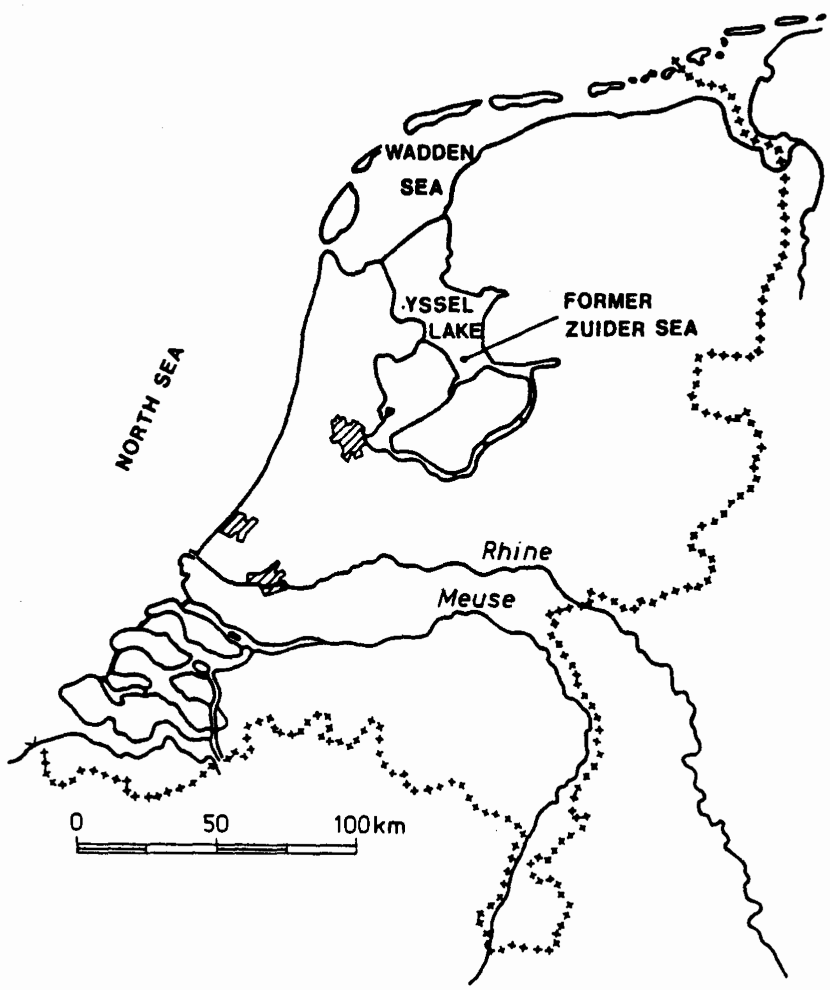

Figure 1. Map of the Netherlands showing the former Zuider Zee, now enclosed and called the IJsel Lake.

tidal inlets have increased by about 15-20%. Due to this morphological change, the tidal system in its turn has been changing as well, causing an extra increase of the tidal range of about 5% over the last 50 years (Misdorp et al., 1989).

The enclosure and the increase in tidal range caused the loss of intertidal and salt marsh area (about 1000 hectares of salt marsh were lost), which affected the ecology of the area. In the long run, a small increase of intertidal and marsh area may be expected (Dijkema, 1987). On the inside of the dam, the impacts were greatest: a large salt intertidal system changed into a freshwater lake. The largest negative impact was felt by the fishermen, who lost their fishing grounds.

THE IMPACT OF THE DELTA WORKS

The impacts on Zeeland due to the Delta Works will be discussed in relation to the water system going from north to south (see Figure 2). The impacts of the storm surge barrier on the Hollansche IJssel will not be discussed; they may be neglected. The Western Scheldt is not included because, owing to shipping to Antwerp, this estuary will remain open.

The Haringvliet

This water system has been enclosed with a huge sluice complex. During high discharges of the Rhine and Meuse Rivers, most of the water has to be discharged via the Haringvliet to the North Sea. The system changed from a brackish tidal estuary to a more or less stagnant freshwater lake. The present tidal range is less than 20 cm; greater water level variations are caused by high river discharges.

At present, an unforeseen impact has given cause for great concern. During the planning of the Delta Works, pollution was not yet of much concern. However, today, sediments of the Rhine, strongly polluted with heavy metals, largely settle on the bottom of the Haringvliet. Plans are being developed to clear these sediments at huge costs. However, this effort will be useful only if the river's future sediments become cleaner as well.

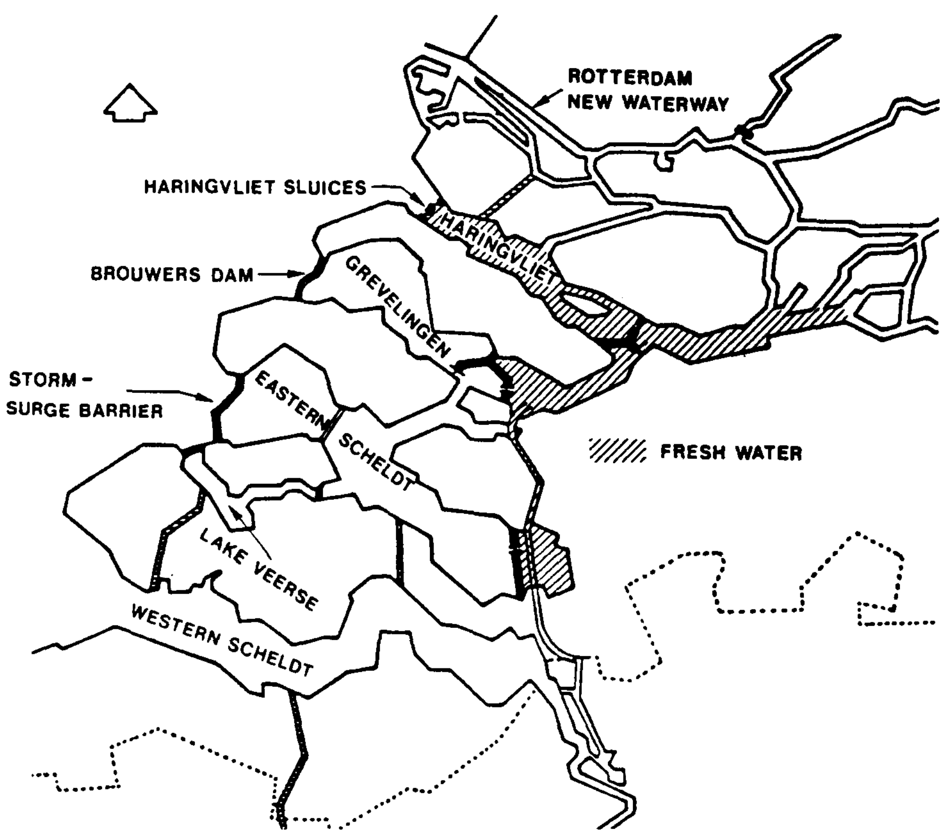

Figure 2. Map of the delta area of the Netherlands.

Environmental Implications

This unforeseen problem would not have occurred if the Haringvliet had remained open; the sediments would have been transported into the North Sea and would have settled in sedimentary areas. At present, officials are discussing reopening the sluices, and closing them only during a storm surge. Owing to these pollution problems, the impact of the enclosure on ecology is rather large, and the system was more valuable in an ecological sense in the past.

The Grevelingen

The Grevelingen Lake was planned to be a freshwater lake after enclosure to supply freshwater to the agricultural areas of the islands north and south of it. At the time the dam was completed (1972), the ecological value of such a freshwater lake as compared with that of a saltwater lake already was questioned, and the lake was temporarily left marine. Despite a heavy protest from the farmers, it was decided, many years later, to leave the lake marine.

In the beginning, seawater was let in and out only through sluices in the Brouwers Dam on the sea side of the lake. It appeared that this strategy caused stratification, accompanied by anoxia. This unforeseen problem was solved by making another sluice on the eastern end of the lake. Now seawater can be taken in from the Eastern Scheldt and can be discharged via the other sluices to the North Sea. With this strategy, stratification no longer occurs. Today, the lake has a very high ecological value due to the rarity of an unpolluted, clean, saltwater lake. The lake enjoys a great number of different species of birds, fish, plants, and especially seagrasses (Zostera). Even the economic value of the lake is important because of high production of oysters and mussels, which was not expected at all.

The Eastern Scheldt

In 1958, part of the plan for the Delta Works was to separate the Eastern Scheldt completely from the sea and to make a freshwater lake of it. After the closure of the Haringvliet and Grevelingen in 1972, the political pressure to preserve the Eastern Scheldt as a marine environment grew so strong that the Dutch government ordered a further study. The study advised against closing the Eastern Scheldt, and in 1976 the government decided to build a storm-surge barrier, which was completed in 1986. To preserve the valuable ecosystem and the oyster and mussel nurseries in the area and to reduce the length of sea dikes by 150 km, the government decided to spend an additional 2 billion guilders (1 billion U.S. dollars) on the Delta Plan.

Still, the storm-surge barrier together with the necessary extra enclosure dams at the end of the estuary had some impacts on the environment. The tidal range in the estuary decreased by 10-15% (the average tidal range is about 3 m). The tidal volume decreased about 30%. Because of the extra enclosure dams and the decrease in tidal range, roughly 30% (6,400 hectares) of the intertidal areas and 65% (1,150 hectares) of the salt marsh areas were lost. Of the remaining intertidal areas (11,000 hectares), another 1,400 hectares will be lost in the next 30 years, as a result of the morphological changes caused by reduction of the tides (Kohsiek et al., 1987).

These losses of intertidal and salt marsh areas have destroyed a large feeding area for birds. Up until now, the numbers of birds have not decreased. Although the birds can move to another place like the Western Scheldt, they have to stay in the delta area. What will happen in the long run is not known. In contrast, the mussel nurseries were able to move to other areas and production remained the same. In fact, future production might even increase because of lower water velocities.

Lake Veerse

The first estuary to be enclosed was the smallest one (Lake Veerse in 1961). The plan was to make it a freshwater lake that would be flushed through with freshwater via a fresh Eastern Scheldt.

At present, with a saltwater regime in the Eastern Scheldt, the water in Lake Veerse is still brackish, with a rather low ecological value. As a water supply for agriculture, the salt concentration of the water is too high. At the moment, the possibility of making the lake saltwater again is being discussed. To get a healthy saltwater ecological system, the lake needs to be flushed with saltwater (a lesson learned from the Grevelingen lake). To make flushing possible, a sluice has to be built in the Veerse Dam. Up until now, this decision has not been made.

The Outer Delta Area

The impacts of the enclosures on the sea side of the delta are mainly morphological. Tidal ranges and storm surge levels increased only locally near the enclosures. Near the Eastern Scheldt storm surge barrier, the level of a design storm surge, with a return time of 4,000 years, is increased by about 40 cm. At greater distances (more than 30 km), changes are less than a few centimeters.

The morphological changes are quite noticeable, especially in front of the Grevelingen and Haringvliet, because of the changing tidal currents (Kohsiek, 1988). Along the shore, large sandbars developed, which started to migrate landward and to increase in height. After about 10 years, the height of the sandbars reached the intertidal zone, after which they stabilized at about -0.5 m below mean sea level.

The further development of this area into a more lagoon-like system has been predicted by some experts. We must wait and see whether this will be the case, and if so, how long it will take.

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LEGAL AND INSTITUTIONAL IMPLICATIONS

INTERNATIONAL LEGAL IMPLICATIONS OF COASTAL ADJUSTMENTS UNDER SEA LEVEL RISE: ACTIVE OR PASSIVE POLICY RESPONSES?

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ABSTRACT

A rise in sea level would inundate lowlands, marshes, and mangroves, alter erosion processes, and, in some areas, change tidal ranges. This paper examines the legal issues resulting from these impacts, which include the effect of tidal changes on the delimitation of coastal and maritime zones resulting from changes in high tide (for coastal zone jurisdiction) and low tide lines (for maritime zone baselines) and the implication of inundation of coastal areas. Various active and passive strategies are compared in light of case studies of coastal zone legislation and the law of the sea regime.

The paper also considers the international law implications of particular national strategies -- such as building sea walls -- which are likely to exacerbate the impacts on neighboring states, and considers the role of international institutions in the coordination of national responses.

The paper concludes with an assessment of the active or passive policy approaches for managing. Certain changes may best be met with inactivity (the passive approach), while others will require immediate action and coordination (the active approach).

INTRODUCTION

In a workshop on policy options for coastal management in response to sea level rise, there must be an inevitable tendency to concentrate on national options and, in a legal context, national law. The purpose of this paper, however, is to explore some of the implications under international law of climate change and sea level rise and to outline a number of restraints that international law imposes or might impose on the range of policy options available and the possible role it might play in the coordination of options.

Two main themes emerge. The first is the problem of maritime boundaries that are defined on the assumption of a stationary coastline. The necessity for their redefinition during a period of rapidly rising sea level requires careful consideration. The second theme concerns the management difficulties that will occur when coastlines change. Their management will require cooperative efforts internationally as well as intranationally. For both sets of problems, there are two distinct approaches: (1) take a passive approach and merely react to the changes as they are imposed upon our coasts, or (2) take a pro-active stance and consider how to anticipate and counter the most damaging of the changes about to take place. The paper concludes with a consideration of the extent of international law obligations to cooperate in the face of rising sea levels.

SEA LEVEL RISE AND MARITIME BOUNDARIES

The first and most obvious effect that sea level rise will have is on high- and low-water marks (HWMs and LWMs). Both of these may have legal significance, but under international law, the LWM has particular significance. Article 5 of the 1982 Law of the Sea Convention[1] (LOSC), which is taken to represent customary international law on the subject provides that:

> ...the normal baseline for measuring the breadth of the territorial sea is the low water line along the coast as marked on large scale charts officially recognized by the coastal state.

This baseline may depart from the low-water mark for a number of reasons (the presence of bays, deeply indented coastlines, fringes of islands, etc.), but the significance of the baseline is that the seaward limit of other maritime zones are measured from it.[2] The use of the low-water mark generally ensures that the maximum maritime area is included within the zone. By contrast, national laws on coastal zone jurisdiction vary, but in the United Kingdom and many other common law states, the high-water mark is generally taken to represent the seaward limit of the jurisdiction of local authorities.[3] Although the intertidal regions is still part of the state, in the UK this generally comes under the jurisdiction of the Crown Commissioners.

Crudely put, rises, or indeed any changes, in sea level that affect high- and low-water marks will obviously have a "knock-on" effect on the measurement of jurisdictional zones. If the low-water mark advances landward, then because

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[1]UN Doc A/CONF, 62/122; 21 International Legal Materials (ILM) 1261 (1982)

[2]i.e., territorial sea, Article 3 LOSC; contiguous zone, Article 33(2); exclusive economic zone, Article 57; and in some situations even the continental shelf, Article 76(1).

[3]Other systems, for example Belgium, use the LWM as the limit of their local jurisdictions.

all maritime zones are measured from that baseline, the outward limits of maritime zones will similarly move landward, and the coastal state's maritime zone limits will shrink proportionately. Where a broad coastline transgresses rapidly, as in the case of areas of Bangladesh being eroded at up to 200 m per year (Stoddart and Pethick, 1984), the cumulative effect could be quite substantial: in this case, over 60 km^2 per year of the maritime zones. In fact Article 7(2) LOSC contains a provision -- derived from the proposal initiated by Bangladesh, which was concerned by the particular problems of constant erosion and deposition at the mouth of the Brahmaputra[4] -- permitting, in restricted circumstances, a straight baseline to be maintained, notwithstanding the movement of the actual coast:

> Where because of the presence of a delta and other natural conditions the coastline is highly unstable, the appropriate points [i.e., for straight baselines] may be selected along the furthest seaward extent of the low-water line and, notwithstanding the subsequent regression [sic] of the low-water line, the straight baseline shall remain effective until changed by the coastal state in accordance with this Convention.

Although, as Prescott (1989) points out, this was drafted for specific circumstances, there is a risk that in the context of sea level rise it will be used more widely than is legitimate under the LOSC regime.

Baseline movement will not normally (see Article 76 LOSC) affect the limit of continental shelf claims that may extend to the edge of a continental margin. However, it could have important economic effects on equidistance lines, which may be significant in areas where boundaries have still to be settled, in that hydrocarbon resources may move over a median line. It may also mean the inundation of small islets or rocks that are currently used, or claimed, as basepoints for maritime zones, such as the tiny islet of Aves in the eastern Caribbean basin (see Freestone, 1989). Although the coral around atoll islands might be able to keep pace with a gradual rise in sea level, it is unlikely that the atoll islands themselves would receive enough sediment to keep pace, although other atoll islands might be created.

Obstacles to Defining Maritime Boundaries

Once signed, maritime boundary agreements belong to that class of treaty whose validity is not affected by subsequent fundamental changes in circumstances.[5] Nevertheless, some treaties do use moving concepts, such as the

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[4]A/CONF/62/C2/L7

[5]1969 Vienna Convention on the Law of Treaties, 8 ILM 679 (1969) Article 62(2)(a).

thalweg,[6] which may be considerably affected. In the more than 300 maritime areas where boundaries have yet to be agreed on (Blake, 1987), changes in baselines could have a significant effect on the negotiating position of the parties. The parties are still influenced by equidistance lines, even though they are enjoined by the LOSC Articles 74 and 83 simply to reach "an equitable solution."

The horizontal magnitude of baseline changes, of course, will depend initially upon the slope of the nearshore zone (Aurrecoechea and Pethick, 1986). The North Sea -- where all the seabed boundaries have been agreed -- presents an interesting theoretical model of possible movements of baselines and equidistance lines. In the case of nations surrounding the North Sea, such nearshore slopes can vary over wide ranges. Thus, the steep nearshore slopes of Norway and Scotland contrast with those of the Wash embayment in eastern England, where the nearshore slopes of 1:5000 mean that a 1-m rise in sea level would shift the low-tide mark 5 km toward the present coastline of the United Kingdom. Assuming a conservative average sea level rise of 1 mm per year, this means a potential landward movement of the low-water mark of 5 m per year. Such a rapidly changing coastline creates major problems in the definition of the maritime boundary. It is clearly impossible to react continuously to such a rapid movement of the natural boundary. A form of episodic adjustment of the legal boundary to the natural movement of the coast again poses many problems, including the most difficult one of predicting the future development of that rate of sea level rise. Ignoring the departure of the low-water mark from the legal baseline -- which is therefore regarded as fixed before sea level rise -- is a possibility that may be welcomed by nations that would lose territorial areas as a consequence, but not by those that may gain areas.

The possibility of an unequal or asymmetric shift in the position of the equidistance line, so that some nations lose while others may gain territorial advantage, is one that must be considered carefully. In the case of nations facing each other across an intervening sea, such an outcome is quite feasible. Thus, in the southern North Sea, nearshore slopes on the western seaboard, such as those extending seaward from the mouth of the Thames, can be as low as 1:2000, while those on the eastern seaboard are steeper, 1:1000 off the Ooster Schelde, for example. In this case, the shift in the baselines on opposite coastlines due to a rise in sea level would be asymmetric and would cause a shift of the true equidistance line toward the coast of the United Kingdom.

It must be realized, nevertheless, that such rigidly geometric calculations do not necessarily apply to the dynamic shoreline under a rising sea level. The parallel movements of low tide and high tide, for example, are possible only if no sediment moves and if tidal range itself remains constant. Sediment redistribution under a rising sea level is discussed later in this paper, but here we may examine the complexities introduced into predictions of baseline movement due to changes in tidal range produced by an increase in water depth.

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[6]A possibly controversial example would be the 1975 Iran/Iraq treaty on the Sh'at al Arab.

In the North Sea, for example, the slight increase in sea level over the past 20 years may have been responsible for the observed increase in tidal range on the coast of Germany, as shown by the Cuxhaven tidal gauge. Tidal range at a shoreline is related to distance from the "amphidromic" point of the tidal system. It may be that as sea level increases in the North Sea, so the amphidromic point shifts slightly toward the west, which would cause a decrease in tidal range on the coast of the United Kingdom and a commensurate increase on the coast of the Federal Republic of Germany. The observed change at Cuxhaven over the past 20 years has been on the order of a 30-cm increase in tidal range. The magnitude of this change is greater than that of the sea level rise, and thus movement of the low-water mark on this coast may actually be seaward under a rising sea level while, on the coast of the United Kingdom, low water would move more rapidly landward than mean water level.

Policy Options for Maritime Boundaries

Such discrepancies in the movement of the low-water mark boundary under a rising sea level may lead to a move for redelineation of baselines -- a matter primarily for the coastal state (see Article 5, above).[7] Prescott (1989) has pointed out that this might present two policy options: (1) the active option -- continuously updating the charts, and (2) the passive option -- leaving the charts alone. Apart from the expense of the active option, significant particularly for small developing countries (who might be the most affected relatively), such action might be seen as the unilateral abrogation of existing maritime areas, and hence, might be politically undesirable. The passive option, however, is dangerous. As we have seen, international law simply requires that the low-water mark be marked on "large scale charts officially recognized by the coastal State." There is no requirement that these be specifically produced for baseline delineation -- and, indeed, they are not. The charts used are designed primarily for navigation. Hence, charts left unchanged for political reasons at a time when important coastal geomorphological changes are under way could be extremely hazardous. Or we could see the widespread evolution of baseline maps (similar to those produced by archipelagic states) simply marking the low-water mark, which is then omitted from other charts. Prescott (1985) has already indicated the degree to which Article 7 LOSC has been abused by state practices; sea level rise could exacerbate this divisive tendency.

COASTLINE ADJUSTMENTS TO SEA LEVEL CHANGE

The relative stability of sea level over the past few hundred years has led to a belief in the permanence of the coastlines of the world. Acting on such an assumption, people have developed a complex physical and institutional infrastructure which will have to be reappraised in view of the predicted sea level rise. In this section, we examine two aspects of this reappraisal.

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[7]Apart from delineation of the outer edge of the continental margin (which for those bound by the LOSC regime may require some exchange with the Commission established under Article 76(8)).

Legal and Institutional Implications

First, the role of the coast as a physical buffer between land and sea has resulted in an equilibrium configuration to which we have in turn adjusted. Sea level rise will initiate a series of changes that will eventually lead to the attainment of a new equilibrium -- but only if we are capable of allowing such changes to take place. The difficulties this may pose for our industrial and social infrastructure and the international cooperation needed to allow changes across political boundaries are discussed.

Second, we examine the problems facing our use of the coast for its intrinsic value -- for its ecological and recreational significance. Here the complex existing network of international obligations establishing nature reserves will need to be borne in mind when responding to changes and losses of habitat under a rising sea level.

Physical Factors

The response of the coastline to sea level changes is not passive. The coast is a dynamic landform that in most cases has achieved a form of quasi-equilibrium with its wave and current environment. Changes in this wave climate or variations in nearshore currents introduced by new water depths mean that the equilibrium is destroyed and that nature will initiate adjustments that will eventually reattain the equilibrium. Although the range of geomorphological adjustments to sea level rise may be extremely wide, we may consider them here under two headings: vertical adjustments and horizontal adjustments.

<u>Vertical Adjustments: The Coastal Profile</u>

In the simplest case of a rise in mean sea level accompanied by a commensurate rise in the high- and low-water marks, there is some agreement that the equilibrium shoreline that existed before the rise will move landward and upward, thus keeping pace with the rise in mean water level. Such a vertical translation in profile was predicted by Bruun (1962), and the hypothesis that erosion of the upper shoreline will be accompanied by deposition of the eroded sediment in the lower shore is now known as the Bruun Rule (Figure 1).

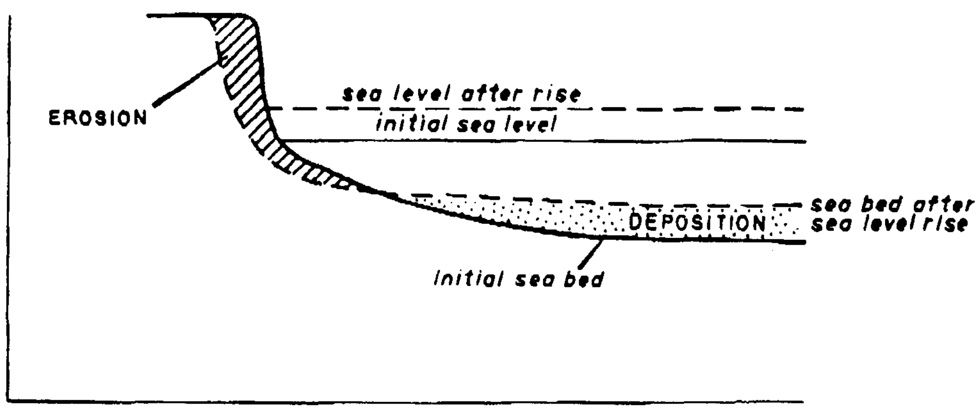

Figure 1. Adjustments of the vertical shore profile to sea level rise (after Bruun, 1962). (See Titus, Problem Identification for additional discussion.)

Although many authorities have questioned the details of the hypothesis (e.g., Dean, 1987), the general pattern of a shoreline keeping pace with sea level rise is a reasonable one. It does depend, however, on the free exchange of sediment between upper erosion and lower deposition zones. As Pethick (1989) has pointed out, such a free interchange will be actively suppressed by local attempts to prevent upper shoreline erosion. Bulkheads and seawalls will prevent sediment being made available for readjustments of the shore, and thus a state of permanent disequilibrium will be forced on the shore profile.

Horizontal Adjustments: The Coastal Plain

A more complex and as yet unexplored aspect of coastal response to sea level rise is the tendency for coasts to adjust their plan or horizontal configuration to the new water level. These horizontal adjustments will be caused by the re-orientation of the wave approach angles at the shore due to a change in wave refraction. Waves refract or bend in shallow water so that their crests tend to become parallel to the bottom contours. The refracted wave crest then meets the shore at a more or less oblique angle which sets up a longshore current whose velocity is directly proportional to the wave approach angle. Such currents create longshore sediment movements along the coast, which cause adjustments in its orientation. An equilibrium is eventually reached when the shore becomes parallel to the refracted wave crests (for example, see Komar, 1976).

An increase in mean water depth caused by sea level rise will disturb this longshore equilibrium. Waves will begin to refract closer to the shore in the deeper water conditions and will meet the shore at an increased angle. This will increase the velocity of the longshore current and set up movements of sediment that eventually will alter the coastline's orientation and thus establish a new equilibrium. The horizontal movement of sediment here can be seen as directly analogous to the vertical movement of sediment described above for the Bruun Rule. The difference from the point of view of policy adoption, however, is that such horizontal movements of sediment may occur across national boundaries, whereas the vertical movements are confined to local jurisdictions.

International Implications

Such vertical and horizontal changes in the coastline must be taken into account in any measured response to the problem of rising sea level. It is important for national authorities. When developing their policy responses to such rises, national authorities need to understand that they should not make their decisions in isolation. In areas such as the southern North Sea or East Africa, where a number of states lie opposite or adjacent to each other with coastal frontages on a single sea, the strategy adopted by one state may have a considerable impact on neighboring states. Indeed, some policy options may even exacerbate the problems of neighbors.

The example of the Fresian Island coast of the southern North Sea may be cited here to illustrate the possible problems. This coast cuts across the national boundary between the Netherlands and Germany. Figure 2 demonstrates

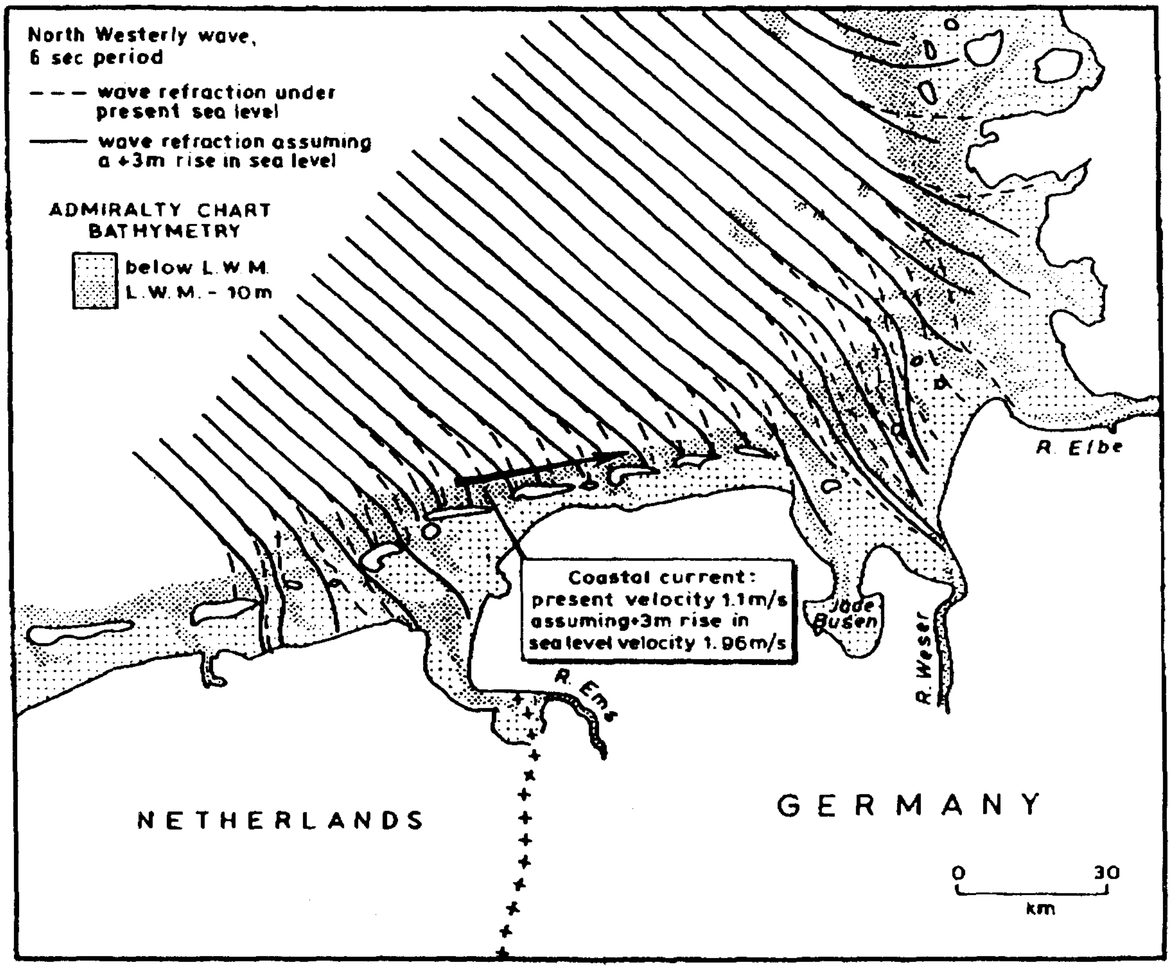

Figure 2. Changes in wave refraction and coastal longshore currents on the Fresian Island coast due to a sea level rise.

that wave refraction in the new water depth will be less marked than previously, so that wave approach angle at the shore will be increased. The result will be a dramatic increase in longshore velocity. A 3-m-high wave, for example, would generate a current of 1 m/s at present, but this would be increased to 1.9 m/s under the new sea level regime. Figure 2 indicates that the effect would be to increase sediment transport eastward along the coast of the Netherlands toward the Federal Republic of Germany. These sediments, derived from erosion of the foreshore of the Netherlands, would accumulate along the German coast between the Elbe and Weser Rivers, eventually causing a reorientation of the whole coastline and equilibrium. The immediate response, however, would be the loss of the foreshore of the extremely vulnerable Dutch Fresian Islands, whereas the marshes and mudflats of the Jade Bay and the Weser Estuary would be provided with an abundance of sediment and would thus perhaps manage to accrete in pace with the rising sea level (see also Nummedal and Penland, 1981). In such a case, were the Netherlands to respond by strengthening shoreline defenses against coastal erosion and by actively preventing the eastward movement of sediment using groins or similar constructions, such action would both deny the Federal Republic of Germany of sediment necessary for the maintenance of the country's coastal marshes under a rising sea level and, more important, in the long term would prevent any return of the whole coastline to an equilibrium orientation.

Similar arguments apply to many of the coastlines of the world. An example recently investigated by one of the authors (JP) is that of the East African coast, which cuts across a number of national boundaries. Advance warning of a major reorientation of this coast may be seen in the Rufiji Delta in Tanzania, where the deltaic sediments are extremely sensitive to any change in wave climate, and where a counter-clockwise swing of the entire coast has already resulted in the erosion of up to 10 km of mangrove in the north of the delta and the deposition of a 2-km-wide margin of mangrove in the south. Such a coastal change may be an indicator of a more general change along this East African coast, with profound implications for the neighboring states. Should erosion of cliff coasts here be allowed to continue so that the more vulnerable low-lying mangrove coast can benefit from the input of sediments derived from this erosion and perhaps keep its head above water? Or would it be more economic to prevent erosion of the cliff areas and allow the mangrove regions to drown? Such decisions may only be taken in the light of a much more extensive knowledge of the interactions between erosive and depositional areas of the coastline and also of the relative economic outcome of either policy.

Intranational Implications

The international implications of such coastline reorientations are matched by intranational ones. Thus, along the coast of eastern England there has been a recent attempt to protect the Humberside cliffed coast from erosion that has continued at a rate of 2 m per year throughout historic times. This erosion, however, is one of the major sources of sediment in the southern North Sea (McCave, 1987). As such, it is vital to saltmarsh areas lying immediately south of the Humberside coast in the Wash. Denied such sediments, these salt marshes would be unable to respond to sea level rise by accretion of their surfaces. Their loss would have profound implications to the stability of the sea embankments that lie immediately inland of the marshes and prevent enormous areas of East Anglia from flooding.

Thus, the proposal to prevent the erosion of these cliffs has understandably met with some opposition from those responsible for preventing flooding in the Anglian region. The problem, however, has perhaps even wider implications because resultant current directions in the southern North Sea indicate that sediment derived from the erosion of this section of the coast of eastern England feeds the pool of sediment in the North Sea. This sediment pool is then available for the maintenance of the Dutch and German salt marshes. In the face of a rapidly rising sea level, any diminution of input into this sediment pool must be viewed with alarm by all nations bordering on the North Sea.

Ecological Factors

The building of artificial defenses would have a radical effect on ecologically important intertidal areas, mudflats, mangroves, and other wetlands, many of which are protected by international treaty as well as by national law. Defenses built landward of them would be highly likely to result in their loss, while to barricade them (an unlikely option in any event because of the cost) would entirely change their ecological character.

There now exists an increasingly sophisticated network of wetland and other coastal areas protected by both national law and international treaties -- e.g., the Ramsar, Bonn, and Berne Conventions and other regional treaties. The wording of these conventions varies. The Ramsar Convention on Wetlands of International Importance especially as Wildfowl Habitat is purely hortatory in tone, simply requiring the parties to "promote" the establishment of reserves and inform an international commission about changes in the ecological character of listed sites (for a list of sites, see RAMSAR, 1987).[8] The Bonn Convention of 1979[9] depends on the conclusion of further agreements. The 1979 European Berne Convention on the Conservation of European Wildlife and Habitat,[10] which came into force on June 1, 1982, Article 4 requires contracting parties to:

> take appropriate and necessary legislative and administrative measures to ensure the conservation of habitats, and the conservation of endangered natural habitats (Article 4(1)) [as well as to give] special attention to the protection of areas that are of importance for migratory species [specified in the Annexes] and are appropriately situated in relation to migration routes, as wintering, staging, feeding, and molting areas (Article 4(3)).

Of particular interest to the matter in hand is the obligation on parties:

> in their planning and development policy [to] have regard to the conservation requirements of the areas protected...so as to avoid or minimize as far as possible any deterioration of such areas (Article 4(2)).

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[8]For text, see Lyster (1985) pp. 411-427.

[9]For text, see Lyster (1985) pp. 428-441.

[10]For text, see Lyster (1985) pp. 428-441.

Similar obligations are undertaken in other regional treaties.[11] Among the most rigorous of these are the obligations of the 1979 EEC Directive on the Conservation of Wild Birds Council Directive[12]:

> to take measures to preserve, maintain, or re-establish a sufficient diversity and area of habitats for all species of wild birds naturally occurring in their territories. (Article 3(1))

Such measures would include not only the establishment of protected areas, but also "upkeep and management in accordance with the ecological needs of habitats inside and outside the protected zones (Article 3(2))." This is no empty undertaking. As we discuss later in this paper, a case currently pending before the European Court of Justice concerns possible unlawful development of such an area.

It seems clear, therefore, that in planning responses to sea level rise, national authorities (particularly, but not exclusively, European authorities) will need to bear in mind their existing binding legal obligations under international law to maintain wildlife habitats in coastal regions.

Policy Options for Coastal Adjustments

The geomorphological adjustments to rising sea level outlined above indicate that an imaginative and cooperative management structure will be required in order to minimize the effects on coastal states. Both active and passive policy options are open to us.

<u>An Active Response: A Bulkhead Policy</u>

The arguments and examples developed above show that in many cases the building of preventative bulkheads in the face of increased coastal erosion may have deleterious results. At a local level, they inhibit the vertical response of the coastal profile to the change in water level, thus maintaining the coast in a state of disequilibrium with the consequent necessity for maintenance of expensive shore defenses and drainage provision. At an international level, unilateral action by one state may have considerable effects on it neighbors. For example, a bulkhead policy by one state that seeks to preserve the current coastal status quo may seriously exacerbate the problems faced by adjacent neighbors.

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[11]1982 Geneva Protocol concerning Mediterranean Specially Protected Areas -- see Article 3, for text see Sand (1988) pp. 37-44; 1985 Nairobi Protocol concerning Protected Areas and Wild Fauna and Flora in the Eastern African region -- see Article 8, for text see Sand (1989), pp. 171-184; and the Draft Protocol on Specially Protected Areas and Wildlife in the Wilder Caribbean -- due for final consideration in January 1990.

[12]79/409/EEC, Official Journal L103/1 (25.4.79)

Legal and Institutional Implications

Accretion and erosion are both well-known concepts in national and international law. Being natural processes, they do not per se give rise to legal claims. However, interference with natural processes may well do so. At a national level, actions will depend on the national legal system. In English law, although the position is unclear, it can be argued that by analogy with river siltation cases, action by one authority in building a barrage that deprives another area of sediment could give rise to liability (see Paulden, 1986). However, again in English law, an action against a public authority under public nuisance would normally be covered by the statutory defense. Although in *Tate and Lyle* v. *GLC and Port of London Authority* (1983),[13] the House of Lords said, in finding the defendants liable in public nuisance for building a ferry terminal that caused siltation of the plaintiff's jetty, that statutory operations must in general be conducted "with all reasonable regard and care for the interests of other persons."

The construction of bulkheads or sea embankments would have two major effects on ecologically sensitive wetland areas, as discussed above. First, if placed to prevent erosion of the upper shore, the bulkheads would restrict sediment movement across the shore profile so that the profile would fail to adjust to the new water level. The resultant profile would therefore be steeper than previously, and thus the ecologically important intertidal area would be diminished. Such foreshore steepening is already noticeable along the shore of eastern England (Anglian Water, 1988) and on the eastern seaboard of the United States (Leatherman, 1987). Second, the active policy of preventing erosion of cliff coastlines would deny the horizontal movement of sediments to the adjoining depositional wetlands, such as salt marshes and mangroves -- areas with extremely high ecological value.

It seems unlikely that states would seek or wish to denounce their obligations under wildlife treaties -- e.g., the Ramsar, Bonn, and Berne Conventions or other regional treaties. Their obligations to preserve habitat are important legal constraints on available policy. In a case pending before the European Court of Justice, the European Court Commission is impugning the Federal Republic of Germany for building dikes in two zones (Leybucht and Rysumer Nacken) that are considered as protected zones under the 1979 European Economic Community Directive on Wild Birds.[14] It is argued in this case that only "exceptional circumstances superior to the law" which endanger human life could justify work in these areas -- and even that would have to be strictly necessary. It seems clear that at a subregional level, the European Court Commission would be zealous to ensure that national strategies did not result in the loss of important habitat, and in their current form would be likely to maintain this position throughout the gradual changes that sea level rise would entail.

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[13][1983] 2 AC 509

[14]79/409/EEC, OJ L103/ (25.4.79)

The Passive Response

A passive response to sea level rise is one which would coincide with much of the current thinking of many coastal geomorphologists -- namely, that coastlines do find a natural equilibrium when left to themselves. There are, however, several obstacles to implementing such an approach.

Artificial Embankments and Reclamation. First, a passive response would be entirely acceptable were it not for the artificial embankment and reclamation of large areas of the world's shorelines. In a completely natural system, it seems likely that existing intertidal areas or coastal wetlands would keep pace with sea level changes by continued accretion. In the case of artificially protected reclaimed lands, this natural response is denied. The "passive" response in this case would entail the abandonment of much low-lying coastal land areas, either to inundation or to controlled inundation by a series of low-lying banks. Areas so inundated would then keep pace with sea level rise by natural accretion, always assuming that sufficient sediments are available from elsewhere in the coastal system to satisfy the imposed sediment demand. In some cases, this process may be accelerated by the introduction of sediment into the coastal system. Thus beach nourishment processes, widely used at present, may be supplemented with the artificial nourishment of intertidal mudflats and marshlands. Such active intervention in natural processes may be seen as a mid-way position between an active policy to prevent natural coastal response completely and a totally passive response that allows natural conditions to act unhindered.

Depleted Biological Activity. A second difficulty facing any passive response policy may also be mentioned here. The most vulnerable areas of the world's coastlines to sea level rise are the low-lying intertidal areas. These areas accrete fine sediments largely due to the presence of biological organisms, both animal and plant. Thus, coral reefs both reduce wave energy in the lagoon areas beyond and at the same time act as a source of sand size material necessary for the accretion of beaches and dunes in these lagoon areas. In mudflat areas, the existence of algae on the surface accelerates the accretion of fine-grained silts and clays, while in mangrove and salt marsh areas the presence of a vegetation cover creates the necessary conditions for the deposition of fine sediments. Consequently, the response of each of these coastal types to sea level rise depends on the presence of one type of organism or another. Yet in many cases, such biological activity has already been removed or depleted by human activity, so that these coasts are not capable of responding to the new conditions.

Coral reefs in the Caribbean and East Africa have been extensively damaged by dynamite used illegally for fishing, and by pollution and coral mining. Mangroves in many areas, such as in eastern Bangladesh (Stoddart and Pethick, 1984), have been totally deforested, and salt marsh vegetation has been reduced by pollution and the extensive reclamation of such areas for agriculture, industry, and housing. In these cases, the biologically impoverished coasts will require active intervention before they are able to respond naturally to sea level changes. The immediate suppression of coral reef damage, the planting of mangrove species in tropical intertidal areas, and the protection of salt marsh areas against further pollution and reclamation are all essential active measures needed before a so-called passive policy may be implemented.

Loss of Major Coastal Habitat. Third, the timing of a coastal response under such a passive policy may cause severe difficulties. Thus, the response of a coastline to rising sea level may eventually be to achieve sediment redeployment by removing material from one area and depositing it in another. But this interaction may not be instantaneous. The loss of a major area of coastal habitat without its immediate replacement elsewhere can have economic, social, and ecological repercussions.

A clear example of these repercussions is given in predictions for the response to rising sea level of the north Norfolk coast of eastern England (Pethick, 1989). This coast encompasses several nature reserves of international importance, comprised of sand dune and salt marsh. Each reserve is separated from the other by intervening stretches of beach that attract commercial recreational activities. An examination of the wave refraction pattern for the area demonstrates that this alteration of beach and marsh is caused by the pattern of wave foci along the shore (Figure 3).

A wave focus is created when a wave refraction pattern results in the concentration of wave energy in one area of the coast. Such a concentration of energy is compensated by the presence of a contiguous area of lower waves, and this pattern of high- and low-energy zones is responsible for the beaches and marshes of the north Norfolk coast. Figure 3 demonstrates that, under a rising sea level, these wave foci will swing eastward along the coast, so that eventually the marsh areas of the National Nature Reserves will be replaced by high-energy beach deposits, and the thriving holiday beaches of today will in turn be replaced by mudflat and marshland. Thus, the commercial and ecological coastal zones here will be interchanged, but the response will be gradual, with the beach areas gradually silting over and the nature reserves gradually being eroded away.

While this is happening the response of both humans and wildlife to the gradual loss of their chosen habitat depends entirely on the rate at which the changes occur and the rate at which they are able to modify their present behavioral patterns. One outcome could well be the failure of both coastal users to synchronize with the changes imposed by the coast, and the loss of both ecological and commercial activities on this coastline.

As well as these practical difficulties facing any passive approach policy, there are many economic and legal issues involved. Thus, a purely passive approach carried out in a developed zone where large areas of reclaimed marshland are present must involve the abandonment of these areas to the rising sea. Such an approach might reflect a cost-benefit analysis of the advantages of the value of low-lying arable lands against the open-ended cost of defending them. New natural wetland areas would be created to replace those inundated ones. However, the problems with this approach are at least twofold:

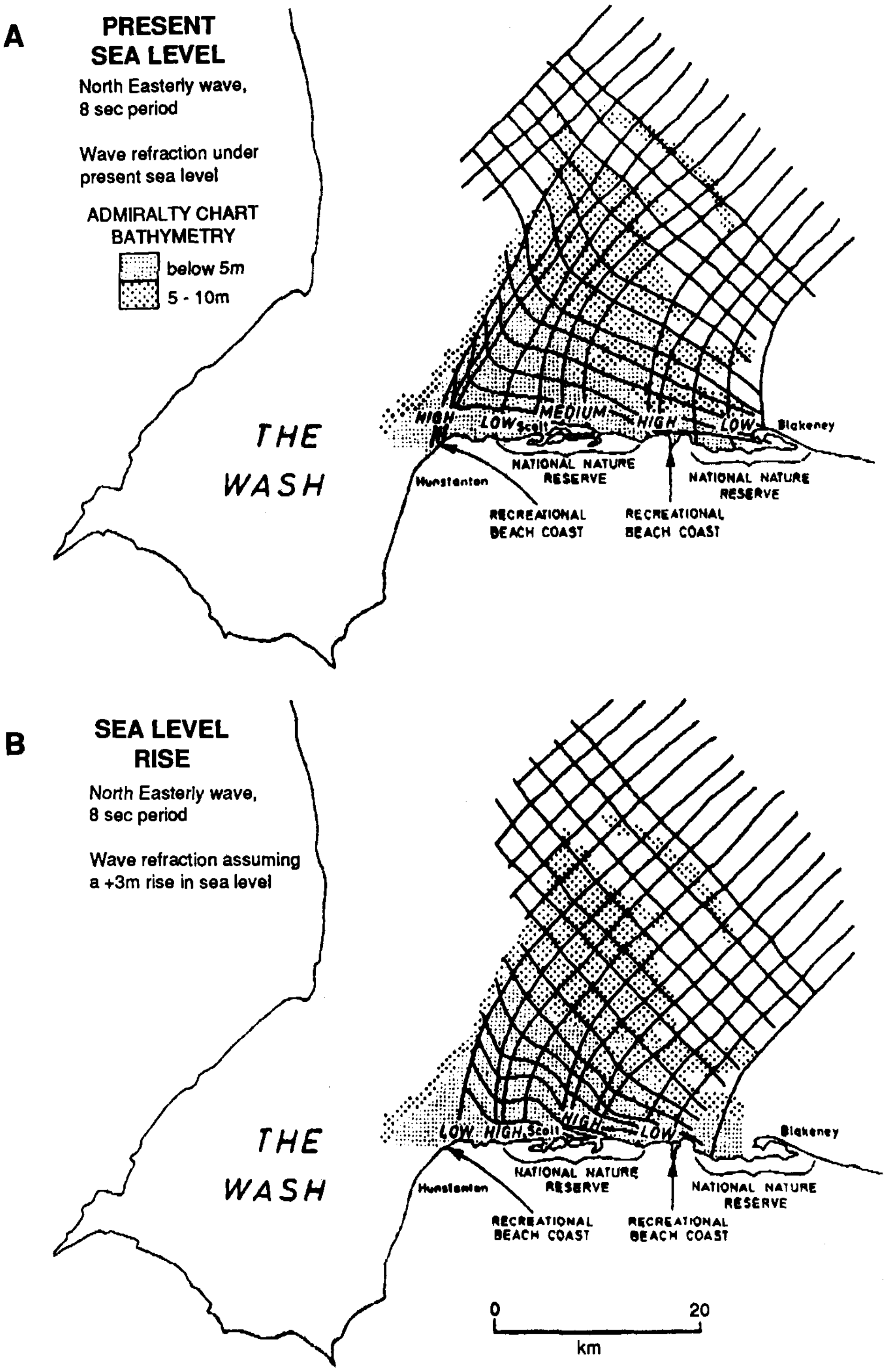

Figure 3. Changes in wave foci on the north Norfolk coast due to sea level rise, showing implications for nature reserves and recreational areas.

Legal and Institutional Implications

1. It would be impossible to pursue such a policy without exceptions. In any cost-benefit analysis, low-lying cities would have to be defended. It would be politically impossible to abandon London or the whole of the Netherlands.

2. It requires cooperation to be successful. It requires both intranational (e.g., Federal Republic of Germany/The Netherlands) and international (e.g., United Kingdom/The Netherlands) cooperation. In order for a coastline to find its natural equilibrium, maximum sediment mobility is necessary. The necessary legal machinery to enable cooperation among states to ensure such mobility must be developed.

So, although this might be a passive policy in some respects, it is not a politically passive option. It would require considerable cooperation at both local and regional levels. The final question to be addressed, then, is whether international law imposes an obligation to cooperate in such a way.

DOES INTERNATIONAL LAW REQUIRE COOPERATION?

Under classical international law, a state had complete and unchallengeable jurisdiction within its own territory. However, it is now recognized that states must respect the rights of their neighbors -- for example, by behaving equitably in relation to shared resources (e.g., the Diversion of Water from the Meuse case[15]) and by not permitting the escape of pollution that would damage its neighbor's territory (Trail Smelter Arbitration[16]). The principles of the 1972 Stockholm Conference[17] declare that:

> States have in accordance with the Charter of the United Nations and the principles of international law, the sovereign right to exploit their own resources pursuant to their own environmental policies, and *the responsibility to ensure that activities within their jurisdiction or control do not cause damage to the environment of other states or of the area beyond the limits of national jurisdiction* [italics added].

In the light of a modern view of the interdependence of ecosystems and, indeed, of the world ecosystem, it seems widely agreed that international law does not permit actions that damage other states or "common areas." An example

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[15](1937) *Netherlands* v *Belgium*, PCIJ Reps, series A/B, No 70

[16](1938/41), *U.S.* v *Canada*, 3 RIAA 1905

[17]Report of the UN Conf on the Human Environment. UN Doc A/CONF, 48/14; 11 ILM 1416 1972. Principle 21

of this is the International Law Commission's proposal[18] that massive marine pollution should be an "international crime" (Smith, 1988).

Any attempt to relate these developments to the novel problems posed by national responses to sea level rise must address the problem that the nature and potential scale of the issue has no direct precedent. It seems clear that the full implications of the effects of sea level rise have not yet been fully appreciated. International lawyers are only just beginning to address the problems that this rise poses. This does not mean that there is an international law vacuum, but simply that the applicable principles are in the process of adaption and crystallization. All that can be done here is to suggest a number of approaches to analogous problems, which may shed some light on possible approaches.

Unfortunately, there are no direct analogies. National laws may suggest a number of principles -- albeit different -- to the problem of state responses that exacerbate erosion and land loss in neighboring states. However, the closest analogy of cross-boundary environmental damage appears to be with the problems of pollution where the behavior of one state affects the interests of others. Actions for damages have tended to be restricted to cases of direct damage; the position is less clear with indirect damage.

Rather than considering liability for breach of obligations, however, it may be more positive to consider whether international law prohibits certain courses of action, or can require cooperation. Of considerable importance in this connection is the emergence in international environmental law of the Precautionary Principle, or the principle of precautionary action. This principle is derived from national environmental law. Gundling (in press) describes the principle as:

> ...a more stringent form of preventative environmental policy. It is more than the repair of damage or the prevention of risks. Precautionary action requires reduction and prevention of environmental impacts irrespective of [proven] risks.

The principle is accepted by the North Sea states in relation to marine pollution, and is included in the 1987 London Declaration on the Protection of the North Sea.[19] This year it was also accepted by the parties to the 1974 Paris

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[18]For text see YB ILC, 1979, part II, page 90 and 1980, Part II, page 14,70. Article 19(3)(d) refers to "a serious breach of an international obligation of essential importance for the safeguarding and preservation of the human environment such as those prohibiting massive pollution of the atmosphere or of the seas."

[19]Second International Conference on the Protection of the North Sea, Ministerial Declaration, Nov 1987. Reproduced (1988) 3 International Journal of Estuarine and Coastal Law, pp. 252-265.

Convention on pollution from land-based sources.[20] While Gundling does not feel that it has yet emerged as a general norm of international law, he identifies its use in a number of important environmental documents, including the Ozone Layer Convention (1985 Vienna Convention[21] and 1987 Montreal Protocol[22]), as well as the 1972 Stockholm Declaration itself[23], the 1982 UNEP Nairobi Declaration[24] (stressing the necessity of environmental management and EIA as well as proper planning of all activities), and the 1982 UN General Assembly "World Charter of Nature"[25] (in which the principle is urged in relation inter alia to protection of habitat and planning).

While these are not strict treaty obligations applicable to the current problem, states that participated in creating these agreements must find it difficult to deny the validity of the principles they set out.

In addition, Principle 21 of the 1972 Stockholm Declaration on the Human Environment (adopted by acclamation of 113 participating states) declared that:

> States have...the responsibility to ensure that activities within their jurisdiction or control do not cause damage to the environment of other states...

It does seem that, faced with a problem -- such as sea level rise -- in which a high degree of coordination and cooperation may be required to prevent unilateral actions exacerbating neighbors' erosion problems, that at the very least states would stop arguing that this is a matter entirely within their own jurisdiction.

There are precedents in international law for obligations to cooperate or to negotiate in good faith. For example, in the field of natural resources law, and more particularly the emerging rules on exploitation of joint liquid and gas deposits, it is now argued that not only is "unconsented" exploitation of a joint liquid mineral deposit (in such a way as to damage the neighbor's right to exploit that deposit) illegal, but also that, as Lagoni (1979) argues, state practice:

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[20]Paris Commission (PARCOM) Recommendation 89/1 22 June 1989

[21]1985 Vienna Convention on the Protection of the Ozone Layer.

[22]1987 Montreal Protocol to the Vienna Convention above.

[23]See above note 17, Principles 2, 3, and 5.

[24]Nairobi Declaration on the State of the World Wide Environment. 18 May 1982, 21 ILM 676 (1982).

[25]1982 UN General Assembly Resolution on the World Charter for Nature, UN Doc A/RES/37/7, 9 Nov 1982, 22 ILM 455.

has given rise to a customary rule of current international law. That rule means that...no state may exploit a common deposit of liquid minerals before having negotiated the matter with the neighboring state or states concerned.

Of course, this rule cannot be translated directly into environmental law. But it does demonstrate that cooperation can develop even in areas that have been traditionally regarded as close to states' vital interests -- hydrocarbon resources.

It is unclear whether there is an obligation for states under customary international law -- independent of treaty -- to cooperate in planning their responses to sea level rise. Nevertheless, this paper has sought to demonstrate that such an obligation is a necessary part of a measured and planned response. If the obligation to cooperate does not emerge through customary international law, it should be enshrined in treaty.

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LEGAL IMPLICATIONS OF SEA LEVEL RISE IN MEXICO

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ABSTRACT

In the search for adaptive options to sea level rise and other impacts of global warming, this paper analyzes the basis for environmental protection in the Mexican legal system and briefly looks at some aspects of international law.

EVOLUTION OF MEXICAN ENVIRONMENTAL LAW

The evolution of environmental law in Mexico has followed the same course as international law. The first 60 years of this century saw an effort by developing countries to assert sovereignty over their natural resources. It was not until 1962 that the United Nations General Assembly adopted resolution 1803, which recognized "permanent sovereignty over natural resources." Although there were other resolutions, it was not until 1972 at the Stockholm Conference on Human Environment, that Principle 21 associated the concept of sovereignty over natural resources with the goal of conservation of the environment for the sake of future generations. Before then, environmental laws were more concerned with the "cleaning" and "reparation" of already polluted areas. Since then, the approach has been to relate the environment to the national welfare and development by providing rules for the exploration, exploitation, administration, and conservation of Mexico's natural resources.

Article 27 of the Federal Constitution of Mexico has been amended 24 times since the Constitution's enactment in 1917. This considerable number of amendments reflects the evolution of the growing control of the Mexican State over its natural resources. The current Article 27 establishes the property regime that determines the specific economic and social system of Mexico. It states that the Mexican territory belongs to the nation, and it establishes direct and eminent domain over all natural resources. Although the Constitution recognizes private property, it allows for the imposition of any conditions on such property required by the public interest.

ECONOMIC ACTIVITIES

The approximately 5,000 kilometers of Mexican coastline are not considered a unitary natural resource. For this reason, there is no single authority to manage them. Rather, they are managed on the basis of their different economic activities.

The federal Constitution of Mexico establishes the areas and activities that are subject to federal legislation. Any activity not expressly set within the federal rules is understood to be under the control of the local rules of states and municipalities.

Mining and Exploitation of Fossil Fuels

The mining and exploitation of fossil fuels in Mexico are highly developed and account for one-tenth of the GNP. Oil and natural gas reserves, as well as salt mines, are located in coastal areas. As mentioned above, the federal Constitution has established that the state has direct domain over these resources. Generally, concessions may be made to nationals and foreigners for exploitation of mines, but not for exploitation of fossil fuels. The petroleum industry is managed by PEMEX, the largest enterprise in Latin America. In compliance with environmental laws, PEMEX has undertaken some preventive and some corrective programs, but none that address the problem of global warming or sea level rise.

Fishing

Fishing is another important federally regulated industry. Fishing cooperatives dominate in the coastal area, especially on the west coast. Well-developed laws exist for the protection of the marine environment, but the impact of potential sea level rise caused by global warming is not currently addressed.

Ports and Harbors

During 1985, Mexican ports handled 2,206,643 deadweight tons of commercial goods. The Mexican Ministry for Communications and Transport spends a great amount of its budget on the construction and maintenance of ports, but there are no laws or programs providing for the prevention of damages from sea level rise.

Tourism

Tourism is another profitable industry along the coast. Mexican beaches are recognized worldwide and bring approximately $2 billion (U.S. dollars) annually into the country. In principle, tourism is a matter for local regulations. However, the tourist industry involves a great deal of foreign investment, which is subject to federal rules.

Two aspects of foreign investment in tourist facilities are of particular interest. One is that local developers built tourist facilities 500 meters to one kilometer away from the beach. It was foreign investment that brought the concept of huge beachfront facilities to Mexico. Another interesting aspect is that the federal constitution prohibits foreign ownership of land for a 50-kilometer-wide belt along the coastline. Because of this, a legal device was created for foreign investment in the form of a trust. The trustee is always a national bank that holds possession of the land, and the foreign investor becomes a beneficiary for a period of 30 or more years.

Mexican law provides for state ownership and federal control of land reclaimed from the sea. Loss of land, however, is considered a natural phenomenon and the owner of such land would bear the cost of a loss, with no right to compensation.

Forestry and Agriculture

Forestry is managed under federal rules, while agriculture and cattle ranching are a matter for local legislation. Environmental laws at both the federal and local levels establish extensive control of the exploitation, conservation, and administration of those resources. Once again, it was not possible to find specific rules to address the potential problem of sea level rise.

Socioeconomic Obstacles to Planning for Sea Level Rise

Relying on the existing legal framework, it would be possible to begin addressing a globally planned response to climate change and sea level rise. But before proposing adaptive options, it is necessary to see how this legal framework relates to the socioeconomic conditions in the coastal areas of Mexico.

There are many conflicts between the development interests and the local economics based on coastal resources. Many of Mexico's coastal communities have marginal economies. In these communities, everyday activities are a matter of survival. Authorities at both the federal and the local levels are attempting to satisfy the basic needs of these communities, rather than thinking about responses to a problem not yet scientifically proven.

Although the Mexican people want to raise their standard of living, we need to ask what kind of development should be allowed. Industrialization and growth on the basis of existing technology will contribute to the problem of global warming.

ADAPTIVE OPTIONS

A great deal of work has been done, but much more work is needed to find a balance between sustainable development and conservation of natural resources and protection of the environment.

Legal and Institutional Implications

At the National Level

To deal with a potential sea level rise, we will have to think of the coastal zone as a unitary natural resource, and then provide for its management either by existing authorities or by a newly created authority. (In relation to hydrological resources, while groundwaters are susceptible to appropriation by individuals, underground water is controlled by the state. In both cases, there are no laws or programs to address the potential impacts from global warming or sea level rise.)

The Mexican government needs to make use of environmental regulations already in force to prevent or to adapt to global warming. It must also disseminate sound scientific information about the causes and risks of global warming among authorities both at the federal and local levels.

At the International Level

A global response of the international community is required to face the climate change. International cooperation is needed, with due respect to national needs and priorities. Now that the principle of permanent sovereignty over natural resources has been achieved, the IPCC process should be used to make governments and people aware of the real value of natural resources.

LEGAL AND INSTITUTIONAL IMPLICATIONS OF ADAPTIVE OPTIONS OF SEA LEVEL RISE IN ARGENTINA, URUGUAY, AND SPAIN

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ABSTRACT

This paper covers the following subjects concerning the legal regimes of Argentina, Uruguay, and Spain, countries riparian to the Atlantic Ocean and having a system of written statutory law originating in the Roman law tradition: factors common to the countries surveyed; two basic legal principles, periculum and commodum, which are allocated by Nature (acts of God); men are responsible for damages produced by sea level rise when this does not happen as an act of God; complexity of the legal and administrative regimes of maritime coastal areas; boundary delimitation of the public and private domain in maritime coastal areas; other lines and strips linked to the legal maritime high-water mark; maritime-coastal wetlands; and legal rules as tools to promote or discourage human influences in changing the high-water mark, and government powers based on them.

INTRODUCTION

The legal systems of Spain, Uruguay, and Argentina are not based on common law. Rather, they are derived from ancient Roman law following a regime of written statutory law. Argentina is a federation, institutionally quite similar to the United States.

This study looks at the legal powers of these three countries with regard to adopting suitable measures to adapt to the difficulties that could arise from the predicted sea level rise. These adaptations may not necessarily include the preservation of wetlands.

TWO BASIC LEGAL PRINCIPLES: "PERICULUM" AND "COMMODUM"

The judicial wisdom of the ancient Romans led them to state the legal principle that it is nature that distributes the periculum (danger, damages) and the commodum (comfort, benefits). We relate "nature" to the agnostics and "acts of God" to the believers. Legally, both expressions have the same meaning.

Since ancient Rome, this principle has governed the relationships among states and individuals and has been translated into a number of rules of the civil codes. For instance, the owner of a piece of land has the right to receive the waters descending onto his land from above it, provided the waters descend as a result of nature and not the work of humans. When the waters are produced directly or indirectly by human influence, the responsibility for any damage lies with the people who have initiated the activity. Argentina's Court Supreme admitted the applicability of this principle in a sentence dictated in 1986 (Fallos 175:133).

The principle has economic implications. If a man chooses to live on a flood-prone riverside, he accepts the risk of being flooded and of bearing the consequences of the periculum, provided the flood is not produced by the work of another human being. If a flood is caused by human activity, the people responsible for the activity are also responsible for the damages the man suffers. But, in this example, the man who chooses to live there also takes into account the commodum, as he benefits from having at his disposal cheaper water to fulfill his needs, perhaps combined with panoramic beauty and a lower price for the land.

In the field of international law, it is a generally accepted principle that no country can produce in a river basin damages that could significantly affect another state of the same basin (Cano, 1979b).

LEGAL AND ADMINISTRATIVE COMPLEXITIES

In the maritime coasts of Uruguay, Argentina, and Spain, there is a mixture of salty seawaters. The regular tides are mainly due to lunar attraction; in fresh waters of continental origin (superficial and subterranean), the tides depend on either rain or snow. Generally, the two kinds of waters are subjected to different legal regimes and are under different administrative organizations. As far back as 1975, several people favored consolidation of the maritime and continental water laws (Cano, 1975; Sewell, 1976).

In addition, the soil along the coasts generally belongs to different people. The beaches and the immediate sea bed are often in the public domain, and the adjacent lands inland are often private property. Thus, they are subject to different legal regimes. In federal countries, like the United States and Argentina, the situation is more complex, since the public domain is sometimes federal and other times local, or the jurisdiction is federal for certain uses of the water (navigation) and local for other uses (irrigation, domestic consumption, etc.). Complicating things even further, other natural resources along the coast are interrelated with the land and the water (flora and fauna, minerals) and are also subject to different laws and authorities (Sneader and Getter, 1985).

Many coastal cities, towns, and ports are administered by another governmental level: the municipalities or town councils. This makes matters worse, especially if there is a sea level rise that floods urban areas permanently. This would displace thousands of people, causing not only legal problems but also social problems. Christina Massei has written about this subject for this meeting (see Massei, Central and South America, Volume 2).

DELIMITING PUBLIC AND PRIVATE DOMAIN

In the maritime coasts of Uruguay, Argentina, and Spain, the beach, the sea bed, and the waters seaward of the maritime high-water mark belong in the public domain. Inland, the land is private property. While the high-water mark or high tide is used to divide the public from the private domain, the low-water mark is used in politico-international relations, as it serves as a starting point to measure the beginning of the territorial sea, or the exclusive economic zone.

That low-tide mark, or low tide, can be physically delimited on the beaches or the cliffs. It is called the normal base mark or reduction plan. Sometimes, however, a riparian government chooses to draw straight lines between the capes that mark either gulfs or bays and to state that all that remains inland in those marks is -- in relationship with other nations -- of its exclusive domain and sovereignty. These marks are called "base straight marks" (Cano et al., 1989). Due to a Joint Declaration made on January 30, 1961 (ratified by the Montevideo Treaty on January 19, 1963), both Argentina and Uruguay defined -- in relationship with third nations -- the frontal border of the Rio de la Plata, which they share. The territorial sea of both countries starts seaward from that straight base mark (which is 230 km long) (Cano, 1979b).

In the Republic of Uruguay, along the coasts of the Rio de la Plata and on the Atlantic Ocean, the high-water mark is determined by the average of maximum annual heights over a 20-year period (Gelsi Bidart, 1981). In Spain, according to its 1985 Water Law, the high-water mark is determined similarly, but is averaged over 10 consecutive years (Gonzalez Perez et al., 1987).

Concerning the river coasts, the civil codes of the three countries we are dealing with provide that if sediments accumulate naturally, the extended surface that forms (called "alluvium") increases the property of the riparian landowners. But if the riverside consists of a road, wall, or another public work, the alluvium becomes public property. This is one example of enforcement of the principle that nature distributes the periculum and the commodum. But the laws of those countries do not offer the same solution for the maritime coasts, because physical aggregate by alluvium cannot be produced in them. On the other hand, it could occur the other way around: erosion by the sea could forever diminish the property of the riparian landowner. It is worth adding that within the public domain (beaches, etc.), individuals cannot build -- or even plant -- anything without a license from the government.

If the maritime high-water mark rose permanently, for example, because of a sea level rise, it would be necessary to redraw the mark, and the riparian or littoral owner would lose the property of the flooded lands. Such a solution has been proposed for a future reform in the Argentine legislation (Cano et al., 1989).

In the Argentine federation, the maritime beaches, the sea bed, and the waters up to three miles seaward are the property of and under the jurisdiction of the government of the littoral province. Navigation is under federal jurisdiction, even though the soil, the water, and the jurisdiction over all the non-navigational uses (fishing, mining, etc.) of the water and the bed still belong to the provincial government (Cano, 1979a). The safety of navigation is also under the jurisdiction of the federal government, through the Prefectura Naval Argentina (equivalent to the U.S. Coast Guard Service). According to the Constitution, the ports can be regulated only by the federal government. Thus, the harbor patrol, even for non-navigational purposes, is exclusively exercised by the Prefectura Naval.

On the maritime Argentine coast there can be more than one legal high-water mark. One is established by the federal government only for the sake of its jurisdiction over navigation; the other one is adopted by the governments of the littoral provinces for all the other purposes. In fact, the government of Buenos Aires Province (Cano et al., 1989) has created a 150-m-wide strip inland of the legal high-water mark, where construction of buildings is prohibited.

In general, this strip is occupied by dunes. If the dunes extend beyond 100 m, the prohibition strip becomes larger to accommodate the full extension of the dunes.

In Argentina, for the purpose of navigation, the legal high-water mark is physically established in terrain by the National Directorate for Port Works and Navigable Waterways. Also in Argentina, along the maritime coast, the legal low-water mark or reduction plan is physically delimited by the Navy's Hydrographic Service, which is also in charge of delimiting the straight base marks.

OTHER LINES AND LAND STRIPS LINKED TO THE LEGAL MARITIME HIGH-WATER MARK

Starting from the legal maritime high-water mark and moving landward, in Argentina there is a strip 50 m wide, all along the maritime coast. The Prefectura Naval (federal agency) exercises its navigational jurisdiction over this strip. Inland of that strip, the soil is the property of the riparian landowner, without restrictions on its use.

Second to the federal civil code, along the bands of navigable rivers in Argentina, there is a 35-m-wide legal servitude, or right-of-way. This is called "towrope servitude," or riverside way. The riparian landowners must keep that strip free to enable transit, and they cannot build on it or plant any trees (Cano et al., 1989).

In the Rio de la Plata (one riverside of which is Argentine and the other Uruguayan), a special situation occurs. The high-water mark is determined both by the tides and by the flow of the Parana and Uruguay Rivers, the union of which forms the Rio de la Plata (that on the whole amounts to a flow of about 17,000

m^3/sec). When strong winds from the southeast prevail in the mouth of the Rio de la Plata, which is 220 km wide, they block the normal flow of the river waters, and the riparian lands become flooded. In Argentina as well as in Uruguay, the Rio de la Plata is legally considered a river and not an estuary. Thus, the strip of 35 m devoted to protect navigation is applicable (Gelsi Bidart, 1981; Cano et al., 1989).

Recently proposed reforms to the Argentine legislation would (1) create in the maritime coast a "service zone" 10 m wide, which the landowner must keep free for transit (such a zone does not exist at present); (2) forbid landowners next to the legal maritime high-water mark from carrying out excavations that could alter the mark's altitude; (3) grant the landowners next to the legal maritime high-water mark the right to request from the government the physical delimitation of the marks, in procedures that must be carried out with the government's participation (the procedures must be carried out again if the mark naturally changes through an act of God); (4) maintain in that maritime coast the strip of 50 m so that the navigational safety police can carry out their responsibilities; (5) create a servitude of floodways along the 350 km of Argentine coast of the Rio de la Plata, which would eventually be subjected to sea level rise (the land use would be subjected to restrictions imposed by the provincial government, which would apply throughout the width of the floodway up to the 25-year floodplain); and (6) create along the banks of the Rio de la Plata another strip called the "flood-prone area," which strip would be determined by the level that flood waters are expected to reach every 100 years (this strip would also be subjected to use restrictions, but they would be less severe than those imposed by the provincial government) (Cano et al., 1989).

According to article 2611 of the Argentine Civil Code, the restrictions to the public property are imposed for the public interest (and not for the interest of any individual person). These restrictions are established by the administrative law, and the power to carry them out belongs to the provincial governments.

On the Atlantic coast are four provinces (Buenos Aires, Rio Negro, Chubut, Santa Cruz) and two federal territories (city of Buenos Aires and Tierra del Fuego). In the two territories, the federal government acts as a local authority where such local powers can be exercised. Restrictions can be imposed on private property without compensating the owners, but when the restrictions call for establishing servitudes (rights-of-way), the owners must be compensated. Even more, when landowners are deprived of their property because of eminent domain, the Constitution requires full compensation. The mere "restrictions" only imply abstentions that the owner must tolerate. They apply to everyone in the same situation and are for the general benefit of the public, rather than of an individual (Cano et al., 1989).

Uruguay has an identical legal regime for the legal high-water mark for its maritime coasts and for those of Rio de la Plata. Its strip of defense along these areas is 250 m wide. Along the strip, the domain of landowners is restricted (landowners may not remove sand), and the government can impose more restrictions as it deems necessary (Cano et al., 1989). Uruguay has a different regime for its other fluvial coasts (the Uruguay, Cuareim, and Yaguaron Rivers, the last two bordering with Brazil) (Gelsi Bidart, 1981).

Maritime Law

Spain specifies two strips (Gonzalez Perez et al., 1987; Cano et al., 1989):

- a zone of servitude 5 m wide, for public use, fishing, and rescue/life-saving; and

- a police zone of 100 m, where a governmental license is required to alter the natural relief of the terrain, to remove stones or sand, to construct buildings, or to initiate any other activity that could obstruct the free flow of flooding waters.

A SPECIAL CASE: MARITIME COASTAL WETLANDS[1]

In Argentina, the wetlands are not administered by the federal government. Some provincial laws (but none of them from provinces with maritime shores) govern them, but those laws allow and even require their drying up so that the provinces can recover their beds for farming and can put the waters to other uses. If the coastal wetlands are below the legal maritime high-water mark, they are part of the public domain and are subject to its regime.

Argentina is not a signatory of the Ramsar Convention. The federal legislation recently planned by the author of this document (Cano et al., 1989) proposes to adopt a definition of wetlands that differs from the Ramsar Convention's definition and that is very similar to the definition of the U.S. Corps of Engineers and of the U.S. Fish and Wildlife Service. The proposed definition would limit the depth to one meter and would demand the presence of anaerobic vegetation. The explicit proposal is to declare wetlands as being in the public domain, as would be the case with coastal wetlands when they surpass the legal maritime high-water mark. How the wetlands would be used would be subject to what each provincial government decided for its territory.

When the Uruguayan government ratified the Ramsar Convention, a conflict arose over the conceptual disagreement between the Convention and the preexisting Uruguayan legislation (the 1979 Water Code and the 1875/1943 Rural Code). This former legislation protects the wetlands when they have autochthonic fauna, whereas the Ramsar Convention refers to migratory birds (waterfowl) (Laciar, 1989). Although the Rocha Swamplands were protected by preexisting rules (article 161 of the Water Code), the Convention authorized their drying up. In 1987, a group of ecologists obtained a judicial verdict that paralyzed the drainage works.

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[1] This study examines only the maritime coastal wetlands and not Mediterranean wetlands.

In Spain, wetlands are ruled by the Ramsar Convention, the 1985 Water Law, and the Coasts Law. For example, the Coasts Law rules over coastal wetlands (Laciar, 1989), especially over how to delimit them. The administration of wetlands is shared by the Water and the Environmental Authorities (Martin Mateo, 1981; Cano et al., 1989). Their legal regime includes the artificially created wetlands, and the margins of any wetland could also be added.

All activity in the wetlands is subjected to licenses or concessions. If the Water Authority decided to encourage their drainage, it would have to consult the Environmental Authority. In the wetlands, the water is within the public domain, but the beds and the other natural resources can be private property (Cano et al., 1989). Wetlands that are declared to be of special ecological interest are subjected to concessions of more severe conditions.

RULES GOVERNING THE HIGH-WATER MARK

We have seen that, in general, the countries under study can administratively impose restrictions on the use of private lands adjacent to the sea without compensating the owners when the restrictions are of a general character, when they relate to the public interest (as determined by the parliaments of these countries), and when they do not imply a substantial limit on the private property. Moreover, if they compensate landowners, these countries can also impose rights-of-way and even forcibly buy the necessary lands based on the public interest.

With regard to programs for mitigating flood damages (Cano et al., 1989), Canadian and U.S. practices have strongly influenced the kind of restrictions these countries are imposing on people who choose to live in flood-prone areas. The program includes mandatory insurance, the cost of which is shared by the population of other areas, through a public subsidy for the insurance. This could be an example valid for the coastal zones subject to sea level rise. However, I only suggest this as a mere possibility that should be open to a more careful study and discussion.

The discussion has already begun on the subject of the responsibilities of governments and individuals due to the global warming.

As the projected the sea level rise has not yet occurred, it is still possible to take preventive measures; this course would be cheaper because it does not try to correct existing situations. It is possible to restrict the present and future uses of coastal properties by introducing long-term planning and land use zoning. Taxation and other restrictions could also be used to discourage settlement in and use of the coastal zones, or to create funds to support the changes.

The question of the diversity of political and administrative jurisdictions in the coastal zones, especially in the cities, deserves special consideration. Horacio Godoy (1981) proposed for Colombia the creation of a Maritime Authority, to address the coastal problems. That form of inter-administrative coordination must be explored to confront the problem we now must fact.

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PRESERVING COASTAL WETLANDS AS SEA LEVEL RISES: LEGAL OPPORTUNITIES AND CONSTRAINTS

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INTRODUCTION

Many scientists are predicting an increase in the Earth's surface temperature as a result of "greenhouse gases" being introduced into the atmosphere. A temperature increase may lead to higher sea levels, inundating coastal wetlands. Under natural conditions, coastal marsh grasses could retreat landward of the inundated wetlands and maintain a constant vegetated edge between dryland and open coastal waters. However, in many parts of the United States, property owners will have already developed the areas that would support new "migrant" wetlands, and will have erected levees and bulkheads to protect dry-land from seawater. Unless the government acts to discourage property owners from taking measures to prevent inland retreat of coastal marshes, the United States will lose most of these valuable wetland resources under the rising tide.

Governments may try a number of different approaches to respond to this potential problem. These approaches may involve land use regulation to forbid development or bulkheading behind current coastal marshes. Acquisition of property rights (including outright (fee simple) ownership, development rights, or leases) through purchase, condemnation, or regulation is another approach governments may consider. James Titus has identified three categories of strategies that the government can use to protect natural shorelines[1]: (1) prevent development by prohibiting it altogether or by purchasing property and dedicating it to preservation; (2) defer action until the seas rise, and then order landowners to abandon their property to the sea or to purchase the coastal property; and (3) prohibit bulkheads on natural shorelines, or acquire a future interest in coastal property. The first and third categories require the

[1]J.G. Titus. "Greenhouse Effect -- A Coastal Wetland Policy: How America Might Abandon an Area the Size of Massachusetts." Environmental Management (in press).

government to act in anticipation of the sea level rise problem. Of the three, the third category is the most politically feasible.

This paper discusses the legal issues that arise from applying these policy approaches. The primary question these approaches raise is whether the government must compensate affected property owners. The paper will focus on the policy actions governments can take now to mitigate problems later as the threat of land loss due to sea level rise becomes imminent. Because there is no need to prohibit development altogether before the migration of wetlands, this paper will focus on options that restrict bulkheading and that acquire future interests.

The power of eminent domain, which rests in both the federal and the state governments, allows condemnation of private property for a public purpose. The aspects of the proposed government actions that involve purchase of property rights face no legal barrier. Governments can negotiate a voluntary sale or condemn property for the purpose of wetland protection.[2]

This paper is concerned primarily with the extent to which governments can act without compensating private property owners who are faced with special restrictions or property loss. In the United States, the fifth amendment of the Constitution, as applied to the states through the fourteenth amendment, limits governments' ability to infringe on private property for public purposes without just compensation and due process of law.[3] Even if the best policy option is to pay all landowners for their sacrifices to allow coastal wetlands to migrate, an understanding of the government's authority to act without compensation will play an important role in negotiations with private landowners. The stronger the government's right to act without compensation, the more likely private landowners are to cooperate, and the lower their reservation prices will be.

The fifth amendment of the U.S. Constitution specifies that people will not be deprived of property without compensation. This limitation on government regulations that do not compensate injured landowners is seldom encountered in other countries. This places all of the other nations whose laws we examined in a better negotiating position to agree with private landowners to allow coastal wetlands to migrate.

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[2]Wetland protection falls comfortably within the bounds the United States Supreme Court has established to limit what constitutes a public purpose. Cf. Berman v. Parker, 348 U.S. 26 (1954) (upholding condemnations to redevelop blighted urban areas as within the broad state power to act on behalf of the public welfare).

[3]U.S. Const. amend. V (No person shall "be deprived of life, liberty or property, without due process of law; nor shall private property be taken for public use, without just compensation") U.S. Const. amend. XIV, §1 (No state shall "deprive any person of life, liberty, or property, without due process of law").

THE "TAKING" ISSUE

In his famous 1922 opinion, Justice Holmes found that a Pennsylvania law restricting underground coal owners from mining some of their property was invalid without compensation to the owners for loss of their rights. He stated: "if a regulation goes too far, it will be recognized as a taking."[4] Although subsequent cases give us a bit more guidance, Holmes' general statement accurately captures the ad hoc law of takings -- there is no precise formula for determining whether a regulation, such as bulkhead or development restrictions, is a taking.[5]

States, which have sovereign power to regulate land use for the health, safety, and welfare of their citizens, confer regulatory authority on local, municipal, and county governments to control land use. Many states reserve authority to regulate land use in areas of special concern, such as coasts. Since state regulations and local regulations based on enabling authority granted from the state both must respect fifth amendment protection of property, we will not distinguish between the two in our legal analysis. However, it is important to note that a landowner can challenge a local regulation as not being within the scope of powers granted to the local jurisdiction by the state law. This issue is a matter of state law, and does not arise in cases where the state directly regulates land use, such as actions by a state coastal zone management authority.

The policy responses to sea level rise fall into two categories for the purpose of our takings analysis. One is permit conditions, which occur when a government authority exacts from a landowner either an acquisition for a future interest or a prohibition on bulkheading in exchange for the necessary permission to develop the property. The other is bulkhead prohibitions on all property, not tied to a grant of permission to modify land use.

Permit Conditions

Building permits for new structures are issued by local authorities who may check to see that the proposed structure meets zoning requirements. In many jurisdictions, special subdivision/land development ordinances regulate major

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[4]Pennsylvania Coal Co. v. Mahon, 260 U.S. 393, 413 (1922).

[5]A regulation also will be invalid if it deprives a landowner of property without due process of law. Because the due process protection in the fifth amendment embodies similar safeguards as the just compensation requirement, courts generally fail to distinguish between the two grounds when overturning regulations. Want, "The Taking Defense to Wetlands Regulation," Env. L. Rptr. (Env.L.Inst.) 10169 (1984). Therefore, the takings issue as defined in this paper includes due process concerns that tend to focus on the rational relationship between the regulation in question and a legitimate government interest (e.g., a state's interest in the health, safety, and welfare of its citizens).

construction activities and often require permit applicants to meet standards relating to environmental protection. Building on undeveloped land in coastal zones generally requires a permit from a state coastal zone management agency.[6]

In fact, it was the conditioning of a permit by a coastal management agency that the Supreme Court ruled invalid as an uncompensated taking in Nollan v. California Coastal Commission.[7] The dispute centered on a condition requiring dedication of an easement imposed by the California Coastal Commission on a permit to replace a bungalow with a larger house. The easement condition was not for public access to the public beach, but for public access along the portion of the dry sand beach owned by the permittee. The Commission argued that the condition was imposed to mitigate the adverse impact of the new house, which would block the public's view of the beach, "psychologically" inhibit the public's recognition of its right of access, and increase private use of the shorefront.

The Court found that the condition utterly failed to meet the legitimate state interest in public health, safety, and welfare. Although the Court suggested that a permit condition must bear a substantial relationship to a valid public purpose, its actual finding that there was not even a rational relationship carries more precedential weight in defining the test for permit conditions. The Court acknowledged that the Nollans had no unfettered right to build on the property, and that the Commission had a right to deny the permit if denial would protect some public right.[8] However, a condition on the permit that is unrelated to the public right (of access, use, and view of the shore) is invalid. The Commission could have conditioned the permit on the provision of a public view or access to the beach. It could also have used its eminent domain power to condemn the dry beach easement.

A coastal management agency seeking to protect wetlands could condition a permit for development or construction on a prohibition of bulkheads. Because the relationship between the presence of a bulkhead and the inability of wetlands to migrate inland is substantial, let alone rational, such a condition would meet the standard set by the Court in Nollan.

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[6]The federal Coastal Zone Management Act (CZMA), 16 U.S.C. §§1451-1464, creates a voluntary program to encourage states to exercise their own authority to establish and implement coastal management plans (CMPs). The CZMA is not a grant of regulatory authority over private property to states. States with CMPs approved by the federal government receive financial assistance and can prohibit (subject to the veto of the U.S. Secretary of Commerce) federal activities not consistent with the CMP. This provision gives states with CMPs leverage to affect activities requiring federal permits, such as dredge and fill operations. The CZMA encourages states to plan how development should occur in a coastal zone where land use has a direct impact on coastal waters. 16 U.S.C. §1453.

[7]483 U.S. 825 (1987).

[8]483 U.S. at 836.

Furthermore, Nollan is a case involving a physical invasion: an easement for public access. The Court traditionally has viewed the right to exclude as a particularly important property right protected by the fifth amendment (regulations involving physical invasions of property often are challenged pursuant to the fifth amendment).[9] A condition prohibiting bulkheads does not invade property or give the public increased access.[10] Given the Nollan opinion's overall critical tone, it is important to note that it did not renounce the validity of environmental protection (or even protection of visual amenities).[11] To ensure the constitutionality of its actions, a regulatory authority seeking to condition permits on bulkhead restrictions should make explicitly factual findings of the relationship between the condition and the goals of environmental protection and public welfare.

A condition requiring the transfer of a future property right (for instance, a future conservation or flowage easement) to the government is more vulnerable to a takings claim than a condition preventing a landowner from building a seawall. Although the result may be the same in terms of current fastland being inundated, the legal effect of transferring a formal property right to the government is likely to tip the scales in favor of just compensation. If the government builds a dam, it is required to compensate landowners for the right to flood their land above the natural high water.

A crucial aspect of the Nollan case is that the Commission had the authority to deny the permit entirely. Without this power, a permitting agency needs to be much more careful about imposing conditions.[12] In Nollan, conditioning development was not such a great imposition, because a bungalow already existed

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[9]Nollan observes that the right to exclude others is "one of the most essential sticks in the bundle of rights that are commonly characterized as property." 483 U.S. at 831 (quoting Kaiser Aetna v. United States, 444 U.S. 164, 176 (1979)). The Nollan Court also observed that where permanent physical occupation has occurred, giving individuals the permanent and continuous right to traverse the property, a taking occurs. 483 U.S. at 831-32 (citing Loretto v. Teleprompter Manhattan CATV Corp., 458 U.S. 419, 432-33 (1982). See discussion of Character of Government Action infra.

[10]At least not in the short run. In the long run, as tidelands migrate onto private property, public rights to use the tidelands also migrate onto the property. See discussion of State Public Trust infra.

[11]Sax, "Property Rights in the U.S. Supreme Court: A Status Report," 7 U.C.L.A. J.Env. L. & Policy 139, 146 (1988).

[12]In fact, without the power to deny the permit, the agency may have no authority to condition the permit. The Nollan opinion offered no guidance for determining whether an agency has the power to deny a permit in a particular case. It is likely that the factors discussed in the next section would determine the issue.

on the property, and some economic use could result even if the permit were denied. Although regulations that leave property owners with no ability to build any houses on their property have been upheld (see the following section), the equities are more difficult to balance.

Bulkhead Prohibition on Existing Development

Regulation prohibiting bulkhead construction, when not tied to a permit as a condition, is a more difficult problem. To the extent a government can ban seawalls outright, it can certainly condition permits to that effect. On the other hand, the power to condition permits for bulkheads (which are privileges, not rights) does not imply an equal power to impose conditions on all landowners. The Nollan Court, which indicated that a permit conditioned on an easement would be valid, given a substantial relationship to a state interest, stated:

> Had California simply required the Nollans to make an easement across their beachfront available to the public on a permanent basis in order to increase public access to the beach, rather than conditioning their permit to rebuild their house on their agreeing to do so, we have no doubt there would have been a taking.[13]

Nonetheless, regulation of land uses that seem more severe than a bulkhead prohibition have been upheld by the Supreme Court. These are discussed below. Generally, a government action is a taking if:

1. it fails to appropriately advance a legitimate state interest;

2. it removes all reasonable economic uses of the property; or

3. its character approaches a physical invasion. The following paragraphs address each of these possible fatal flaws of a regulation.

Legitimate State Interest

Although some state courts have found that preservation of land in a natural state is a valid state interest,[14] most courts look for an interest that is explicitly tied to human concerns. To the extent that coastal wetland migration is important for fish spawning, for instance, a regulation advancing this interest is more likely to be upheld if it is based on maintaining

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[13]483 U.S. at 831.

[14]The most famous case is Just v. Marinette Co., 201 N.W.2d 761 (Wis. 1972), which upheld an ordinance prohibiting a landowner from filling a wetland. "The ordinance...preserves nature from the despoilage and harm resulting from the unrestricted activities of humans" (201 N.W.2d at 771).

fisheries (for humans) rather than merely protecting fish.[15] Any legislative (or even administrative) finding that migration of coastal wetlands is in the interest of human health, safety, welfare, or business will help a regulation meet the requirement that it be supported by a legitimate state interest.[16] Protection of noneconomic resources, such as wildlife or aesthetics, arouses more judicial scrutiny.

The U.S. Supreme Court has upheld regulations designed to preserve open space, avoid premature development, and prevent pollution and congestion[17]; protect wetlands[18]; and reclaim mines.[19] The Court has also indicated support for the legitimacy of a state interest in slum clearance[20] and visual/psychological beach access.[21]

Economic Impact

In Pennsylvania Central Transportation Co. v. New York City,[22] the United States Supreme Court upheld a New York City Landmarks Preservation Commission ruling that multistory office space could not be built above the designated landmark of Grand Central Terminal. Although the terminal's owner was denied the ability to fully exploit the economic value of the property, the owner was still left with a viable economic use of the property. Furthermore, city law permitted the owner to sell air development rights to owners of nearby blocks. The Court held that for the purposes of takings analysis, a single parcel should not be divided into discrete segments to determine whether

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[15]Public expense for maintenance of fisheries may be avoided by maintaining wetlands (cf. 427 N.E.2d 750 (Mass. 1981) (regulations designed to avoid public expense for flood control measures made necessary by unwise choices in land development upheld)).

[16]As discussed above, such a finding is important, not only to define the legitimate interest but also to demonstrate the nexus between the regulation and the interest it seeks to advance.

[17]Agins v. City of Tiburon, 447 U.S. 255 (1979) (upholding a zoning ordinance limiting the number of buildings a plaintiff could construct on his property and deferring to legislative findings).

[18]United States v. Riverside Bayview Homes, 474 U.S. 121 (1985) (upholding wetland protection regulation under the federal Clean Water Act).

[19]Hodel v. Virginia Surface Mining and Reclamation Ass'n, 452 U.S. 264 (1981).

[20]Berman v. Parker, 348 U.S. 26 (1954) (upholding an exercise of eminent domain but stating that redeveloping a blighted urban area is a legitimate police power interest).

[21]See discussion of Nollan in previous section.

[22]438 U.S. 104 (1978).

> rights in a particular segment have been entirely abrogated. In deciding whether a particular governmental action has effected a taking, this Court focuses rather both on the character of the action [discussed in the next section] and on the nature and extent of the interference with rights in the parcel as a whole.[23]

Thus, even if an entire segment of the property bundle is destroyed, the continued viability of other rights in the property bundle will prevent a taking.[24] A large tract of land affected by a prohibition on bulkheading is likely to be only partly inundated by advancing seas. The smaller the portion of the land affected, the less likely the regulation is to be ruled a taking.

The Supreme Court has upheld regulations that result in a severe loss in value, with no compensation in the form of transferrable development rights.[25] However, to the extent that fastland owners can be offered transferrable rights if their land floods, regulatory authorities will increase the likelihood that a prohibition of bulkheads will be upheld. Also helpful is a regulation prohibiting certain uses that states explicitly what property owners may do. Severe restrictions on land use have been upheld where the only residual economic uses were agriculture, recreation, or camping.[26]

The abatement of a public nuisance, even if at great expense to a private landowner, more likely will be upheld than a regulation forcing a private landowner to provide a public good.[27] In this sense, the economic prong of the takings test is related to the state interest prong. A greater diminution in

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[23]438 U.S. at 130-31.

[24]Note: This may not be true if a court find a physical invasion, discussed in the following section.

[25]Cases quoted favorably by Penn. Central, 483 U.S. at 131 include Euclid v. Ambler Realty Co., 272 U.S. 365 (1926) (upholding a regulation causing 75% diminution in value of property); and Hadacheck v. Sebastian, 239 U.S. 394 (1915) (upholding a regulation causing 87.5% diminution in value). See also the more recent case of Keystone Bituminous Coal Ass'n v. DeBenedictis, 107 S. Ct. 1232 (1987).

[26]Claridge v. State Wetlands Board, 485 A.2d 287 (N.H. 1984) (camping use for land is reasonable economic use); Turnpike Realty v. Town of Dedham, 284 N.E.2d 891 (Mass. 1972), cert. denied 409 U.S. 1108 (1973) (agriculture or recreation are uses sufficient to surmount the taking hurdle); Turner v. DelNorte County, 24 Cal. App. 3d 311 (1971) (recreational use sufficient).

[27]Keystone Bituminous Coal Ass'n v. DeBenedictis, 107 S.Ct. 1232, 1246, n.22 (1987) (abatement of public nuisance to promote safety is not a taking, even if it destroys the value of property).

value is likely to be upheld if the regulation is framed as preventing harm. Even Just v. Marinette County framed its natural wetland preservation language in terms of preventing the public nuisance of destroying wetland values.[28]

Character of Government Action

Where the government regulation is of such character as to physically invade property, the court will find a taking, even if the economic loss is small. In Kaiser Aetna v. United States,[29] the Court ruled that the Army Corps of Engineers could not prevent a lagoon owner from excluding the public without compensation. In Loretto v. Teleprompter Manhattan CATV Corp.,[30] the Court found a taking where a New York statute required apartment owners to allow cable companies to install facilities on their premises for a fee established by a commission.

Once a court finds that a regulation effects a physical invasion, it becomes extremely likely that the regulation will cause a taking. It is critical that regulations to prevent bulkheads be drawn by making reference to bulkheads as a nuisance to business (such as the fishing and recreation industries) and other aspects of public welfare. A regulation that is found to exact a flowage easement for the sea over private property is more likely to be considered a taking than one that is found to restrict a seawall construction activity.

Conclusion on the Takings Issue

The best rule of thumb for deciding whether outright bulkheads will be a taking is to return to Justice Holmes' pronouncement that a regulation that goes "too far" is a taking. Whether a regulation goes "too far" depends on the circumstances of the particular case. A bulkhead prohibition will most likely be upheld if it:

- advances public health, safety, or welfare (including business) interests;
- is based on a legislative finding that ties the regulation to the health, safety, and welfare interests;

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[28]201 N.W.2d 761 (Wis. 1972) See also Miller v. Schoene, 276 U.S. 272 (1928) (upholding ordinance requiring landowners to cut down their cedar trees to protect apple trees from being affected by disease); Hadacheck v. Sebastian, 239 U.S. 394 (1915) (upholding a local decision to ban a brickyard because of the nuisance it creates to surrounding residences that were erected while the brickyard was operating).

[29]444 U.S. 164 (1979).

[30]458 U.S. 417 (1982).

- treats interference with a migrating wetland as a nuisance;
- leaves landowners with some viable economic use of their land; or
- provides some sort of transferrable right to ease the economic burden on affected landowners.

A policy to prohibit use of bulkheads for property just now being developed (as opposed to applying it to all property) can be implemented by using a pre-existing regulatory system to condition permits. An anti-bulkheading condition will be upheld if it appropriately advances a state interest and if the underlying permit has not already been vested as a right in the landowner's property.

THE PUBLIC TRUST DOCTRINE

We have seen that regulation designed to restrict land use to allow coastal wetland migration must not run afoul of the fifth amendment. However, because wetlands are valuable natural resources in which the public has a substantial interest,[31] a government may be able to act within its trust responsibilities to address sea level rise. Furthermore, the law recognizes the coastline as a uniquely important location and grants the government special rights and responsibilities to act on the coast in the public interest.

The public interest is a legal doctrine with ancient roots that concerns inalienable common rights to use certain natural resources. There is no single public trust theory; different trusts operate for different resources and different sovereigns (state and federal). State and federal public trust doctrines are relevant to considering responses to sea level rise because the coast is an area where private lands traditionally have been subject to public rights. Furthermore, protection of these public rights may be an affirmative duty for governments.

Federal Public Trust: The Navigational Servitude

Pursuant to the commerce clause of the U.S. Constitution, the federal government impresses a servitude on all navigable waters. To ensure free commerce, navigation, and fishing, the federal government can improve both inland and coastal waters by building dams, jetties, diversions, etc. Private property owners who are injured by loss of the benefits of access to water due to these federal improvements have no legal recourse.

The commerce clause, besides defining the scope of the federal navigational servitude, also defines congressional regulatory authority over navigable

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[31]Important wetland functions include flood control; habitat for fishing, hunting, and recreation; and sediment, erosion, and pollution control. See J.A. Kusler. Our National Wetland Heritage: A Protection Guidebook. 1-7 (1983).

waters. This regulatory authority is broader than the navigational servitude,[32] and its exercise by Congress may sometimes require compensation under the fifth amendment. For instance, in Kaiser Aetna v. United States,[33] the Court ruled that a non-navigable private fish pond, when dredged and connected to the ocean to create a marina, is subject to the U.S. Army Corps of Engineers' regulatory

authority, but not to the federal navigational servitude, which would have required free public access to the marina without compensation to the owner.

The commerce clause authorizes Congress to exercise eminent domain to provide public access, so long as the owner is compensated. However, a federal action that alters access to waters subject to the navigational servitude, even if the alteration completely deprives a littoral owner of all access to the waters, does not require compensation. This is because the owner's title has never been so complete as to include continued enjoyment of the benefits of access to navigational waters. Even when the government condemns fastlands for a water-related project, compensation to the owner does not include the value of those lands attributable to their location near the water, such as for a port.[34]

The federal government could use the navigational servitude to prohibit a littoral landowner from erecting a bulkhead below the high-tide line, and no compensation would be required. The federal government could use its broader commerce clause regulatory authority to ban fastland bulkheads; however, it would be required to compensate the landowner if the regulation resulted in a taking. As seas rise, there is no question about the federal government's ability to ensure that coastal wetlands be allowed to migrate. The difficult question is whether the federal government also could exercise its authority to prohibit bulkheads without compensating inundated landowners.[35] Would the Supreme court hold that the navigational servitude migrates inland as the seas rise?

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[32]In fact, Congress' authority to regulate interstate commerce is much broader than the federal navigational servitude. Not only can Congress regulate waters that are non-navigable, it can regulate virtually any class of economic activities that cumulatively affect interstate commerce. Wickard v. Filburn, 317 U.S. 111 (1942) (upholding regulation of farmer's production of wheat for his family's consumption); United States v. Darby, 312 U.S. 100 (1941) (upholding exclusion of certain goods manufactured by factories violating labor standards from interstate commerce).

[33]444 U.S. 164 (1979).

[34]United States v. Rands, 389 U.S. 121 (1967).

[35]Landowners who delay in building a bulkhead and find their property partly under water during high tide may lose some rights to exclude the sea from that area. The following discussion concerns the situation where a landowner builds a bulkhead before the property is inundated.

Courts could decide the issue either way. Kaiser Aetna and its companion case, Vaughn v. Vermilion,[36] indicate that the Court will focus on past use of areas that become subject to the ebb and flow of the tides as a result of private construction. In both cases, a landowner altered property that was not navigable to make it navigable for private use. In both cases, the Court held that such improvements did not result in the extension of the federal navigational servitude to cover the new navigable waters. Therefore, a landowner who, in order to protect existing fastland, erects a bulkhead to keep a rising sea at bay will probably retain all of his private rights, even if the sea level rises to a point where it would otherwise inundate the fastland. Current Court doctrine seems to support the principle that land not previously subject to the navigational servitude will not be impressed with a new servitude due to artificial construction. Since construction of a bulkhead will prevent the land from becoming subject to the ebb and flow of the tides, the land will remain free from the servitude. It is hard to see how a Court that does not recognize the migration of the federal navigational servitude to an area that becomes navigable-in-fact would extend the public trust to an area that is kept dry by a seawall.

Nonetheless, the Court has not addressed the issue of whether landowners can avoid a servitude by keeping the sea off their property under a condition where inaction would result in an expansion of the servitude. In Kaiser Aetna and Vaughn, the inaction would not have resulted in an expansion of navigable waters. The Court did not wish to penalize enterprising landowners who expand navigable waters through construction. Where inaction will result in rising sea levels moving navigational waters upland, the Court may find that the servitude moves, regardless of construction activities. In a sense, this interpretation of the reach of the navigational servitude is tied to the "natural" reach of navigable waters in the absence of construction. This interpretation is consistent with a policy of promoting an increase in navigable waters, evinced in Kaiser Aetna and Vaughn.[37]

The Vaughn opinion left open the question of whether diversion or destruction of a pre-existing natural waterway concomitant to the construction activity that, on its own, does not alter the reach of the navigational servitude, would result in extending the servitude to the new navigable area created at the "expense" of part of the public servitude.[38] If harm to pre-existing navigable waters extends the servitude, then bulkheading that results in the degradation of navigable waters (perhaps including wetlands) may be subject to the public trust.

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[36]444 U.S. 206 (1979).

[37]If the Court had found that the navigational servitude had moved in these cases, property owners would be discouraged from expanding navigable waters because they could not capture the benefits.

[38]444 U.S. at 208-10.

Because the Court has not dealt with a case involving areas where navigable seas inundated former fastland,[39] the extension of the navigational servitude is speculative. Does the human-induced nature of global warming change the analysis? Does an artificial seawall constructed to block an "artificial" rise in the sea level result in no net loss of property rights to the landowner? Or, does the potential loss of public rights trump private rights? These are questions the Court is certain to face in the future.

State Public Trust

As inheritors of the sovereign rights of the Crown, the thirteen original states acquired ownership of all lands subject to the ebb and flow of the tide. The "equal footing" doctrine has granted all subsequent states the same rights as the original thirteen.[40] Therefore, upon statehood, each state received title to lands under the high-tide mark.[41] The public trust prevents the federal government from conveying title to tidelands either before statehood or after.

States may own submerged tidelands, regardless of their navigability.[42] Where the federal public trust is primarily concerned with free navigation

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[39]Hughes v. Washington, 389 U.S. 290 (1967), distinguished between the effects of changes in a river course and changes in the sea shoreline. Sea shorelines are sufficiently important to justify a federal rule governing ownership resulting from accretion and erosion where title rests with or is derived form the federal government. California ex rel. State Lands Commission v. United States, 457 U.S. 273, 282-83 (1982) (interpreting Hughes and Wilson v. Omaha Indian Tribe, 442 U.S. 653 (1979)). Ownership of land involved in changes in river courses, so long as they do not affect state boundaries, is a matter of state law.

[40]Pollard's Lesee v. Hagan, 3 How. 212 (1845).

[41]Shively v. Bowlby, 152 U.S. 1 (1894). (States also received title to beds underlying navigable waters not subject to the tide by extension of the English law doctrine. The Propeller Genesee Chief v. Fitzhugh, 12 How. 443 (1852)).

[42]Phillips Petroleum Co. v. Mississippi, 108 S.Ct. 791 (1988). Not all states own submerged tidelands (it is a matter of state law). However, all submerged tidelands, whether publicly or privately owned, are subject to certain public easements. See, e.g., Bell v. Town of Wells, 57 U.S.L.W. 2590 (Maine Sup. Jud. Ct. No. 5029 3/30/89) (intertidal landowners hold title in fee subject to public easements); People v. California Fish Co., 138 P. 79, 88 (Cal. 1913) (private ownership subject to a paramount right to use by the public).

Generally, though, state public trust lands extend from the mean high-tide line (otherwise known as the mean high-water mark) seaward to the three-mile territorial limit. This public trust land includes tidelands (otherwise known as foreshore) from mean high tide to mean low tide and submerged lands seaward of the low tide. Existing wetlands generally fall in tidelands. Comment, "Public Access to Private Beaches: A Tidal Necessity," 6 U.C.L.A.J.Env. L. & Policy 69.

issues, state public trust is more expansive and is concerned with a wide variety of interests, including fishing rights, environmental quality, and recreation.[43] Therefore, state doctrines of public trust are more helpful than the federal doctrine in protecting the public interest in wetlands preservation. States hold submerged tidelands for public purposes.

Rather than being a single doctrine, state public trust is fifty separate bodies of law, each created by a state. Whether a rise in sea level will add to state public trust land at the expense of private landowners is entirely a question of state law.[44] In this paper we will discuss the State of Mississippi because of (1) its involvement in an important, recent Supreme Court case; (2) its shore location on the Gulf of Mexico with extensive wetlands; and (3) its representative common law system (as contrasted with the State of Louisiana's system, which is influenced by civil law).

Mississippi's Public Trust

Mississippi's public trust in submerged lands, vindicated by Phillips Petroleum,[45] includes an interest in public bathing, swimming, recreation, fishing, environmental protection, and mineral development.[46] Despite the fact that Phillips Petroleum Co. had been paying property taxes on submerged lands for which it had recorded title, the Court held that the submerged lands (and their valuable mineral rights) belonged to the State of Mississippi, which had never granted the company the rights it was claiming.

The Mississippi Supreme Court, in Cinque Bambini Partnership v. State,[47] held that state public trust lands may be augmented by

> natural inland expansion of the tidal influence...If over decades...the tides rise -- that is, the mean high water mark rises (and there is reason to believe this has happened and may continue to happen) -- the inward reach of the tidal influence expands...[T]he new tidelands so affected accrete to the trust.

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[43]See, e.g., Marks v. Whitney, 491 P.2d 374, 380 (1971).

[44]Oregon ex re. State Land Board v. Corvallis Sand and Gravel Co., 429 U.S. 363 (1977).

[45]108 S.Ct. 791 (1988).

[46]E.g., Treuting v. Bridge and Park Comm'n of City of Biloxi, 199 So. 2d 627, 632-33 (Miss. 1967); Miss. code Ann. §§ 49-27-3 and -5(a) (Supp 1985) (cited in Cinque Bambini Partnership v. State, 491 So. 2d 508, 512 (Miss. 1986), aff'd Phillips Petroleum, 108 S. Ct. 791 (1988)).

[47]491 So. 2d 508, 519-20 (Miss. 1986), aff'd Phillips Petroleum Co., 108 S.Ct. 791 (1988).

On the other hand, artificially created water courses, inlets, marinas, and other non-natural alterations to private land do not cause ownership to pass to the state public trust, even though they become subject to the ebb and flow of the tides. This finding was not appealed to the U.S. Supreme Court with the other issues in Phillips Petroleum.

Therefore, in Mississippi, as seas rise, ownership of new submerged land passes to the state. However, there is no existing state legal doctrine that imposes a public interest in lands that lie below sea level but that are not subject to the ebb and flow of the tides due to bulkhead protection. Also, to the extent that one could argue that sea level rise caused by the greenhouse effect is not a natural event, then the state may not be entitled even to the submerged land. However, the natural/artificial distinction seems to be as much based on rate of change as anything else. Since sea level rise will occur slowly (over the course of decades), it may be regarded as a natural change because of the gradual way the alteration to the shoreline occurs.

The Expanding Public Trust

Since the 1970s, many courts and commentators have argued that the public trust doctrines should reach beyond the federal navigational servitude and state ownership of submerged lands to protect public rights to certain natural resources incapable of or inappropriate for private ownership.[48] As the modern public trust doctrines evolve along with the problems posed by increased coastal wetland loss from rising seas, the reach of public rights may extend to privately owned fastlands. Some courts view the public trust as a dynamic doctrine to "be molded and extended to meet changing conditions and...[that] was

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[48]The seminal article that reinvigorated the public trust doctrine is Sax, "The Public Trust Doctrine in Natural Resource Law: Effective Judicial Intervention," 58 Mich.L.Rev. 473 (1970). See also Sax, "Liberating the Public Trust from Its Historical Shackles," 14 U.C.D.L.Rev. 185 (1980); Stevens, "The Public Trust: A Sovereign's Ancient Prerogative Becomes the People's Environmental Right," 14 U.C.D.L.Rev. 195 (1980). Criticizing the expansion of the public trust doctrine at the expense of private property rights are Huffman "Avoiding the Takings Clause Through the Myth of Public Rights: The Public Trust and Reserved Rights Doctrines as Work," 3 Fla.St.U.L.Rev. 171 (1987); rose, "The Comedy of the Commons: Custom, Commerce, and Inherently Public Property," 53 U.Chi.L.Rev. 711 (1986).

The most widely cited court decision implementing the broader notions of the public trust is National Audubon Society v. Superior Court of Alpine Co., 658 P.2d 709 (Cal.), cert. denied 104 S. Ct. 413 (1983) (incorporating public trust considerations into the existing state system of water rights by balancing reasonable, beneficial uses of water with competing public interests, such as environmental protection). See National Audubon Society v. Department of Water, 858 F.2d 1409 (9th Cir. 1988) for the latest case in the ongoing Mono Lake controversy.

created to benefit [the needs of the public]."[49] To the extent that the public has a right to enjoy the benefits of coastal wetlands, a trust may exist to ensure that those wetlands do not disappear under the rising seas.

The past two decades have seen the greatest expansion of the public trust right in the area of recreation. Where the traditional public trust extended only up to the high-water line and was concerned with navigation, commerce, and fishing, recent cases have expanded the trust to include dry-sand areas of public beaches for recreation.[50] The extension of the public trust in the State of New Jersey above the high-water mark to the area of dry sand that lies landward of the high-water mark to the vegetation line (or artificial barrier) presents an interesting analogy to the problem of migrant wetland protection.

In Matthews v. Bay Head Improvement Ass'n,[51] the New Jersey Supreme Court confirmed that the public's right to use tidelands includes a variety of recreational activities.[52] It found that the use of the dry-sand beach immediately above the high-water mark was necessary to the exercise of the public right. This ancillary right includes not only the right to use the dry-sand beach for access to the tideland, but also "the right to sunbathe and generally enjoy recreational activities."[53] The court declared that this right of use of the dry-sand beach exists on private as well as public lands.[54] The public use must be reasonable, and we may expect that some uses that are reasonable on public lands are not reasonable on private lands. Nonetheless,

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[49]Borough of Neptune City v. Borough of Avon-by-the-Sea, 294 A.2d 47, 54 (N.J. 1972) (quoted in Matthews v. Bay Head Improvement Ass'n, 471 A.2d 355, 365 (N.J.), cert. denied 105 S.Ct. 93 (1984)). See also, Marks v. Whitney, 491 P.2d 374, 380 (Cal. 1971) ("The public uses to which tidelands are subject are sufficiently flexible to encompass changing public needs.").

[50]See e.g., Matthews v. Bay Head Improvement Ass'n, 471 A.2d 355, 365 (N.J.), cert. denied 105 S.Ct. 93 (1984). Not all states share an expansive view of the public trust. A recent case in the State of Maine held that a legislative determination that intertidal lands (held in fee by private landowners with a traditional public easement for fishing, fowling, and navigation) are impressed by a public trust that includes a right to recreate is a physical invasion of private property that requires compensation of landowners. Bell v. Town of Wells, 57 U.S.L.W. 2590 (Maine Sup. Jud. Ct. No. 5029 3/30/89).

[51]471 A.2d 355 (N.J.), cert. denied 105 S.Ct. 93 (1984).

[52]See Borough of Neptune City v. Borough of Avon-by-the-Sea, 294 A.2d 47 (N.J. 1972).

[53]471 A.2d at 364.

[54]In fact, the defendant in the case was a non-profit corporation that acted as a quasi-public association. The court's language regarding purely private dry-sand beaches is dictum.

the court's willingness to impose public rights on private lands to allow public enjoyment of existing public trust lands indicates a flexibility that holds promise for providing a basis for imposing public trust restrictions on fastlands located upland of existing coastal wetlands.

Wisconsin, in its celebrated but not widely followed opinion of Just v. Marinette Co.,[55] declared ecological stability to be a public trust imposed on private lands. In Just, a landowner was prevented from building on his land because of its ecological importance as a natural wetland. Because destruction of a wetland injures others by upsetting the natural environment, it can be considered a nuisance. Abating a nuisance is not a taking. California has a similar ecological interest in its public trust doctrine for tidelands.[56] It is important to note that there is a difference between prohibiting development of a tract of land because of its existing value as a wetland and prohibiting the erection of a seawall because of a tract of land's potential to evolve into a wetland. Owners are on notice of the natural character of their land, but not necessarily of its importance as a future wetland if the sea level rises. As Professor Sax points out, the sea level rise situation is analogous to prohibiting a woodland owner from fighting a forest fire on his property because of the benefits to wildlife.[57]

Enforcing the Public Trust

Although our consideration of the public trust has been with an eye toward finding authority for willing state and federal governments to claim a public interest in protecting migrating coastal wetlands, the public trust is sometimes applied to compel a government to take or refrain from an action. The classic case of this application of the trust is Illinois Central Railroad v. Illinois,[58] where the Court declared invalid a state legislative grant of title to the railroad for a major section of the Chicago waterfront. The state was powerless to alienate a natural resource as important as Chicago's harbor. Although there are exceptions to the rule against alienation of the public trust in the event

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[55]201 N.W.2d 761 (Wis. 1972).

[56]Marks v. Whitney, 491 P.2d 374, 380 (Cal. 1971) ("[O]ne of the most important public uses of the tidelands...is the preservation of those lands in their natural state, so that they may serve as ecological units...").

[57]J. Sax, unpublished typescript, (undated) (on file with authors). Cf. Miller v. Schoene, 276 U.S. 272 (1928) where a landowner was forced to destroy trees to protect a local apple industry from harm. Forcing landowners to refrain from building bulkheads to benefit the industries (such as commercial fishing) that depend on coastal wetland ecosystems is analogous to the Miller situation, which resulted in no taking.

[58]146 U.S. 387 (1892).

the transfer is for a public purpose,[59] state inaction that leads to seawalls that stop the natural migration of the public trust may be viewed as an improper abdication of the public trust.

If the government does have the power to prohibit bulkheads, then it may be required to exercise that power to fulfill its public trust responsibilities. In a series of cases relating to the U.S. Department of the Interior's management of Redwood National Park,[60] a federal district court found that the department failed to meet its fiduciary responsibilities to protect the park and required it to fulfill its trust by lobbying Congress for an expansion of park boundaries. The court ordered the department to report back to the court on proposals made for more park protection, more management authority, more money to purchase land, and more negotiation of cooperative agreements with neighboring timber companies (whose practices were causing erosion and sedimentation).

Although the situation with coastal wetland migration differs from these two examples in that publicly owned land is not involved, it is similar in that public rights are at stake. The fiduciary duties may arise from different sources, but if the trust exists, these cases indicate that it is enforceable against the government.

Conclusion on the Public Trust Doctrine

Under the traditional view of the public trust, states that assert public ownership of intertidal lands may gain control of new wetlands only if landowners let their property fall under the influence of the tide. This is a matter of state law. However, property owners who build seawalls before their land is inundated will most likely be protected by the fifth amendment. The Kaiser Aetna case warns that, at least in the case of the federal navigational servitude, public trust authority does not exempt the government from its obligation to compensate a landowner for a taking. The public trust does not offer an easy solution to the difficult problem of responding to landowners who wish to keep back the sea with bulkheads.

Professor Sax describes the primary justification of the modern public trust doctrine that protects a wide variety of public resources as "preventing the destabilizing disappointment of expectations held in common but without

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[59]See e.g, City of Milwaukee v. State, 193 Wis. 423 (1927) (upholding Milwaukee's grant to a steel company to develop a public harbor).

[60]Sierra Club v. Department of Interior, 424 F. Supp. 172 (N.D. Cal. 1976), 398 F. Supp. 284 (N.D. Cal. 1975), 376 F. Supp. 90 (1974). See Wilkinson, The Public Trust Doctrine in Public Land Law, 14 U.C.D.L.Rev. 260 (1980) for a probing analysis of these cases.

formal recognition such as title."[61] Few courts have recognized explicitly such a broad public right over private property. Even those jurisdictions that have recognized broad public rights, such as New Jersey and Wisconsin, give little indication that they would extend the right to landowners who wish to protect the existing character of their property.

However, if the public trust lives up to its potential as described by Sax, it may be an effective tool in the future for asserting a public right to the continuing enjoyment of the benefits of coastal land. The changing circumstances to which a flexible doctrine must adapt[62] may demand an explicit recognition of the public values served by our threatened natural systems. The most effective strategy today for encouraging this evolution in the doctrine is to put private landowners on notice of the importance that the public places on coastal wetlands and of the role that fastlands will play in the future viability of marsh ecosystems.

LEGAL MECHANISMS AVAILABLE IN OTHER COUNTRIES

While application of the legal regime in the United States to the migration of coastal wetlands is the primary focus of this paper, the preservation of wetland ecosystems in the face of rising sea levels is an issue confronting many nations. Legal systems, however, vary in their treatment of property rights and coastal protection, and conservation mechanisms available in one nation may lack a legislative or constitutional basis in another. Accordingly, current laws that may enable the conservation of coastal lands adjacent to existing wetlands in several Atlantic Basin countries are briefly discussed below as examples of the adaptability of different legal regimes to meet this problem.

Argentina

Provincial Authority

In Argentina, all of the area seaward of the mean high tide line, including coastal wetlands, is within the public domain. This littoral region is generally under the jurisdiction of the provincial government, although the federal government has jurisdiction over activities affecting navigational uses. There are four provinces on the Atlantic Coast and two federal territories--the city of Buenos Aires and Tierra del Fuego. The provinces and the federal territories both have authority to regulate land use and to protect natural resources. Private property rights adhere only inland of the mean high-tides line, and development is prohibited within the public domain, unless expressly

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[61]"Liberating the Public Trust Doctrine From it Historical Shackles," 14 U.C.D.L.Rev. 185, 188 (1980).

[62]See Borough of Neptune City v. Borough of Avon-by-the-Sea, 294 A.2d 47, 54 (N.J. 1972) (quoted in Matthews v. Bay Head Improvement Ass'n, 471 A.2d 355, 365 (N.J.), cert. denied 105 S.Ct. 93 (1984)).

permitted by the government.[63] It appears that in the area below the mean high-tide line, provinces can easily prevent the building of seawalls and jetties, which would inhibit the migration of coastal wetlands.

Conservation of land inland of the mean high-tide line, however, may require compensation. Expropriation of private property requires full indemnification under the Argentine Constitution. The creation of upland parks or reserves to enable the migration of coastal wetlands would, therefore, clearly require compensation. However, land use restrictions imposed upon private property in the public interest do not require compensation, unless such restrictions imply the creation of an easement or servitude.[64] The Province of Buenos Aires has established a zone 150 meters inland of the mean high-tide line in which subdivision and construction are prohibited[65]; this regulation does not require compensation.

To the extent that prohibitions on building seawalls and jetties result in the inundation of private lands due to rising sea level, Argentine case law indicates that this would not be considered expropriation, but rather noncompensable damage attributable to natural forces.

Federal Navigation Law

As mentioned above, the federal government has authority over the navigational uses of waterways. Under federal navigation law, owners of property along navigable rivers or channels apart from the seashore are prohibited from developing a 35-meter-wide "towpath" area adjacent to the river bed.[66] Riverside landowners do not receive any compensation for this restriction, since the limitation is considered to have adhered to the property in remote time.[67] If the river changes course due to natural causes, such as a rise in sea level, this protected zone would migrate inland. This riparian provision may be used to allow migration of estuarine wetlands.

Flood Control Law

The Executive Branch of the Argentine government may, through its authority to issue executive decrees, define floodplains and floodprone areas, establish land use restrictions for these areas, and require the demolition of obstacles

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[63]See Codigo Civil (Civil code), art. 2340.

[64]See G. Cano, Legal and Institutional Implications of Adaptive Options of Sea Level Rise in Argentina, Uruguay and Spain (1989).

[65]Decree 9196/50.

[66]Codigo Civil, arts. 2639, 2640.

[67]See National Constitution, arts. 14, 17.

to the free runoff of water.[68] In addition, loans and subsidies may be established for the resettlement of inhabitants displaced as a result of floods. The use of this executive authority, which is in some cases subject to legislative approval, could assist in enabling the migration of coastal wetlands.

Brazil

Brazil's new Constitution declares the coastal zone to be a resource of "national heritage," the use of which must be under conditions that ensure its preservation.[69] How the government intends to implement fully this constitutional provision is not yet clear, but there are several existing statutory provisions that could be used to preserve coastal wetlands as sea level rises.

First, the Codigo Florestal (Forestry Code) has been interpreted to prohibit any use of mangrove swamps throughout the country.[70] Second, all flora and fauna are considered property of the federal government, which can restrict the use of private property in order to preserve areas important for species' conservation.[71] Therefore, the government has the power, for example, to prohibit the building of seawalls to conserve areas for future breeding sites for waterfowl. Such land use restrictions do not require any indemnification, although expropriation for conservation purposes would require the payment of compensation to affected landowners. Third, all beaches are considered to be in the public domain, and no use of the land adjacent to the beach may hinder the public's access.[72]

Canada

Land Use Controls

In Canada, protection of natural resources, including coastal wetlands, is primarily the responsibility of provincial governments. The authority to institute land use controls also resides with the provinces, including the power to enact legislation prohibiting the construction of seawalls or otherwise limiting development to permit the inward migration of coastal wetlands. The provinces may delegate planning and zoning authority to municipalities.

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[68]Codigo Civil, art. 2611.

[69]Constitution of 1988, tit. VII, ch. VI, item VIII, para 4.

[70]See Codigo Florestal, law 4771 of Sept. 15, 1965, art. 2, items a.3 and f.

[71]See Federal Law 5197 of January 3, 1967; Codigo Florestal, art. 1.

[72]Constitution of 1988, tit. III, ch. II, art. 20, item IV.

Legal and Institutional Implications

The Canadian Constitution does not require the Dominion or the provinces to pay compensation when private lands are expropriated for public purposes.[73] Although expropriation without compensation is legal, a common law presumption in favor of compensation does exist in the absence of any express legislative provision for confiscation without compensation.[74] In addition, the provincial legislatures have instituted Expropriation Acts, which authorize compensation for the confiscation of private property.

Despite the existence of the presumption in favor of compensation and the Expropriation Acts, a province can legally enact legislation that both provides for the confiscation of coastal lands adjacent to threatened wetlands and specifies that no compensation will be paid. Of course, the question remains as to whether such legislation would be politically feasible, especially given the tradition of compensation upon expropriation.

Land use restrictions that may affect a landowner's economic interests, but that do not amount to an expropriation, do not carry a presumption in favor of compensation.[75] Provinces or municipalities may prohibit development that would prevent inward migration of coastal wetlands, such as the building of seawalls or jetties. Such legislation does not need to specify compensation for any economic loss suffered as a result of those restrictions.[76] In contrast to the expectation of compensation upon expropriation, there is no tradition of "takings" law in Canada, and the public is more accepting of stringent land use controls without compensation than it is in the United States.[77]

An example of existing restrictions that could be used to conserve coastal uplands in anticipation of wetlands migration is found in Quebec Province. The Quebec Expropriation Act provides that privately owned land may be reserved for public purposes and cannot be developed for a specified number of years. The statute, however, does provide the affected landowner with compensation.[78] Such a provision could be applied to the conservation of uplands adjacent to current coastal wetlands.

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[73]E.C.E. Todd, The Law of Expropriation and Compensation in Canada 32 (1976); G.S. Challies, The Law of Expropriation 75 (1963).

[74]Challies at 33.

[75]See Todd at 24-25.

[76]Id. at 25.

[77]Conversation with Dr. Jim McCuaig, Canadian Wildlife Service, November 16, 1989.

[78]Todd at 12.

England

Land Use Controls

In England, the national town and country planning legislation vests in the state and its agencies, the local planning authorities, all rights to develop land.[79] Before developing any land, a landowner must obtain planning permission from a government agency, which can be local or central.[80] No compensation is due to a landowner who is unable to obtain planning permission.[81] It follows that local and national government agencies may prohibit development of lands adjacent to existing coastal wetlands without providing any compensation.

Expropriation of private lands, however, does require the payment of compensation to the landowner.[82] In addition, if planning permission has been withheld and, as a result, a landowner's property is rendered incapable of reasonably beneficial use, the landowner may serve a purchase notice on the district planning authority.[83] Similarly, if planning proposals cause a dwelling to become unsalable, the owner may serve a blight notice.[84] In either case, the planning authority is then required to purchase the property for the existing use value.[85] It follows that landowners would attempt to obtain compensation if a planning authority's refusal to permit the construction of seawalls or jetties caused or threatened to cause the inundation of their property. Since the actual inundation is an act of natural forces, however, it is unlikely that the landowners would prevail.

Coastal Protection

The idea of conservation of coastal lands is well established in England. A national agency, the Nature Conservancy Council, assists in the management of undeveloped coastal areas. The Council may establish, maintain, and manage "natural reserves," which are areas that provide special opportunities for the

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[79]Garner, 1986, "Town and Country Planning Law in England and Wales," J.F. Garner and N.P. Gravells (eds.), Planning L. in West. Eur. 125.

[80]Id. at 125.

[81]Id.

[82]Id. at 124-125.

[83]Id. at 127.

[84]Id.

[85]Id.

study, research, and preservation of flora and fauna.[86] The Council may also designate areas to be of "special scientific interest" by reason of their flora, fauna, or geological or physiological features.[87] While an area of such interest may be under private ownership, the landowner is prohibited from carrying out activities that are likely to damage the features of interest without receiving the Council's consent.[88] Both nature reserves and special scientific interest areas may be used to conserve land inland of threatened coastal wetlands.

Most of the authority to manage coastal lands, however, rests with the local County and District councils. In 1972, the Department of the Environment asked the County councils to designate stretches of nationally outstanding "heritage coast" and to provide in their land use plans for the long-term conservation and management of these coastal lands.[89] Approximately 40 percent of the undeveloped coast is designated as "heritage coast."[90] County plans vary, but, for example, the County of Kent's plan provides that unspoiled coastal areas and their adjoining countryside are protected from development that would detract from their scenic or scientific value.[91] This county plan clearly would assist in enabling coastal wetlands to migrate to the "adjoining countryside."

In addition, voluntary organizations are also active in the protection of English coastal lands. The Royal Society for the Protection of Birds manages in excess of 70 reserves, while the National Trust manages almost 1000 square kilometers of coastal lands.[92] The National Trust was created through an Act of Parliament, but is supported through private subscriptions, donations, and bequests. Tax concessions are given to private landowners in exchange for property bequests.[93]

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[86]Burton and Freestone, 1988. Legal Regulation of the Humber, The Humber Estuary: Environmental Background 87.

[87]Id. at 67.

[88]Id.

[89]Waite, 1981. "Coastal Management in England and Wales." In Comparative Marine Policy 66.

[90]Id. at 67.

[91]Id.

[92]Id. at 67.

[93]Id. at 73-74.

France

Planning Code

While government expropriation of land entitles the landowner to compensation in France, land use restrictions may be instituted without indemnification.[94] Amendments to France's Planning Code in 1986 created a new chapter, which requires local authorities in littoral zones to take into account the conservation of coastal ecosystems of special interest, including wetlands, estuaries, marshes, and breeding sites.[95] In addition, any activities permitted on or near the coastline must allow for public access to the shore.[96] In undeveloped areas, no building is permitted within 100 meters inland of the highest point on the shoreline, and local authorities may extend this zone.[97] New highways must be placed at least two kilometers from the shoreline, and local roads cannot hug the coast unless required by geographical necessity.[98] Any act adversely affecting the natural seashore, such as the construction of seawalls or jetties, is prohibited, unless it is certified as in the public interest and required by the site's topography.[99] By protecting the coastal lands adjacent to the shoreline, the Planning Code's restrictions on development allow the migration of wetlands.

Natural Fragile Areas

The French political subdivisions, known as Departments, also have the ability to designate natural fragile areas where camping and building are prohibited. These areas may also be acquired through pre-emption (meaning the state has preference over all other buyers), after which they must be kept open to the public. Natural fragile areas are purchases through a tax on building permits.[100] Of 25 coastal departments, 22 have designated natural fragile areas, and this mechanism could be used to conserve sensitive lands just inland of coastal wetlands.

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[94]See Besson-Guillaumot, "Town and Country Planning France," J.F. Garner and N.P. Gravells (eds.) in Planning L. West. Eur. 153.

[95]Foster, 1986. "Current Legal Developments: France," Int.J. Estuarine & Coastal L. p. 309.

[96]Id. at 310.

[97]Id.

[98]Id.

[99]Id.

[100]Prieur, 1988. "France: A Step Towards Comprehensive Programmes for Coastal Areas in France," Int.J. Estuarine & Coastal L. 3:161.

Legal and Institutional Implications

Seashore Conservatory

In 1975, France created a national agency called the Seashore Conservatory, which has the power to acquire coastal lands for ecological protection. The Conservatory's main objectives are to purchase natural coastal areas threatened by development; to set priorities for sites according to their ecology, geography, or landscape; and to preserve coastal agricultural lands.[101] The Conservatory may acquire land by negotiated purchase, pre-emption, eminent domain, or donation.[102] Conservatory land must be kept open to the public. The Conservatory's authority, especially its ability to preserve coastal agricultural lands, is easily adaptable to the problem of wetland migration.

Nigeria

The law concerning Nigeria's Atlantic coast is contained in a few statutes and a handful of common law cases that deal with the rights of ownership and the usage of coastal zones. Some provisions and precedents may be applied to the issue of coastal wetlands migration.

The Public Lands Acquisition Act lists the public purposes for which private land may be expropriated, including general public use, and provides for compensation. Under the Land Titles Registration Law, the foreshore is in the public domain, unless excepted in the land titles register.[103] Likewise, the state also has title to beach land.[104] The government, therefore, has the authority to prohibit construction of seawalls or jetties along the coast. In addition, one commentator states that as the sea "advances further into the land of the riparian owner, that part of his land that is swallowed by the sea together with the new high-water level belongs to the State."[105]

However, the government also recognizes the customary rights of usage of the foreshore and beach by the local indigenous people as a community. While the state retains title to these areas, local customary ownership interests prevail over individual control. Case law establishes that individuals or private companies will be denied exclusive property and usage rights to coastal land on the grounds that such land is communal in nature.[106] It is unclear, however, whether government restrictions on the building of seawalls or jetties

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[101] Id.

[102] Id.

[103] T.O. Elias, Nigerian Land L. appendix (1971).

[104] Henshaw v. Henshaw and Org. and Compagnie Francaise, 8 N.L.R. (1927); Chief Young Dede v. African Association Ltd. 1 N.L.R. 130 (1910).

[105] B.O. Nwabueze, Nigerian Land L. (1972).

[106] Attorney General of Southern Nigeria v. John Holt, 2 N.L.R. 1 (1910).

would constitute an interference with these communal uses, or whether such restrictions would require compensation as existing coastal wetlands migrate.

Swamps and marshes in Nigeria are generally considered unoccupied land that may be claimed by the government for public purposes. However, in Amodu Tijani v. Secretary of Southern Nigeria, 4 N.L.R. 18 (1923), the government wished to assert ownership of palm and mangrove swamps and grasslands; the local community asserted a claim to the land. The court held that the government had to compensate the local inhabitants, who made significant use of the land for cultivation, livestock grazing, and industrial purposes. Substantial ongoing beneficial use of the land was the determinant factor.

Finally, the Water Sources (Control) Law authorizes the government to declare any river, stream, lake, or navigable waterway a "prescribed source of water," with which no one can interfere, unless granted prior approval.[107] Estuarine wetlands presumably could be declared "prescribed sources" and allowed to migrate as sea level dictates.

Spain

Coastal wetlands in Spain are regulated primarily pursuant to the Coastal Law and the 1985 Water Law. The area seaward of the high-water mark (the foreshore)--including coastal wetlands--is public domain in Spain.[108] In addition, Spain maintains a 100-meter "police" zone along the coast, where a license is required to alter the terrain's natural relief, to engage in construction, or to in any way obstruct the water's floodpath.[109] It would appear relatively easy, therefore, to prohibit the construction of seawalls and jetties along the coast.

For wetlands that fall inland of the foreshore, the water contained in wetlands is considered to be public domain, although the bed and other natural resources contained in the wetlands, such as flora and fauna, may be privately held.[110] However, all activity in wetlands is subject to government authorization or concession.[111] Regulations adopted pursuant to the Water Law also provide that, in determining the boundaries of a wetland, a natural buffer area may be delimited around the wetland.[112] Government permission is also required for

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[107]M.G. Yakuba, Land L. Nigeria 179 (1985).

[108]Spanish Constitution.

[109]Cano at 12.

[110]Ley de Costas, art 2a.

[111]Id.

[112]Reglamento of 1986, art. 275.2.

activities conducted within this buffer area.[113] This buffer-area regulation could be used to conserve areas for wetland migration.

While the Spanish Constitution provides for compensation upon expropriation,[114] the imposition of land use restrictions generally does not require the payment of compensation to affected landowners.

CLOSING REMARKS

With the inundation of existing coastal wetlands as sea levels rise, governments are faced with the problem of allowing wetlands to migrate, while avoiding the financial strain of compensating affected landowners. In the United States, a restriction on the development of uplands would have to advance a legitimate state interest and preserve some reasonable economic use of the property to avoid being classified a compensable taking. While it would be relatively easy to find that such restrictions advance the public's health, safety, and welfare, preserving some economic use of inundated property may require creative legislative approaches, such as the creation of transferrable development rights. Disputes over the extension of the public trust doctrine to cover potential new coastal wetland sites may provide the impetus for the resolution of the takings issues. The most legally feasible policy option for preserving coastal wetlands is to exact a covenant not to build a bulkhead from any landowner seeking to develop fastland property in the coastal zone.

Other nations generally do not face the issue of compensation when implementing restriction on land use. Government prohibitions against building bulkheads or otherwise restricting the path of wetland migration would, therefore, be easier to introduce from a fiscal perspective. The political feasibility of such restrictions both in the United States and in other nations, however, depends in large part on the value placed on diffuse coastal wetland benefits.

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[113] See Ley de Aguas, August 29, 1985, ch. V, art. 103.

[114] Spanish Constitution, art. 33.3.

STATE AND LOCAL INSTITUTIONAL RESPONSE TO SEA LEVEL RISE: AN EVALUATION OF CURRENT POLICIES AND PROBLEMS

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INTRODUCTION

Nearly 65% of the population in marine coastal states, or 102.5 million people, now live within 50 miles of the coast (Edwards, 1989). Coastal communities are being challenged to accommodate this expanding demand by providing the necessary space, facilities, and infrastructure to support the swelling population. Sea level rise further complicates and exacerbates the process of planning in coastal communities.

A rise in sea level within the predicted ranges of 50-368 cm by the year 2100 would subject coastal communities to inundation, increased frequency and severity of storms and wave surge, increased rates of shoreline erosion, wetland inundation and recession, modification of dynamic coastal physical properties, and damage to or reduction in shoreline protective structures and facilities (Davidson, 1988). Some coastal areas have been experiencing a relative rise in sea level due to subsidence, reduced sedimentation, and chronic erosion, and are already actively pursuing policies to ameliorate their effects. The resulting social and economic impacts on coastal communities from an accelerated rise in sea level would be unquestionably dramatic and severe.

How state and local institutions respond to sea level rise is very important, since it is at this level of society where the initial impacts will be felt and where efforts to mitigate them will occur. As pressure from the public, the media, and political interests increases, coastal resource managers and planners may be forced to consider actions to mitigate future sea level rise impacts before questions arising from scientific uncertainty are resolved.

This study is not concerned with the accuracy of sea level rise predictions. Rather, it examines how policy makers and institutions have begun to address the issue. This essay begins with a brief description of the institutional framework and decision-making processes of the coastal zone management systems. It summarizes the activities and policies that have been initiated by state coastal zone management programs in response to sea level rise. Responses are categorized according to the development of sea level rise as an issue, from its initial identification as a problem through the implementation of a policy addressing it. A table showing the level of activities of 24 marine state coast'al zone management programs is included. A series of case studies provides an examination of the responses of selected state programs in more detail. The observations section examines the shared problems and tendencies of state coastal zone management programs (CZMPs) as they attempt to address the issue of sea level rise. The study concludes with a discussion of policy trends and what they might suggest for future action.

COASTAL ZONE MANAGEMENT SYSTEMS

Coastal zone management is broadly interpreted to mean any type of public activity, intervention, or interest that is applied to the coastal and marine environment and its resources. Management style, either separate for individual resources or comprehensive over a wide range of activities and resources, varies widely. The comprehensive management systems attempt to integrate policy and planning into a balanced program that addresses the multiple uses, environmental uniqueness, and economic potential of the coastal zone. Generally speaking, integrated coastal zone management is embodied in an ongoing government program charged with resolving the conflicts that arise between the various users and interests inherent to the coastal environment (Sorensen et al., 1984).

The United States was the first nation to fully develop such a program on a national scale (U.S.C., 1972). The Federal Coastal Zone Management Act addresses a broad range of issues: protection of environmental resources, managing development to minimize loss from flooding, setting priorities for water-dependent uses, providing public access, redevelopment of urban waterfronts, the simplification of management procedures, and enhanced public participation in decisionmaking. The act provides money for state programs through section 306 grants, which are intended for program administration, technical studies, local grants, etc.

The act envisions collaborative planning among federal, state, and local authorities. It is intended to instill a broader "national" interest into the process of coastal land use planning -- a responsibility that has traditionally resided with local governments. As conceived in the act, coastal zone management is a state responsibility. However, implementation is often delegated to local governments, with the implicit assumption that local authorities accept the state's role as their partner in regulating land use in the coastal zone (Brower and Carol, 1984). Federal activities must be conducted in a manner that is consistent with the federally approved state programs -- a provision that requires collaboration with federal agencies.

Other federal laws require the involvement of numerous federal agencies and departments in coastal zone decisionmaking. The National Environmental Policy Act requires all federal agencies to consider the environmental effects of their decisions. The Clean Water Act involves the Environmental Protection Agency (EPA) through such programs as its Office of Marine and Estuarine Protection. The Army Corps of Engineers has the longest and most direct involvement in coastal development through the authority vested in the Corps by the Rivers and Harbors Appropriations Act of 1899. The National Flood Insurance Program brings the Federal Emergency Management Agency into the process through coastal floodplain management. The Upton-Jones Act created a voluntary program that provided monetary incentives for property owners to remove damaged structures or relocate threatened structures in hazardous flood areas. The Coastal Barriers Resources Act of 1982 creates a national system of coastal barrier areas within which the federal government prohibits federal subsidies for infrastructure and hazard insurance; in addition, it requires congressional action to include new areas within the system.

The management of hazards in the coastal zone is a major feature of coastal zone management programs. The hazards include inundation and storm damage to private property and public infrastructure and longer-term risks from erosion, bluff destabilization, and saltwater intrusion. Coastal hazards can significantly alter critical coastal environments and eliminate recreation and transportation resources. In this sense, the hazards issue raises many other issues important to coastal zone management, such as protecting coastal habitat, preserving access to shorelines, and ensuring coastal development. Because sea level rise will exacerbate all other coastal problems, it becomes an issue that is central to the concerns and objectives of coastal zone management. Developing strategies that fulfill the basic goals of coastal zone management while addressing the potential threat from sea level rise will require policies that are politically feasible, conditionally flexible, and strategically forward looking. How the system responds will determine the future of our coastal communities.

RESPONSE CRITERIA AND RANGE OF POLICY INITIATIVES

Table I classifies how state CZMPs have responded to the concerns about sea level rise. CZMP responses fall into four stages: (1) official recognition and assessment of problems and issues; (2) new public and intergovernmental processes; (3) existing adaptable regulation; and (4) new policies responding to sea level rise. The four steps in the process evolve from formal recognition to direct policy response. The separation between categories is not always clearly evident, and it requires some subjective judgments on the authors' part. Nevertheless, it provides a method for organizing a broad and dissimilar range of activities into a form that is more easily accessible and from which an analysis may be drawn.

Table 1. State CZMP Responses to Seal Level Rise

	Official recognition and assessment of problems and issues by CZMP	New public and intergovern-mental processes	Existing adaptable regulation	New policies responding to sea level rise
Alabama	No	No	Partial	No
Alaska	No	No	No	No
California	Yes	No	No	No
(SFBCDC)[a]	Yes	Yes	NA	Yes
Connecticut	No	No	No	No
Delaware	Yes	Yes	Partial	No
Florida	Yes	Yes	Partial	No
Georgia	No	No	No	No
Hawaii	Yes	No	No	No
Louisiana	Yes	Yes	No	No
Maine	Yes	Yes	NA	Yes
Maryland[b]	Yes	Yes	Partial	No
Massachusetts	Yes	Yes	No	No
Mississippi	No	No	No	No
New Hampshire	Yes	No	No	No
New Jersey	Yes	Yes	Partial	No
New York	Yes	Yes	Partial	No
North Carolina	Yes	Yes	Yes	No
Oregon	Yes	Yes	No	No
Pennsylvania[c]	Yes	No	No	No
Rhode Island	Yes	Yes	Partial	No
South Carolina	Yes	Yes	NA	Yes
Texas	No	No	Partial	No
Virginia[c]	Yes	No	No	No
Washington	Yes	Yes	No	No

NA: Denotes that the state Coastal Zone Management Program officially considered sea level rise in its policy.
Partial: Denotes existing adaptable policies provide partial restrictions on coastal development.
[a] Regional authority having limited jurisdiction within California.
[b] Response as coastal state and as participant in Chesapeake Bay Agreement.
[c] State's activities limited to participation in the Chesapeake Bay Agreement.
Puerto Rico, Virgin Islands, N. Marianas, American Samoa, and Guam are not included.

Official Recognition and Assessment of Problems and Issues

This category consists of any activity by the state or local CZMP that involves the formal recognition of sea level rise as an environmental condition with implications for that region. Documentation may take the form of any departmental report, memo, newsletter, executive proclamation, legislative finding, or other official statement to the effect that sea level rise is a contributing factor to coastal hazards and erosion. Though program managers and planners may be personally familiar with the issue, problem recognition as it is being used here requires that sea level rise be referred to in an official document describing its climate origins and potential impacts.

Six states have not officially recognized sea level rise as a problem worthy of attention: Alabama, Alaska, Connecticut, Georgia, Texas, and Mississippi. Of these, Mississippi is in the initial stages of planning a sea level rise workshop in the coming year (Mitchell, 1989). Connecticut has not taken any official steps. However, in 1987 the Town of Fairfield held a two-day symposium on sea level rise attended by state and federal officials, some of whom made presentations (Bienkowski, 1989). The reasons given for this lack of official recognition or response include concern for more immediate and urgent matters, limited resources and staff expertise, the belief that current policies are adequate for addressing the problem, and political constraints inhibiting the coastal zone management program's ability to effectively attend to all of its responsibilities (Hightower, 1989; Marland, 1989; Miller and Leatherman, 1989).

There appears to be no correlation between the threat sea level poses for a particular state and its response. Nor has a common institutional feature been found in the states that have not yet recognized sea level rise. Some states that have yet to actively respond, such as Georgia and Connecticut, could face significant problems in the event of sea level rise. Several states with less exposure to damage, inundation, and loss of property -- such as Oregon and New Hampshire -- have already initiated studies of the implications of sea level rise for their coastlines.

Eighteen coastal states have recognized sea level rise as an event with implications for their coastal areas. In most cases, the state CZMP makes the initial recognition and subsequently guides the process of researching and assessing the impacts that sea level rise may have for the state or region. The California Coastal Commission report, "Planning for an Accelerated Sea Level Rise Along the California Coast," issued in 1989, is typical of the initial efforts seen in many states. It contains an overview of the scientific theories and findings concerning climate change and sea level rise, the range of possible impacts on the state's coastal resources and environment, a review of available policy options, and an assessment of further research needs. These initial studies and reports consistently point out the uncertain nature of the problem and often avoid analyzing the alternative policy choices -- in some cases skipping over them completely. Hawaii, one of the first states to address a sea level rise, has yet to develop specific policy recommendations as called for by the state's CZMP report and the Senate resolution that ordered it in 1984.

Legal and Institutional Implications

New Public and Intergovernmental Processes

This category refers to the systematic process of agenda setting and policy formulation. This includes efforts to build a consensus through a task force, legislative hearings, or a series of public workshops. Efforts to inform local governments and affected citizens are instrumental in the process and are designed to integrate the views and considerations of the public and other interests into the formulation of a policy response.

At this stage, the issue has progressed to the point of being recognized as both salient and legitimately of government concern. It is formally addressed by a wide range of decisionmakers who must take an active part in considering what, if any, type of policy should result. Also, the participation of both the public and private sectors and the types of forums within which the issues will be contested are established at this stage. Who gets involved and to what extent they participate in the formulation of policy determines who will have the authority and how that policy will eventually be implemented. There is evidence of new agenda-setting processes in 14 coastal states.

In New York, the Long Island Regional Planning Board has recognized sea level rise as a causal factor in flooding and erosion in its South Shore Hazard Management Program. Mandated by the New York State Department of State to prepare a comprehensive program addressing chronic erosion and severe storm events, the board is trying to develop strategies and policies that would integrate the federal, state, and local interests into a coordinated response. Its goal is to focus on long-term (i.e., 30- to 50-year) planning strategies based on land use planning policies and taking into account the local geomorphic conditions (N.Y.D.S. 1988). The board has outlined a preferred management plan based on strategic retreat, selective fortification, and conditions for new development. It has inaugurated a series of workshops, in conjunction with the state Sea Grant Program, involving coastal engineers and researchers and focusing on technical and scientific topics. The New York/New England Coastal Zone Task Force sponsored a study evaluating the long-term economic impacts of various options for controlling chronic erosion, which was to be used as a model for evaluating policy alternatives. That study, "Developing Policies To Improve the Effectiveness of Coastal Floodplain Management," compared the costs and revenues associated with various responses under different sea level rise scenarios.

In Oregon, the issue of sea level rise is one of many being addressed by the state's Task Force on Global Warming. The state's Department of Energy has prepared a report, "Possible Impacts on Oregon from Global Warming." The report examines the impacts of sea level on selected Oregon coastal communities, but makes no reference to policy strategies or responses, except to say that the price of protection may be too high. Oregon's Department of Land Conservation and Development is the agency through which the CZMP is implemented, and it has not issued any official report of its own on the issue.

The State of Washington's Shorelands Division of the Department of Ecology has formed a sea level rise task force. The task force has initiated a number of technical studies and a policy alternatives study in an attempt to establish a comprehensive understanding of the issue. One of the primary features of the Washington task force is the effort to involve other state agencies, local and regional governments, environmental groups, and private commercial interests into the process of establishing the policy agenda (Canning, 1989).

Similarly, Delaware is establishing a new comprehensive beach management policy based upon the recommendations of the Beaches 2000 planning group and citizens' advisory committees. The recommended plan would be a strategic retreat policy consisting of beach renourishment programs, setbacks based on historical erosion rates, postflooding redevelopment restrictions, and public land acquisition programs.

Existing Adaptable Regulations

This category includes statutes, codes, or rules that are designed to be effective regulatory instruments within a range of environmental conditions. They may be regulations that are intended to cope with conditions like those that would result from sea level rise. Examples are a setback requirement established according to a physical feature, such as tideline, that is periodically recalculated, or a law that prohibits redevelopment of a hazard-prone area. While not specifying sea level rise as the causal factor, the practical application of such flexible regulatory instruments would effectively limit development in response to changing environmental conditions.

There are many instances where existing policies may be responsive to sea level rise. Seven coastal states have setbacks that are based on an average annual recession rate derived from a multiplier of the annual erosion rate. Of these, North Carolina could be characterized as having the most progressive and adaptable setbacks, since it has the most thoroughly defined baseline for measuring setbacks that are adjusted periodically to account for changes in the shoreline. It also restricts the size of the structure based on its distance from the baseline (N.C. CAMA, 1989). Setbacks calculated on erosion rates are designed to recognize the ongoing erosion of the shoreline; thus, they would be responsive to changes in sea level. The Rhode Island Coastal Resources Management Program lists historic sea level rise as one of the contributing factors for erosion in its Shoreline Features section. The state has variable setbacks equal to 50 feet or the erosion expected in 30 years (assuming current trends), whichever is greater. It uses various physical features of the shoreline, such as dune crests and vegetation lines, as the baseline from which the setback is measured.

The construction control line in Florida demarcates an area bordering the shoreline within which certain building standards and permits are required. The line is periodically recalculated for each county to account for changes in the shoreline. In some states, a static setback control line is established. These setbacks do not reflect dynamic changes in the shoreline. For example, in Hawaii, where the setback is 40 feet from the highest wash of the waves, the line of protection can easily be erased by severe storms (Noda, 1989).

Legal and Institutional Implications

The Texas Open Beaches Act, which will be discussed in the case studies, states that any property seaward of the vegetation line is open to public access. Many property owners have found their homes on the wrong side of the line after a storm, and are prohibited from repairing or rebuilding their damaged structures (Martin, 1989). While the law forces the eventual abandonment of developed property in the eroding beach areas, it does not prevent new development from being placed in equally hazardous circumstances.

New Policies Responding to Sea Level Rise

New policies can be in the form of a legislative act, regulatory rule, or administrative decision wherein sea level rise is identified as a causal component of the problem being addressed. It provides a regulatory instrument for integrating potential sea level rise considerations into coastal management and planning decisions. Though it may be incorporated into a regulatory response to chronic beach erosion, wetland destruction, or increased flooding, sea level rise is specifically identified as a contributing factor to that problem. The resulting regulatory instrument is designed to effectively adapt to the changes in the environment brought about as a result of sea level rise.

Three states (South Carolina, Maine, and Rhode Island) and the San Francisco Bay Conservation and Development Commission have designed new policies that respond directly to sea level rise. In each case, the policy and the way it came about have similarities and differences. They are all the result of concerted efforts on the part of CZMP and other related professional agency staffs, who introduced the initial technical research information and initiated the process of public debate and political machinations. However, the types of policy outcomes that resulted are dissimilar.

South Carolina, which will be discussed in the case studies, has established setbacks based on current erosion rates very similar to those of North Carolina. The difference in categorization is that South Carolina stipulated the role of accelerated sea level rise in the new statutes. Maine, under its Sand Dune Law, has restrictions on the size and density of new development in hazardous areas and limits the construction of structural protection devices like seawalls and revetments (Dickson, 1989). It also restricted permits for extracting water from the coastal aquifers in order to protect them from saltwater intrusion. The San Francisco Commission amended its Bay Plan to establish a new permit requirement for development. Future structures will have to meet engineering standards that could withstand increased water levels. The Commission did not establish any fixed estimate of sea level rise and each project is evaluated on an individual basis by a technical engineering review board (BCDC, 1989).

CASE STUDIES

The need to explore and examine the response of coastal zone management systems to the issue of sea level rise becomes more significant as public officials and private interests begin to struggle with its implications. In the early stages of policy development, this is best done through a series of case studies. As events progress, it is necessary to take an inductive measure of the process that is driving new policy-making activities. An examination of a broad range of experiences provides a more comprehensive understanding of the context within which issues are being addressed and policies are being formed.

The case studies that follow were chosen to illustrate the variety of ways in which state CZMPs have responded to sea level rise. The first case, South Carolina, is an example of a program that has new policies controlling development and land use practices in response to sea level rise. That is followed by Florida, which is in a transitional phase of policy development. Texas, on the other hand, has not begun to address the problem of sea level rise and has no mechanisms in place that are capable of doing so comprehensively.

South Carolina[1]

In South Carolina, the issue of sea level rise has been entwined with the chronic coastal erosion problems that have plagued that region for decades. Coastal flooding and inundation problems caused by natural processes, in this case the geomorphic transformation of the barrier islands and subsidence, are being exacerbated by rapid development. In 1984, Charleston was the site for an EPA study about the impacts of sea level rise. Numerous other studies were conducted over the next few years, all of which confirmed in ever greater detail the risk that was posed by sea level rise for coastal communities in that state. A symposium on sea level rise that same year brought forth strong opposition from local interests concerned with the negative impacts that any action might have on development and property investments.

The issue became one of the focal points for the South Carolina Blue Ribbon Committee on Beachfront Management, which was formed in October 1986 to investigate the problems of beach erosion and to propose long-term solutions. The committee consisted entirely of representatives from coastal county and municipal governments. A major storm on New Year's Day of 1987, which destroyed numerous structures and vastly accelerated the erosion process, increased public awareness and ameliorated the political conditions for new coastal development policies.

The coastal zone program in the state is administered by the South Carolina Coastal Council under the Coastal Tidelands and Wetlands Act of 1977. One of the committee's findings was that the Council was unable to effectively implement the legislation because it was not given sufficient authority over development in the beach and dune areas. Consequently, property owners were building structures in erosion-prone beach areas susceptible to storms and flooding and

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[1]References include: South Carolina Blue Ribbon Committee on Beach Management; South Carolina Beach Management Act 1988; Future Sea Level Rise and Its Implications for Charleston, South Carolina; The Physical Impact of Sea Level Rise in the Area of Charleston, South Carolina; Local Responses to Sea Level Rise, Charleston, South Carolina; and Coastal Zone Management Newsletter.

were able to obtain permits to build protective devices as well. In addition, they were allowed to rebuild houses and structures damaged in coastal storms.

The committee's findings stated that the state's coastline was in crisis because of erosion and that sea level rise was the primary cause. It further called for the legislature to amend the coastal councils' enabling legislation to give it the authority it needs to provide effective stewardship of the coastal resources. The committee's findings became the impetus for a legislative bill that sought to institute a retreat policy while limiting the construction of protective devices. The bill, which amended the originating statute, was opposed by property owners, developers, and lending institutions who felt that property values and opportunities would be adversely affected.

Though the eventual bill, known as the Beach Management Act of 1988, was slightly diluted and required considerable debate before passage, it did achieve much of what was sought. Effective as of July 1, 1988, setback lines were established at 40 times the annual erosion rate for residential buildings. The baseline for the setback, the crest of the ideal sand dune, was to be determined using current monitoring and scientific analysis by coastal geologists and engineers. It would be reset within 10 years and between every 5 to 10 years following. The act calls for a 40-year planning horizon. Within the next 30-year period, all vertical seawalls would have to be replaced with an approved protection device, and those that had been more than 50% damaged must be removed. The bill also requires that property owners renourish beach sand at a rate of one and half times the yearly volume lost to erosion whenever an erosion device is damaged or destroyed. This requirement promises to become increasingly cumbersome and costly.

The Beach Management Act also stipulates that local governments create their own beachfront management plans. These plans must be consistent with the South Carolina Coastal Council's long-range comprehensive beach management plan, which the act requires to be developed by 1990. Any local government failing to establish a plan would be subject to the planning guidelines established by the Council. If a local government failed to enforce the beach management plan, it would lose its eligibility to receive state money for beach or dune projects.

The experience in South Carolina illustrates the successful linkage of sea level rise with ongoing and significant issues. It also represents the persuasive impact of research and information on decisionmakers and the public. The role of the Blue Ribbon Committee in advancing the issue on the political agenda reflects the necessity of incorporating the perspectives of local decisionmakers in the formulation of policy. The advocacy of state regulatory agencies, the research and academic community, and key local decisionmakers on behalf of the new regulatory regime resulted in its passage.

Nevertheless, the state's actions remain controversial among property owners and, though it has been sued at least five times for the "taking" of property rights, it continues to adhere to a strong retreat policy. The Council's "Dead Zone" policy, which restricts the building or rebuilding of structures damaged by storms in an area deemed as highly hazardous, has been successfully challenged in a lower court, with one property owner winning $1.2 million. The policy, which states that structures that are more than two-thirds destroyed may not be rebuilt, will affect approximately 159 of the 700-900 buildings damaged by Hurricane Hugo. The Flood Insurance Administration estimates it will be paying $300-$400 million in claims as a result of Hugo, with most of that coming from South Carolina.

It remains to be seen whether the catastrophic impacts of Hurricane Hugo will foster a more stringent attitude toward coastal development. Experience has shown that such events do provide the impetus for more restrictive coastal development policies. The reconstruction and continued development of the barrier islands in the next few years will test the seriousness of South Carolina's resolve to enforce its retreat policy.

Florida[2]

Florida's Coastal Management Program originated in 1981 following the state's Coastal Management Act of 1978. The program is based on 27 state laws administered through 16 state agencies, with the Department of Environmental Regulation as the lead agency in which the Office of Coastal Management is housed. The Departments of Natural Resources and Community Affairs are also involved in implementing the CZMP. An Interagency Management Committee, consisting of the heads of the agencies with major roles, acts as a board of directors in formulating policy and ironing out interagency jurisdictional issues. The Interagency Advisory Committee consists of staff from various agencies who undertake specific tasks and make recommendations to their departments about the program. The Coastal Resources Citizen's Advisory Committee provides an opportunity for public input and review of the CZMP. The committee's members are drawn from government, environmental, and other interest groups, and private citizens appointed by the governor to two-year terms.

Sea level rise poses a substantial threat to Florida, where 70% of the population resides along the coast, and which has been experiencing a relative rise of 8 to 16 inches per 100 years since 1932. Many areas would be inundated, and tens of thousands of people displaced. Major infrastructure, such as coastal power generators, roads and bridges, drainage systems, and flood protection structures, would be affected. Saltwater intrusion into coastal aquifers could create water resource problems, and a higher water table would exacerbate flooding. Shifts in marine ecosystems could alter the distribution of fisheries

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[2]References include: Florida Beach and Shore Preservation Act, 1987; Florida Coastal Resources Management Citizens Advisory Committee Annual Report, 1989; Department of Environmental Regulation memo on Coastal Resources Interagency Advisory Committee Sea Level Rise Subcommittee; The Inundation of South Florida: Past, Present, and Future; Impact of Climate Change on Coastal Resources: Implications for Property Values, Commerce, Estuarine Environments, and Fisheries, with Special Reference to South Florida; Cosper, C., personal communication.

and increase nuisance marine organisms. Precious mangrove habitats and coral reefs may suffer deterioration.

Sea level rise has become a component of the large debate that concerns increasingly dense coastal development and the implications that development has for storm-induced damage and coastal flooding, erosion control, beach preservation, water resources, subsidence, and a number of other environmental and social factors. Though the state CZMP and some members of the Interagency Advisory Committee and Citizen's Advisory Committee made a concerted effort to have the issue of sea level rise ratified as an issue of special focus for the Interagency Management Committee, it was not accepted. In the Management Committee's opinion, responding to sea level rise is a federal problem, and if the federal government has made no declaration or directive concerning it, Florida has no cause to act. The conventional wisdom of the Management Committee was that the state has only two choices -- build a wall or move the buildings -- and that no policy existed to do either. It was pointed out by the CZMP staff at that time that, although no policy existed, the wall had already been constructed in the form of dense development and the protective devices associated with it. Furthermore, the state has made it a policy to preserve the beaches fronting the developed areas through beach renourishment programs.

Florida first implemented its Coastal Construction Control Lines in 1970 and strengthened them in the Beach and Shore Preservation Act of 1987. The control lines cover a 100- to 1,000-foot band along 795 miles of sandy beaches and dune areas subject to the 100-year storm surge. Implemented on a county-by-county basis and requiring a public hearing to be held by the Governor and Cabinet, the control lines are intended to mitigate further beach erosion and to protect upland properties. New structures within the area designated by the control lines must meet building codes designed to withstand a 100-year storm and flood tide. Control lines are set according to current data establishing a 30-year erosion zone. The data are based upon a comprehensive engineering study and topographic survey that considers the historic storm and hurricane tides, wave surge, beach and offshore contours, erosion trends, the dune or bluffline, and existing development. Counties are allowed to establish zoning and building codes in lieu of the control lines, provided they are found adequate by the Department of Natural Resources to serve the same function.

Simultaneously, the legislature created the Beach Management Fund and allocated at least $35 million for the Department to use annually toward erosion control, hurricane protection, beach preservation, restoration, and renourishment. In fiscal year 1988-89, the state legislature approved $13.3 million for beach renourishment projects, which, when added to federal matching funds, amounted to almost $30 million. These funds finance the renourishment projects that serve as the state's primary method of erosion control and shoreland preservation. The local government is required to fund 25% of the cost for any projects deemed necessary by the Department of Natural Resources. The state also uses the fund to pay for its share of federally approved erosion control renourishment projects. Florida has also implemented a public lands acquisition program over the past decade, buying beach property for public recreational uses and resource protection.

The recent onslaught of Hurricane Hugo has posed some questions and opportunities for Florida. An increase in the number and severity of tropical storms has been predicted as a result of climate-change-induced warming of surface water and sea level rise. The extensive damage seen in South Carolina may be small compared to the level of damage that would have resulted if the hurricane had struck South Florida. The state is now beginning to consider whether its current post-storm reconstruction practices are adequate for the protection of life and property after such a storm. The implications for areas such as Florida, with its low beach profile and porous substrate, are serious. While the control lines have prevented many poorly conceived and designed development projects from being built, post-storm redevelopment has not been limited to any degree, and many property owners have used grandfather clauses to rebuild in areas susceptible to storm damage and flooding.

Currently, the state CZMP, in conjunction with the research community, is planning to conduct a symposium on sea level rise as part of the statewide coastal conference in hopes of attracting the participation of technical experts and planners. They are also submitting a grant request for federal funds under section 306 of the Coastal Zone Management Act to conduct a study of the regional impacts of sea level rise on the Tampa Bay area.

Florida faces some hard choices and difficult problems, regardless of whether sea level rise predictions hold true. The rapid and dense development of its coastal areas has exacerbated environmental problems and has frustrated hazard mitigation efforts. Attempts to address those issues naturally clash with the pressure for more development. Officials within the state's CZMP, public interest groups, and others who support programs that would provide for more comprehensive planning and stricter controls on coastal development find it very difficult to muster the necessary political support. Current policies are limited to storm-proof building requirements and extensive beach preservation and renourishment programs. The value of Florida's beaches and shorefront property make this a predictable outcome. Sea level rise, if it ever is seriously addressed, will probably "piggyback" onto more immediate and tangible issues, such as hurricane mitigation and post-storm redevelopment policies.

Texas[3]

Texas is suffering from chronic erosion along 60% of its 400-mile shoreline, consisting largely of barrier islands. Decreased sediment supply, subsidence, and relative sea level rise, compounded by intense storm events, cause some areas to lose up to 50 feet per year. Despite the considerable risk this may pose to valuable property, infrastructure, fisheries, and the Gulf Intracoastal Waterway, the state has been reluctant to invest in coastal projects that may mitigate the erosion process.

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[3]References for this case study include: Texas Beaches and Dunes Regulations Chapter 63; Martin and Dearmont in Texas Shores; Texas Shorelines Newsletter; Hightower, M. and Bright, T., personal communications.

Legal and Institutional Implications

Texas has not developed a federally approved CZMP and has no comprehensive statewide program addressing coastal resource protection and development. After the demise of the Texas Coastal and Marine Council in 1985, no institutional mechanism was left in the state to deal with coastal issues. Attorney General Ken Cross stated that there is a vacuum in the state in terms of managing its coastal resources. Although at least 10 state and federal agencies are involved in coastal matters, there is no consistency or lead authority, and local communities retain almost total control over land-use planning and development strategies, with very little outside guidance. The response of many local communities faced with erosion problems is to transfer it down the beach by seeking some hard protective solution that aggravates the problem by reducing natural sediment movement.

In the case of Sargent Beach, a 10-mile strip of shoreline fronting the Gulf Intracoastal Waterway and resting upon a mud base, the erosion rate exceeds 100 feet per year. The Army Corps of Engineers, charged with the responsibility for the waterway, may require anywhere from 5 to 15 years to study, plan, and respond to the problem. Meanwhile, there is a possibility that the area may be included in the Coastal Barriers Resource System and become ineligible for federal funds for projects that would restore the beach or move the channel.

In recognition of the loss of approximately 12.5 square miles of land during the past century, the Galveston Bay area was the site of a 1984 EPA-sponsored study, "Coastal Geomorphic Responses to Sea Level Rise: Galveston Bay, Texas," Leatherman (1984). Estimates from Titus and Greene (1989) project a cost of $83 million for bulkheads and relocations in Corpus Christi should there be a 7-inch rise in sea level. The cost of renourishing sand on Texas beaches over the next century, under that scenario, was estimated at $17.6 billion. Numerous other studies have been conducted focusing on the erosion problems along the Texas coast, but the weight of evidence has not had an impact on coastal development practices.

Though the state has yet to recognize sea level rise officially, it does have a law that inadvertently but effectively reduces the redevelopment of erosion-prone beaches. Through the Texas Open Beaches Act of 1959, the public has the right to use all beach areas seaward of the vegetation line, and no one may erect barriers to prevent the public from using them. This act will have an increasing impact as the vegetation line recedes beyond existing development as a result of chronic erosion and severe storms. After Hurricane Alicia struck in 1983, the vegetation line retreated from 20 to 145 feet. This prompted over 100 lawsuits by property owners against the state, and 15 suits by the state against property owners who were rebuilding. The courts have thus far upheld the state's position, and legal action by property owners challenging the statute as a taking have failed. Assistant Attorney General Ken Cross remarked, "We didn't create this problem. This is a harsh situation, not because of what we did, but because of Mother Nature."

Nevertheless, local communities continue to permit coastal development in erosion- and hazard-prone areas. The experience of Texas illustrates the problems that result from a lack of comprehensive planning and sound fundamental objectives in coastal development and land-use practices. The legislation that is in place acts as a reactive mechanism, creating conflict and further degrading the public's perception of the state in coastal affairs. Without significant changes in the pattern of development along the coast, these problems are likely to continue. Yet there is little support for developing a statewide program that could address these problems, and even less for a federally approved CZMP. Ironically, the most effective policy response affecting Texas may eventually result from federal efforts to encourage a retreat from areas subject to coastal erosion and hazards, such as provided by the Upton-Jones amendment to the National Flood Insurance Program and the restrictions on coastal barrier island development established by the Coastal Barriers Resources Act.

OBSERVATIONS AND CONCLUSIONS

Common Problems

All state and local CZMPs share a common set of problems related to sea level rise. The most prominent is the issue of property rights. The delicate balance between private property interests and public policy objectives is becoming increasingly difficult for CZMPs to maintain, as conflicts between development and environmental concerns mount. Changes in coastal development policies are directly linked to land use planning, and are often perceived by developers, property owners, and lending institutions as a taking of private property for the general public's benefit for which they should be compensated. (See Fishman and St. Amand this section, this volume.) Legal challenges to policies that require property owners to yield the use of their property are to be expected. When the Coastal Barriers Resources Act was being debated in Congress, the National Association of Realtors and the National Association of Home Builders charged that the bill discriminated against coastal property owners and infringed on their property rights (Dearmont, 1989). Policies addressing the potential impacts of sea level rise that are sensitive to local property and development interests and that are on firm authoritative ground are preferred, but it is not certain that they are doing the job.

Aside from the uncertainties regarding sea level rise, there is a lack of information and data concerning how it may affect particular coastal regions. Without comprehensive baseline data for regional coastal ecosystems and geophysical conditions, it is difficult to reliably monitor geomorphic changes. Few local governments have the resources to obtain such information, and state CZMPs are not always able to provide the necessary technical assistance. This contributes to the problem of local implementation once policies are in place.

Political constraints are another prominent factor. In light of the inherent uncertainties of climate change and the lack of regional impact data, policy- makers are reticent to support controversial initiatives without substantial evidence that those policies are necessary and in the public interest. While CZMPs strain to promote long-term planning policies, many state and local officials and private interests are influenced by a different set of dynamics: short-term economic objectives, electoral cycles, and a reluctance to surrender control over the local planning process.

Common Activities

A number of factors are common to many CZMPs responding to sea level rise. One is that the issue is usually internally generated by key professional staff within the CZMP network. Often staff members are responding to peer pressure, as concern about climate change has raised the concern about sea level rise among coastal officials, researchers, and the public throughout the nation and the world. Key staff people become policy entrepreneurs, actively promoting the issue and establishing a network among other agencies, technical experts, and local governments.

Section 306 grants under the Coastal Zone Management Act are the primary source for funding the initial technical studies and program activities related to sea level rise. Under a section 306 grant, up to 30% of the grant must be spent on projects that result in "significant" program improvement, rather than ongoing program implementation. Funding for followup studies and research must be sought from state sources or through federal agencies, like EPA or the Federal Emergency Management Agency, to conduct research studies related to their particular areas of concern. The availability of funding for baseline data research and monitoring is critical to the success of CZMP efforts to develop policy responses to sea level rise.

Typically, sea level rise is linked to existing programs and objectives. Policies that are based on pre-existing authority are more politically acceptable and easier to implement. The uncertainty of sea level rise is offset by its association with a significant existing problem. The focus of attention is transferred to existing long-term objectives and goals. Be it wetlands, beach or dune preservation, or protection from storm flooding, linkage provides credibility and alleviates some of the uncertainty by making sea level rise more of a present-day issue. Those issue areas benefit because sea level rise heightens concerns about achieving existing program goals. The states that have integrated sea level rise into their policies have done so on the basis of pre-existing program goals.

Policy Trends

Strategic or adaptive retreat policies are becoming the preferred response to sea level rise among state CZMPs. Typically, strategic retreat encompasses a range of regulatory activities and programs in the form of a comprehensive management and planning program. There are a number of features common to strategic retreat policies, the most prominent being laws or regulations that allow the conditional use of property located in areas susceptible to erosion and flooding, restrictions on hard structural protection, protection of critical environmental areas, and post-storm redevelopment restrictions. Strategic retreat policies also recognize that densely developed areas will require some form of structural protection, while the dynamic geologic processes should not be impeded in less developed and undeveloped coastal areas.

The use of setbacks based on historical erosion rates, like those in South Carolina, and restrictions on coastal development size and density as found in Maine, are attempts to provide an opportunity for property development in a manner consistent with the long-term goals of the CZMP. Allowing the conditional use of the property avoids some legal challenges and reduces the opposition of property owners. Implementing such regulations requires a mapping program to establish a baseline and a periodic monitoring program to track the geomorphic changes in the coastline. As the relative sea level changes, the setbacks can be adjusted accordingly.

The use of hard structural protective devices is increasingly restricted, especially in areas considered to be critical environmental resources like sandy beaches, dunes, and wetlands. Many states require property owners to use non-intrusive protective measures, such as planting grasses or building artificial dune barriers, rather than seawalls and revetments. In many states, critical environmental resources are areas that receive special protection in the form of buffer zones and building restrictions. Ecosystem restoration programs using "soft" engineering strategies, such as revegetation, are becoming more prevalent. Conservancy land acquisition programs, both public and private, are another innovative way of preserving critical habitats and environments.

Post-storm redevelopment policies that require structures to be moved or abandoned if they receive substantial flood damage and are susceptible to continued flooding are also instrumental in forcing a retreat. Another means is to transfer the real cost of owning coastal property to the owner by removing the subsidy provided by federal flood insurance coverage for structures in hazardous locations. Requiring property owners situated in hazardous areas to bear the part of the cost for improvements to the infrastructure that serves them is another way of transferring the cost to the property owners. The use of tax incentives and disincentives to promote the preservation of undeveloped property is another vehicle for controlling land use, as are incentives to locate or relocate structures in preferred areas and disincentives for placing them in hazardous areas.

Renourishment programs are an important component of strategic retreat policies because they help preserve the status quo by selectively maintaining the beachfront. Programs like those in Florida, designed to preserve the beach as a method of hazard mitigation, also distribute the costs over a wider base. Renourishment programs are a trade-off as long as they are economically feasible. Like other soft engineering strategies, renourishment provides an environmentally acceptable method of preserving beachfront for areas that are simply too valuable not to protect.

The federal government has provided some support for states seeking to initiate retreat policies by implementing similar strategies within areas where they have authority. The Upton-Jones Act is a voluntary program under the National Flood Insurance Program that seeks to change redevelopment practices by providing direct monetary incentives not to rebuild, but to tear down or move structures in highly hazardous coastal flood zones. It received only moderate acceptance during the first two years of the program, with nearly half of the

188 claims coming from the state of North Carolina (Buckley, 1989). The Coastal Barriers Resources Act eliminated federal expenditures for flood and disaster insurance and restricted public expenditures for infrastructure on designated undeveloped barrier islands. It requires congressional action to expand the barrier system, and local officials and congressional representatives often resist federal expansion into state jurisdiction.

Sea level rise poses both a problem and an opportunity for state CZMPs. State coastal zone management programs normally do not have the authority or the political leverage to directly control local land use and planning. They are dependent on a partnership with other federal and state authorities, local governments, and private interests. CZMPs must continue to work toward the multiple and sometimes contradictory objectives of the Coastal Zone Management Act. Yet, they are the one institution capable of addressing the issue of sea level rise comprehensively and systematically. Linking sea level rise to more immediate and tangible issues provides an opportunity for CZMPs to increase their role in coastal land use policy. Programs that are able to incorporate sea level rise considerations into their overall program objectives will succeed in broadening the scope and range of the planning process.

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ROLE OF EDUCATION IN POLICIES AND PROGRAMS DEALING WITH GLOBAL CLIMATE CHANGE

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ABSTRACT

Much attention is now focused by government, academia, and the popular press on the short-term and long-term effects of sea level rise and other impacts of global climate change. Many uncertainties and much confusion are associated with global climate change today. However, despite the ambiguity of information and the uncertainty about future events, national and international decisions and policies, which deal with limiting and/or adapting to climate change and sea level rise, are now being debated and made.

Any governmental policies or programs that are adopted will need the strong support and endorsement of the local citizenry to be successful. To date, the majority of citizens are either unaware of the issues, problems, and potential impacts of global climate change, or they are confused by the conflicting information that they receive via the mass media.

Citizens in both developed and developing countries need to receive accurate, objective information about global climate change and its implications. More important, not only do citizens need to have a better understanding of the processes involved and the implications of global climate change, but they, along with the business and industrial communities, also need to receive information on what type of local actions can be taken to respond to this issue. Regulation alone is not enough. A long-term pro-active educational response is needed. As is the case within the research community, an interdisciplinary, coordinated, and international educational program needs to be developed.

This paper will discuss the role of education and the rationale for developing a strong, coordinated interdisciplinary educational program to deal with the issue of global climate change. It will discuss the "Extension Model" used by the Sea Grant Program as one possible approach. Finally, it will discuss other possible educational options and program opportunities.

ROLE OF EDUCATION IN POLICIES AND PROGRAMS DEALING WITH GLOBAL CLIMATE CHANGE

The potentially devastating impact of human activity on the environment has become the international issue of the late 1980s. It seems that one cannot pick up a newspaper or view a television newscast in the United States without at least one story devoted to this issue. These stories focus on such problems as threats to the climate and damage to our populated coasts and social infrastructure due to sea level rise resulting from greenhouse warming; damage to plant, animal, marine, and human health from increased ultraviolet radiation due to the depletion of stratospheric ozone; extinction of species due to tropical deforestation; threats to marine life and human recreation from coastal and estuarine pollution; human, animal, and environmental damage and contamination from nuclear and hazardous waste; and damage to lakes and forests from acid rain.

Of course, these threats are not really new. Some of the world's leading scientists have warned about these global dangers for many years. Global climate change is not new either. Since the dawn of creation, the earth and its resources, the climate, and the atmosphere all have changed, since they constitute a dynamic system. But what is new is the concentrated focus by government, academia, and the popular press on these issues.

Why this new focus? There are many reasons. Technological and scientific advances now allow us to better measure, model, and predict what is happening within the earth's dynamic systems. The dedication of scientists and managers in the 1980s to step beyond their laboratories and classrooms to discuss these issues in the public arena has caught the attention of our government officials. Major climate events of the late 1980s -- droughts, hurricanes, major flooding episodes, evidence of holes in the ozone layer -- have also brought print exposure, television air time, and international attention to environmental issues. The result is a rising consciousness of the accelerated changes in the earth's systems due to man's influence, particularly in the last 100 years.

However, there are many unknowns, fierce debate among the scientific community about potential impacts, and public confusion about issues of global climate change. Two issues of particular concern to members of the marine community are the potential breakdown of the ozone layer and the impacts of the greenhouse effect.

The predominant scientific opinion today is that chlorofluorocarbons (CFCs) destroy the ozone layer, and that the consequences of enhanced ultraviolet radiation on the biota are dangerous. Located in the thin stratospheric layer some 15 miles above the earth's surface, the ozone layer acts as a protective shield from the sun's lethal ultraviolet (UV) rays. CFCs have been used in increasing quantities in a variety of industrial and consumer products because of their properties as a stable, inert gas. However, because of this stability, they do not break down, but rather slowly drift into the stratosphere. There, through a series of complex reactions, they break down, and free chlorine ions are released that destroy thousands of ozone molecules. In the last few years, scientists have discovered an average annual worldwide ozone loss of 2%, with up to a 50% seasonal loss in the polar regions. The increase in UV radiation may be devastating for humans, plants, and animals. For humans, the increase in skin cancer may be significant; less is known about the effects on crops, trees, and the ocean food chain. The Montreal Protocol was the historic first step in regulating CFC production, but it may not be enough. Despite a planned phaseout of CFCs to 50% of their levels, many scientists are urging that CFCs be eliminated entirely, using substitutes that already exist.

The sources responsible for the greenhouse effect are well known: CFCs, deforestation, carbon dioxide from fossil fuel combustion, and methane from increased biological activity. There is growing confirmation among scientists that global mean temperatures will increase. The latest computer models predict an average global increase of up to 5°C, with rises of up to 12°C in the polar regions. This temperature change is comparable to the warming since the last ice age. Of great concern and uncertainty are regional effects on weather, such as storms, and particularly changing rainfall patterns. Sea level may rise by one meter in the next 50 years. Our understanding of this problem is poor. New models are being developed, but it may be several more years before our predictive and analytical tools are any better at forecasting what will occur.

The scientific community is embarking on a new research plane that is integrated, coordinated, and interdisciplinary. Millions of dollars are being spent, or are in the process of being budgeted, for needed research that will increase our knowledge of what is happening to the world in which we live. Also, despite the paucity of information, scientific debate, and uncertainty of future climatic events national and international decisions and policies are now being debated and made to deal with the adaptation to global climate change and sea level rise. Clearly, the global climate issue will reach the agenda of most major governments in the 1990s, if it has not already arrived.

However, any government policies or programs that are adopted will need the strong support of the local citizenry to be successful. To date, the majority of citizens are either unaware of the issues, problems, and potential impacts of global climate change, or they are confused by the conflicting information that they receive via the mass media.

Unfortunately, to date not much coordination or thought has been given to providing the proper type of citizen involvement and educational effort. The educational activities that have occurred have been disjointed, with the information based more on emotion than fact. Many educational and informational activities are occurring, however. Following are a few that have recently been brought to my attention:

Nonprofit Organizations

Union of Concerned Scientists (Cambridge, Massachusetts) coordinated a "week of education" with over 200 individual projects in 47 states of the U.S.A., and also developed a "Global Warming Briefing Packet" and an expert speakers list.

Legal and Institutional Implications

Oceanic Society (San Francisco, California) will include in its "Project Ocean" educational curricula the latest information on global climate change and its impacts on the oceans.

National Wildlife Federation has developed "Cool It," an informational packet on the greenhouse effect and other global climate change issues.

Numerous environmental organizations have developed special newsletters, specifically designed to deal with global climate issues. One example is "Atmosphere," a publication of Friends of the Earth International on Ozone Protection.

Industry Groups

American Society of Mechanical Engineers developed a briefing paper, "Energy and the Environment" (July 1989), which took a broad look at the relationship between energy and the environment.

National Association of Manufacturers developed a white paper, "Global Climate Change" (July 1989), that investigated the economic issues impacted by greenhouse gas emission reduction, targets and the risk of premature inadequate causes of actions that may hurt, rather than help an effective international response.

Many International, National, State, and Local Conferences

"Global Natural Resources Monitoring and Assessments: Preparing for the 21st Century" (September 1989 - Venice, Italy).

"Globescope Pacific" (October 1989 - Los Angeles, California, U.S.A.), sponsored by the Global Tomorrow Coalition Project, brought 1,000 individuals together to begin discussions to launch a decade of creative actions to achieve sustainable development.

"Climatic Fluctuations and Their Socio-Economic Impact Concerning Countries Around the Atlantic Ocean" (November 1989 - Toulouse, France).

"Environmental 2010" (November 1989 - Seattle, Washington, U.S.A.), sponsored by the Washington Department of Ecology and U.S. Environmental Protection Agency, brought 600 individuals together to discuss State of Washington environmental issues and priorities and strategies to deal with them.

"Northwest Sea Level Rise Conference" (December 1989 - Seattle, Washington, U.S.A.), sponsored by the Washington Department of Ecology to bring state agency officials, politicians, and interested individuals together to focus on the implications of sea level rise for the Pacific Northwest. Different approaches will be presented for dealing with the issue.

"World Conference on Preparing for Climate Change" (December 1989 - Cairo, Egypt).

European Conference on Landscape--Ecological Impact of Climatic Change (December 1989 - Lunteren, The Netherlands).

"Climate Change: Planning Ahead for South Carolina" (January 1990 - Charleston, South Carolina, U.S.A.), sponsored by the South Carolina Sea Grant Consortium to bring together national and state experts to present a scientific overview of climate change and its implications for South Carolina.

"Global Warming: A Call for International Coordination of Scientific and Policy Issues Facing All Governments" (April 1990 - Chicago, Illinois, U.S.A.).

"International Conference on the Role of the Polar Regions in Global Change" (June 1990 - Fairbanks, Alaska, U.S.A.).

"Beijing International Symposium on Global Change" (August 1990 - Beijing, Peoples Republic of China).

"Chemistry of the Global Atmosphere" (September 1990 - Chambrousse, France), sponsored by the Commission on Atmospheric Chemistry and Global Pollution. Seventh Annual International Conference.

Mass Media

It appears that saving the earth's environment will blanket network and cable television channels during 1990 in the United States -- everything from news specials to sit-com episodes will address this issue.

Turner Broadcasting System, Inc. (TBS) began airing the half-hour program "Earthbeat" on October 15, 1989, which is an advocacy-oriented program showing how individuals, countries, and corporations can help save the planet. Earthbeat has an activism format, such as using telephone surveys to record viewer opinion on various issues, and inviting viewers to call in to put their names on "electronic petitions" that will be sent to politicians and corporations. Producer Jeanette Ebaugh states: "TV is the most powerful tool in the world, and it wasn't being used to aid the most serious issue of our time...." ("TV is Giving Star Status to Environment" Wall Street Journal, 10/2/89).

TBS is also working on an animated cartoon series to be called "Captain Earth."

TIME Magazine in January 1989 named its Man of the Year "The Endangered Earth."

Columbia Broadcasting System (CBS) in September 1989 began airing 60-second "Earth Quest" spots. CBS News also plans on showing five 1-hour specials on the environment in April 1990 in conjunction with Earthweek.

Barbra Streisand, Kevin Costner, and several other Hollywood celebrities will host a 2-hour special called "A Practical Guide to How You Can Save the Planet," to be aired on Earth Day, April 22, 1990.

Olivia Newton-John (Australian-born pop singer), United Nations goodwill ambassador for the environment, plans to air a television Christmas special entitled "A Very Green Christmas."

Puppeteer Jim Henson (creator of The Muppets) is developing a children's show about nature to be called W.I.L.D."

Although there appear to be many such efforts, most are not coordinated or integrated with one another. Neither are they tied to a strong research base that can provide the citizenry with accurate information on the issues and the latest findings about global climate research. Nor are they really aimed at the local citizenry of the world.

There is a need for citizens in both developed and developing countries to receive accurate, objective information about global climate change and its implications. More important, not only do citizens need to have a better understanding of the processes and the implications involved, but they, along with the business and industry communities, also need to receive information on what type of local actions can be taken to respond to this issue. Government programs and various regulations alone are not enough.

As envisioned by Jean Jacques Rousseau, John Locke, John Stuart Mill, and other eighteenth-century philosophers, democracy requires that all citizens have the right to influence political decisions that affect them. A basic assumption of this philosophy is that all citizens are -- or can be -- essentially equal, in both their concern for public issues and their competency to make decisions about them. However, to make these decisions, citizens need accurate and understandable information. Unfortunately, many of the recent articles on global change and ozone depletion are sensational, technical, or too abstract for the general public, and they really do not help people make a connection between their everyday actions and the impending long-term global changes that will probably take place.

A long-term proactive educational response is needed that is research-based and multi-pronged for both formal and informal settings. As is the case with global climate research, the educational program needs to be interdisciplinary, coordinated, and international in scope. One educational model that already exists within the United States and that could be used in this effort is that found within the Land Grant and Sea Grant systems. The Land Grant system was established around the turn of the century, focusing on increasing agricultural productivity. The Sea Grant system was established in the mid-1960s to encourage the understanding, wise use, and conservation of our marine resources. Both systems use a three-pronged effort involving research, education, and extension and advisory services to carry out their mission.

With funding from federal, state, and local sources, a unique partnership among federal and state governments, major universities, and industry has been forged through the years. For the Sea Grant Program, the majority of its operating funds come from the U.S. Department of Commerce's National Oceanic and Atmospheric Administration (NOAA). Sea Grant's research and advisory service programs around the country have worked at some time or other with virtually every one of NOAA's agencies. In general, Sea Grant programs work most closely with NOAA's National Marine Fisheries Service (NMFS), National Weather Service (NWS), Office of Coastal Zone Management, Environmental Research Laboratories, and National Ocean Survey.

In the rest of the federal arena, Sea Grant has worked closely with the U.S. Coast Guard, U.S. Fish and Wildlife Service, regional fisheries management councils, U.S. Army Corps of Engineers, U.S. Department of Agriculture, and U.S. Environmental Protection Agency. Most of these contracts are made on the regional or local level and take the form of information exchange or joint sponsorship of advisory service projects like conferences or publications. The resources of these federal agencies often enhance Sea Grant's ability to solve a local or regional problem, and the federal agencies, in turn, often use Sea Grant's communications network.

An intricate infrastructure of public outreach is in place through the Land Grant and Sea Grant system of campus-based specialists and field agents. Within this system, there is a dissemination point within every country of the United States that could be mobilized for information exchange and technology transfer related to the global climate issue. Additionally, since these programs are housed at various universities around the country, there is yet another mechanism to tap into a large portion of the research community within the United States.

In dealing with the issue of global climate change, these two systems could be harnessed in several ways. First, the Sea Grant and Land Grant networks could join in partnership with other research programs already in progress to provide hard scientific data on the effects of the projected global changes on the marine and coastal environments. Second, we could bring regional, national, and international extension initiatives to educate the general public about the severity of the problems facing us, and even more, about steps that might be taken to deal with the causes on an individual level. Our educational approach has always been proactive and positive. Our mandate is to provide citizens with relevant facts about a issue. If there is controversy or uncertainty, our educational formula is to provide citizens with the various options and actions that might be taken to deal with the issue. Our extension component provides local technical assistance and public information programs to citizens and links them with university research. We take a non-advocacy point of view, striving to present the best information to citizens so that they can make the best decisions about our natural and marine resources.

Legal and Institutional Implications

To be effective, an educational program needs to be long-term and to have both formal and informal elements. Regarding formal education, the latest scientific findings concerning global environmental changes must enter the school systems of the world. The future resource managers of the world need to become environmentally aware and informed. They need to develop an environmental literacy that reconnects them with the world in which they live. At present, the Sea Grant Network is awaiting word from the National Science Foundation on just such a project, entitled "Interpreting Current Research on Global Environmental Issues for Teachers and Students." The goal of the three-year project is to create among middle-school teachers and their students an enhanced awareness and understanding of global environmental issues by providing a structure for the transfer of marine and aquatic research results and methods to middle-school educators throughout the U.S.A. From this prototype program, additional informal education materials could be developed for youth that could be disseminated throughout the United States through the Land Grant network via its 4-H and Youth Programs. I, along with my counterpart in the Hawaii Sea Grant Program, are also working with the National Marine Educator's Association to Develop a one-day training session on global climate change at their annual meeting, scheduled for August 1990 in Hawaii.

Informal educational activities also need to be developed to educate adults on the issues and the associated problems, and their responsibilities to take action. To achieve the objectives of informed citizen participation and action, we must provide individuals with numerous opportunities to acquire the skills and information necessary to change their behavior and lifestyle. It must also be stated that working with the adult population, one needs to develop a different educational strategy. Until recently, adults were often treated the same as students in any elementary, secondary, or college classroom, with little attention paid to differences in their experiences, needs, and motivations. The proliferation of adult education and training experience has brought new ways of thinking about how adults learn and change behaviors. In fact, the special needs, and characteristics of adult learning were recognized by Malcolm Knowles, who created the word "andragogy" to describe "the art and science of helping adults learn," which is distinguished from "pedagogy," which deals with teaching children.

Several formal and informal meetings have already taken place between Land Grant and Sea Grant administrators to discuss coordination of global climate educational efforts. These discussions will continue as we develop joint long-term educational strategies. The logical next step should be to broaden these discussions with other local, state, national and international government and nongovernment actors who are developing educational programs, in order to avoid duplication of effort and to maximize use of the funds available for such activities. Many of my counterparts in the Sea Grant network have already made contacts with various local and state agencies to jointly develop educational programs and materials. National and international coordination and cooperation are also needed.

There are many examples of informal educational programs that could be developed. Many of these are not new to extension educators. However, the educational tools that could be used could be expanded to include the latest in print and audiovisual media, including cable television and satellite hookups. Here are a few of the generic programs that could be developed:

Initiate Programs Designed to Prevent Further Global Change

Develop educational programs to stress reductions in CO_2 emissions through energy conservation, resurrecting projects that were implemented in the 1970s. Improving home insulation, increasing automobile mileage, switching to cleaner fuels for home and work, conserving electricity at home and work, and supporting development and use of mass transit are a few examples that could be stressed in this program. Educational programs could also be aimed at recycling, reduction of excess packaging, and reduction of nonessential use of CFCs.

Design Programs That Will Directly Mitigate Future Global Change or its Effects

Implement tree-planting programs. We could also develop (1) educational projects related to protection from increases in ultraviolet (UV) radiation increases, and (2) educational materials and liaisons with state agencies to factor sea level rise into coastal planning efforts.

Encourage Needed Research to Answer Uncertainties About Global Warming and Ozone Depletion

Promote research that would close gaps in our knowledge of in situ effects of enhanced UV on marine plankton, coral, and food plants. Study the economic impact of UV and global warming so that costs or mitigation and prevention can be compared and evaluated. Initiate sociological studies to predict public response to global change.

Initiate Leadership Development in Citizens on Global Climate Change Issues

Provide educational programs for citizens so that they understand the public policy process, and how they can become effective an part of the process.

Develop Educational Programs That Encourage an Environmental Ethic

Provide educational programs that are interdisciplinary and that provide a global ethic that recognizes the interrelationship of our air, water, and land resources.

In developing an educational program to empower an individual toward action or behavioral change, several guidelines and techniques should be remembered to ensure success.

- Make the issue the individual's problem. It's not just the government's problem. Personalize the problem to solicit action.

Legal and Institutional Implications

- Switch from an institutional orientation to an individual orientation. Switch from a "this is what is important to us" mentality to one of "what is important for the individual."

- Repetition counts. People rarely understand the issue the first time. It often takes many times to change an opinion, behavior, etc. Keep the message in front of the individual.

- Don't sell the process, sell the outcome. Only the sponsoring organization is interested in how it happened. Individuals are only interested in what is in it for them.

- "Less is more." Don't complicate your educational program with too much detail. Keep it simple and as nontechnical as possible.

- Keep the issue in its context.

- Don't just speak to those already committed to the cause. Use nontraditional means to get the information out to the public.

- The biggest challenge is keeping the issue in front of the individual, and keeping it on the public agenda.

In conclusion, although it appears that the global environmental crisis is extremely serious, it also is one that is ripe with opportunity for positive social changes. As some of you may know, the Chinese symbol for crisis consists of two characters. One means danger, and the other means opportunity. The scientific community has clearly articulated the danger, and the alarms have been sounded throughout the world. However, it appears that there also is a responsibility and an obligation for all of us -- educators, policymakers, scientists -- to seize the opportunity that this global issue presents to unite us on an issue that cuts across economic, social, political, geographic, and environmental boundaries. There clearly is a role for both government action and local responsibility. International government incentives, regulations, and agreements will need to be put into place to deal with this global issue. Individual actions and choices that involve an understanding of the global environment in which we live are also needed. With the lessening of tensions between East and West, we may have an opportunity to turn our attentions, funds, and manpower away from weapons of destruction and instead turn them to activities that will prevent or lessen the destruction of our planet.

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ECONOMIC AND FINANCIAL IMPLICATIONS

FUNDING IMPLICATIONS FOR COASTAL ADAPTATIONS TO CLIMATE CHANGE: SOME PRELIMINARY CONSIDERATIONS

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INTRODUCTION

The purpose of this document is to explore the implications for funding of options for coastal adaptation to climate change. The paper focuses on issues of allocation of financial resources for coastal adaptation and considers priorities for immediate assistance.

BACKGROUND

There is considerable uncertainty about the effects of climate change upon coasts. Impacts may arise from rising sea level, increased storminess, changed wave climates, and changes to freshwater and sediment contributions brought about by inland climate changes. There may be significant lags in the manifestation of the impacts of climate change on the coast.

Almost all coastal countries will be affected by rising sea level or other changes brought about by climate change. Many countries have large populations in low-lying areas, and a number have considerable economic investment in their coastal zones. According to demographic projections, the current global population will have doubled over current levels before greenhouse gases reach twice their pre-industrial levels. A great deal of this population growth will be in coastal cities and other lands likely to be vulnerable to sea level rise and other effects of climate change.

Coastal erosion and loss of natural coastlines, often associated with unsustainable development projects, are commonplace in many areas. There is an urgent need to ensure that current practices for using coastal resources are environmentally sound, which could have implications for the funding of coastal development projects, irrespective of the issue of climate change.

Economic and Financial Implications

The IPCC Response Strategies Working Group (RSWG) has prepared a paper on financial measures as part of its Task B activities. A similar paper has been prepared on technological development and transfer measures. These papers serve as the basis for the following discussion of funding implications for possible coastal adaptation to climate change.[1]

INTERNATIONAL COOPERATION

Climate change is a global problem whose solution will require international cooperation. This necessity has been widely recognized with respect to strategies for limiting global warming and the encouragement of their adoption by all countries. As a result, most discussion regarding financial or technological assistance to developing countries has focused on these activities.

However, the impacts of climate change are not likely to fall evenly, and many of the nations affected will have insufficient financial resources to adapt effectively. There is, therefore, an equal need for international cooperation to ensure that no countries are unduly or excessively burdened by the effects of climate change or the costs of adapting to them.

All nations contribute to the greenhouse effect, but the industrialized nations have contributed the greatest share. Moreover, these nations have many of the resources, both financial and technological, necessary to ensure effective adaptation. From this perspective, the industrialized nations have a special responsibility to assist the developing countries that are adversely affected, or likely to be adversely affected, by changing climate.

In some sectors, adaptation may yield some positive economic outcomes (for example, changed climate conditions may enhance agricultural productivity). However, while some opportunities for gain may unfold in coastal areas, they are likely to be relatively uncommon.

THE MAGNITUDE OF FINANCIAL REQUIREMENTS

The Task B report notes that "the special needs of developing countries including their vulnerability to problems posed by climate change and their lack of financial resources must be recognized and assistance tailored to meet their individual needs. Financing requirements might be considerable." The probable quantum of financing requirements is, however, unknown. This applies to the likely costs of funding options of limiting, as well as adapting to, the effects of climate change.

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[1]The Task B activities of the RSWG program focus on measures to implement response strategies or policies. The task includes five specific areas: Legal Measures and Processes, Technology Development and Transfer Measures, Financial Measures, Public Information and Information Measures, and Economic (Market) Measures.

The costs of adapting to the impacts of climate change on coastal areas may include capital investment not only in protective works but also in the maintenance of these works. If sea level continues to rise, the works may have to be replaced or augmented. Similarly, land use planning methods to reduce vulnerability to sea level rise may require constant adjustment to changing conditions. Therefore, it is important to recognize that financial requirements for adapting to climate change may include not only initial costs but also ongoing costs as well. If limitation strategies either are not implemented or fail, the costs of adaptation will grow through time.

One adaptive response is to do nothing. Recourse to this option may be widespread if financial assistance to vulnerable communities is not available. However, under such conditions, there may nevertheless be massive costs in terms of economic and social disruption, possible destruction of property, and, indeed, loss of life. International disaster relief for coastal calamities would become increasingly common. This relief may be needed at the same time that demands on donors are growing for other climate-related hazards, such as drought.

There is an urgent need for a detailed assessment of the costs of the impacts of climate change and of various adaptive strategies for communities at risk. There is also a need for indications of the likely timing of the financial requirements for coastal adaptation.

FINANCIAL RESOURCES FOR COASTAL ADAPTATION

The Task B report on financial measures makes a clear distinction between (1) generating funds for responding to climate change and (2) allocating these funds. It is an important distinction: the generation of financial resources is a generic issue that is not substantially different for any of the response subgroups, be they for limitation or adaptation. However, linking sources of funds to emissions of greenhouse gases may serve as an incentive for limiting emissions. Such an approach should nevertheless take into account that while adaptation may be necessary because of past emissions, linking responsibility for offsetting the costs of adaptation to current "emitters" may especially disadvantage countries that do not have a long history of, and have not yet benefited from, industrialization.

THE GENERATION OF FUNDS

There are a variety of suggestions for the generation of climate change funds, ranging from building on current multilateral and bilateral arrangements and using voluntary contributions to making specific calls for an international fund based on greenhouse gas emissions. The source of funds is a generic issue that is most appropriately addressed in the Task B work of the Response Strategies Working Group. However, the need to provide information on the likely demands on such a fund, its magnitude, and the areas to which it may be applied, is the responsibility of the coastal and terrestrial subgroups. This paper focuses on these issues with respect to coastal adaptation.

Economic and Financial Implications

Funding to assist the adoption of limitation strategies may ultimately serve the common interests of all countries in ensuring that global climate does not change. Such common interest may not be as strong in the consideration of helping individual countries cope with the consequences of climate change. In particular, those countries that contribute little to the problem may have little leverage in seeking assistance.

If the generation of funds is based on greenhouse gas emissions, the size of the fund will decrease as emissions fall. In this event, while the magnitude of long-term climate change may be reduced, the shorter- and medium-term impacts may not be avoided due to lags. Those who must raise financial resources to assist adaptation may have to seek other sources.

ALLOCATION OF FINANCIAL RESOURCES

There are four major issues relating to the allocation of funds: (1) the allocation of financial resources between limitation and adaptive strategies, (2) allocation among the various adaptive strategies, (3) determination of who should receive such funds, and (4) determination of what institutional arrangements are likely to be appropriate.

Limitation versus Adaptation Strategies

Much of the Task B work on financial measures focuses upon the question of promoting limitation strategies. It states that "priority should be given to those financial measures and policies which can have an early impact in reducing emissions of greenhouse gases and which make economic sense in their own right." While the purpose of this paper is to outline the funding implications of coastal adaptation, it is important to note the link between limitation and adaptation. This is portrayed schematically in Figure 1.

Under Scenario A in the figure, in which there is no limitation response and in which global warming does indeed occur, there will be a growing need for financial resources to support various adaptive responses. The demand upon these resources may grow if the area at risk increases over time. Early strategies to deal with predicted changes may prove inadequate if global warming continues unabated beyond the dates used in impact scenarios or for planning purposes.

In Scenario B, limitation strategies are only partly successful in reducing greenhouse gas emissions and thus serve only to slow the rate of climate change. Under this scenario, there will be an early demand for funds to support the implementation of limitation strategies. The financial requirements for limitation strategies will fall as initial technological development is completed, industrial conversion costs are eliminated, and new industrial developments include the strategies as normal processes. The need for adaptation will rise initially at the same rate as outlined in Scenario A owing to lags in the atmospheric and oceanic response to greenhouse gas emissions up to the time when limitation strategies are initiated. At some point, the rate of impacts of climate change and demands upon resources for adaptation to it will slow.

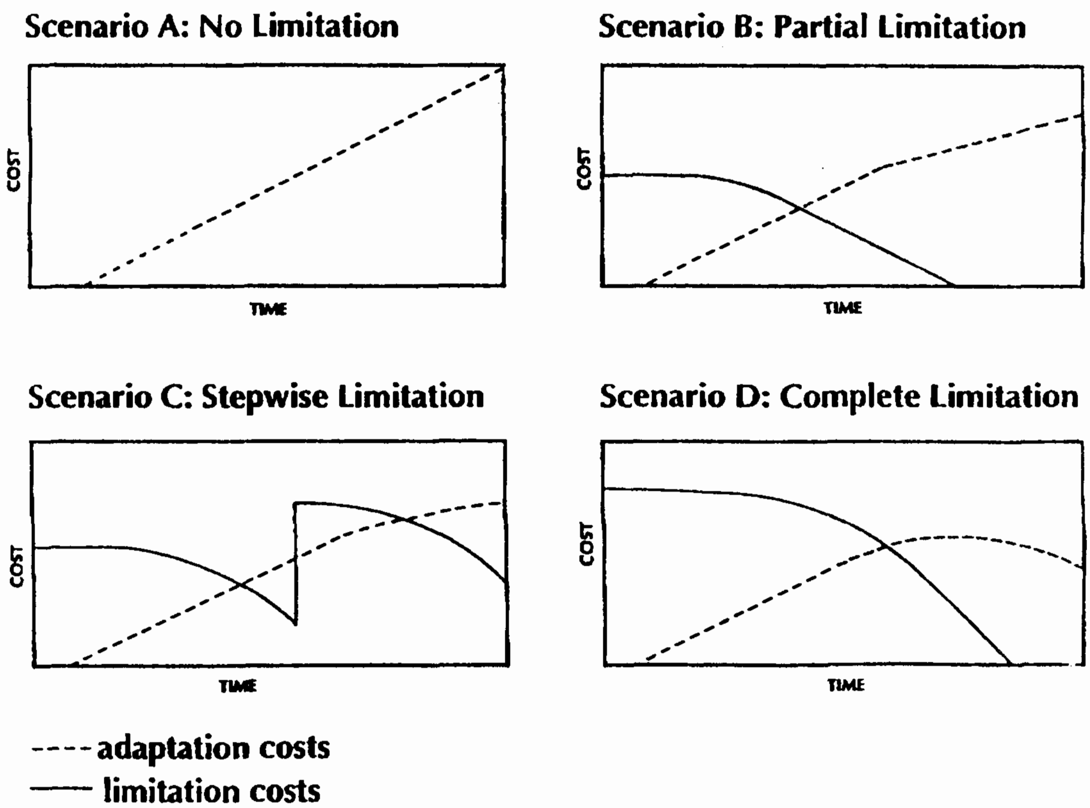

Figure 1. Conceptual timepath of costs for limiting and adapting to global warming for four scenarios on the timing of efforts to curtail emissions. Because adaptation and limitation costs are not necessarily drawn to the same scale, the reader should not attach any significance to the points at which the curves cross.

However, because the limitation is incomplete, demands for resources to enable increasing implementation of adaptive options will nevertheless continue to grow, albeit at a slower rate.

Under Scenario C, limitation strategies are agreed upon and implemented on a step-wise basis. Depending on the completeness of the limitation strategies finally chosen, the demands upon resources to enable adaptation will slow, notwithstanding the lags in the response.

In Scenario D, heavy initial support for limitation strategies sees a stabilizing of atmospheric concentrations of greenhouse gases. While there will still be some demands for assistance for adaptation to the impacts of increases occurring before concentrations are stabilized, adaptation costs will eventually fall. Depending, however, on what point the system stabilizes, there may be an ongoing need to maintain options that have been taken to adapt to a new status quo.

Economic and Financial Implications

The implications of this model of financial requirements are clear. The greater the rate of implementation of limitation measures, the less serious the impacts may be, and the less onerous the burden of coping with or responding to them. It is extremely important that the relative costs of limitation and adaptation are obtained so as to indicate the order of magnitude of financial requirements for the various options.

Moreover, there is no current certainty as to what the effects of climate change will be on coastal areas and indeed what the time frame of their occurrence will be. It is therefore important, given this uncertainty, that immediate emphasis be on limitation, and funds should be allocated accordingly.

Funding Needs for Coastal Adaptation

If strategies to limit the emissions of greenhouse gases are successful, the destructive impacts upon coastlines may be reduced. However, there is considerable concern that even if limitation strategies do succeed, the climate change already set in motion will take its toll. Moreover, initial limitation efforts are likely to only partly reduce the rate of atmospheric change.

Consequently, there are some urgent requirements for coastal adaptation:

- improving scientific understanding of climate change, sea level rise, and other effects, such as tropical cyclones;
- monitoring sea level and coastal changes;
- undertaking vulnerability studies to identify those areas most likely to be prone to the effects of sea level rise;
- conducting site-specific impact assessments, especially in areas considered to be vulnerable to sea level rise;
- initiating public education, forward planning, and consultation among communities likely to be affected by the coastal impacts of climate change;
- investigating into and developing the full range of coastal adaptations, including nonstructural or nonengineering option; and
- providing information transfer of existing coastal adaptation strategies and training professionals in implementing them.

It is equally important to foster adaptive strategies that will be of benefit even if there is no change in sea level. Such strategies include the following:

- improving the disaster preparedness of vulnerable areas; and
- fostering sustainable coastal management programs in all areas.

International development agencies involved in funding projects in coastal areas should ensure that the projects foster sustainable coastal development.

There is a need to establish the level of assistance required to meet these initial priorities for coastal adaptation. An indication of probable long-term funding requirements is also necessary. We expect these long-term requirements to be much greater than the initial needs. Because the need for funds is likely to substantially escalate, it may be appropriate to begin now the process of developing such a fund.

Criteria for Allocating Funds

If financial requirements are extremely high, demands for assistance may exceed the funds available. Thus, criteria for allocation of funds may be necessary. Such criteria may include both evaluation of the recipient's requirements and assessment of the adaptive option being promoted.

The scale of financial resources needed may vary considerably, depending on the nature of the adaptive option and the area and impact being addressed. While considerations of cost-efficiency should apply in deciding priorities for allocation, the social, cultural, and environmental implications should not be ignored.

The following is a list of possible criteria that could be incorporated.

<u>The Recipient</u>

- Financial resources to the recipient;
- Contribution of the recipient to the greenhouse effect;
- Importance of the area at risk in a national context:
  - proportion of national land area at risk;
  - population of area at risk;
  - economic importance of area at risk;
  - social, cultural, and ecological importance of area at risk; and
  - threat to national sovereignty.

<u>The Proposed Adaptation</u>

- Cost of adaptive option;
- Effectiveness of adaptive option;
- Impacts of adaptive option:

- social,
- economic,
- ecological, and
- cultural.

• Sustainability of adaptive option, taking into account the likelihood of continuing climate change impacts, including sea level rise.

Since the greatest need for funds will occur well in the future, there is time for these criteria to be more carefully developed. The complexity of the problem and the lack of any easy answers point clearly to the urgency of ensuring that limitation strategies are adopted promptly.

Institutional Arrangements

The Task B financial measures paper explores two main options for institutional arrangements. First, existing multilateral and bilateral institutions and arrangements may be built on, and second, new mechanisms, such as an international fund, could be created. In the case of the international fund, the emphasis is on fund generation, with existing institutions maintaining the role of allocation.

Given the wide range of options for the use of funds to respond to climate change, new institutional arrangements may be necessary to coordinate and to ensure that equitable, timely, and effective allocation of resources is achieved. This will help ensure that limitation strategies are widely accepted, and that appropriate adaptation options are widely available.

TECHNOLOGY DEVELOPMENT AND TRANSFER

As with funding questions, much of the discussion to date on technology development and transfer has focused on measures to reduce emissions of greenhouse gases. However, there is also an urgent need for the development of innovative and sustainable adaptive options. These include both technical and nontechnical measures. Similarly, there is a need to train people to undertake and manage adaptation to climate change. Areas where there is such need include the following:

- impact assessment,
- vulnerability analysis,
- monitoring of coastal change,
- disaster preparedness planning,

- engineering, and
- land use planning.

A variety of means of technology transfer can be considered. These include training programs, technology research centers, extension services, technology advisory committees, technology research and development, technology conferences, and pilot transfer programs. The existing multilateral and bilateral arrangements for technology transfer should be strengthened and expanded. And, most important, in developing and transferring technology, the social, cultural, and environmental needs of the nations receiving the technology must be accounted for.

CONCLUSION

Adapting to climate change may require very large financial resources. Some countries will need assistance, particularly those for which coastal impacts will impose an unacceptable risk and those for which adaptation activities will impose an undue burden.

Demands for financial resources to adapt to the coastal impacts of climate change will compete with other response requirements, including limitation strategies and adaptation to noncoastal impacts. There is a need to evaluate the probable magnitude of these financial needs and their timing.

Some time will pass before the coastal impacts of climate change are clearly manifested. There is an urgent need to support limitation strategies in the first instance to reduce the rate of change that is likely to occur. Nevertheless, there will be some immediate needs for anticipatory adaptation, particularly for monitoring, assessing vulnerability, and developing responses. Funding of development projects in coastal zones should encourage options that are sustainable in the long run.

DISCLAIMER

This paper has been prepared as a draft chapter for the Coastal Zone Management Report of the Response Strategies Working Group (RSWG) of the Intergovernmental Panel on Climate Change (IPCC). The purpose of this draft is to stimulate discussion at the Miami meeting of the CZM subgroup of the RSWG to be held in November 1989. As such, it represents preliminary views only. It does not constitute the policy of the New Zealand Government.

This paper was prepared without detailed information regarding the impacts of climate change on coastal areas or information about the range of possible adaptive options and their costs. The information produced in these proceedings, as well as a second conference in Perth, Australia, is expected to contribute to the final version of this paper as a chapter of the IPCC report.

PREPARING FOR SEA LEVEL RISE AT THE LOCAL LEVEL

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ABSTRACT

In 1984, Terrebonne Parish in Louisiana became the first local government in the world to officially recognize the greenhouse effect, sea level rise, and their corresponding economic, social, and cultural implications. With current relative sea level rise rates of 1.03 to 1.30 cm/yr, both immediate and long-term solutions had to be addressed. After nearly 10 years of disjointed and misdirected state and federal activities, these parishes (or counties) realized they would have to undertake the management of their coastal areas themselves. Any program they developed would have to be long term and would require the support of their citizenry. Thus, they fashioned a multi-pronged comprehensive approach.

This paper examines the elements of this approach. The research element includes over 100 reports on the causes and effects of sea level rise and possible local solutions. Education includes billboards, public service announcements, and school curricula. Lobbying includes the creation of a grass-roots, non-profit organization. Funding includes a tax on petroleum extraction royalties. Finally, design and implementation of construction projects relied on improved coordination of local, state, and federal officials.

INTRODUCTION

The landscape of coastal Louisiana has always been changing. The Mississippi River works and reworks its delta plain and inner continental shelf through the combined effects of the constructive and destructive forces of the delta cycle and fluctuations in sea level. Through the last phases of the Holocene transgression, the mighty Mississippi built six major delta complexes. Today, active delta building occurs in only 20% of the delta plain and is restricted to the Balize delta of the Modern complex and the Atchafalaya delta complex. The remaining 80% of the delta plain consists of four abandoned delta complexes (Penland et al., 1988). It is these abandoned delta complexes that provide us an excellent living example, sped-up in geologic time, of the impending effects of sea level rise in other, more stable, coastal environments.

The apparent and relative rise in sea levels will affect the physiography and the social structure of the coastal areas. Examined herein are the physiographic changes resulting from relative sea level rise within the south-central region of Louisiana and its inhabitants' reaction thereto.

LOUISIANA'S PHYSIOGRAPHY

The landscape of south-central Louisiana is dominated by abandoned distributaries of the Mississippi delta complex. The southern two-thirds of the region is dominated by southward radiating, abandoned distributaries, and their associated interdistributary basins. At the Gulf of Mexico lie two barrier shoreline systems: the Isles Dernieres and the Lafourche. The northern one-third of the region is bisected by the active channel of the Mississippi River and its abandoned back swamp habitats. Lake Pontchartrain lies at its northern border.

Because the region is being influenced by the abandonment and transgressive phase of the delta cycle, rather than the progradation phase, it is experiencing the accelerated effects of a global sea level rise. The combined effects of subsidence and sea level rise are termed "relative sea level rise." Penland et al. (1988) define relative sea level rise as the long-term, absolute vertical relationship between land and water surfaces, excluding the short-term effects of wind and astronomical tides. Relative sea level rise in south Louisiana is controlled by seven major factors: eustasy, geosyncline downwarping, compaction of Tertiary and Pleistocene deposits, compaction of Holocene deposits, localized consolidation, tectonic activity, and subsurface fluid withdrawal. Although subsidence is the primary cause, the resultant effect of these factors is a regionally recorded rise in relative sea level between 1.03 and 1.30 cm/yr. Potential sea level rise is estimated to be 0.62-2.80 m over the next century (Penland et al., 1988).

The combination of relative sea level rise, the abandonment of the delta complex, and abusive mineral extraction practices has caused drastic landscape changes. Land loss rates have at times exceeded 17 acres a day. One parish, Terrebonne, has had losses of 2,053 hectares (ha)/yr. From 1955 to 1978, this same parish lost 43,314 ha of its land area, while the region's barrier islands have steadily decreased at an average rate of 0.27 km^2/yr (Wicker et al., 1980; Penland and Boyd, 1981; Penland et al., 1985). Specific social impacts of this massive destruction are already apparent.

For example, the potable water supply of the city of Houma, located in Terrebonne Parish and nearly 50 miles from the Gulf of Mexico, has already been contaminated by saltwater intrusion. In neighboring Lafourche Parish, the only north-south highway linking workers to the region's largest Outer Continental Shelf support staging area has been periodically washed out. Also at risk are Louisiana's vast, unique wetlands, which are a natural factory for the production of renewable resources. Louisiana's annual production value for shrimp is $50 million; oysters, $4 million; menhayden, $80 million; fur and hides, $8 million; and recreation, $175 million. Also at risk is the region's property, infrastructure, homes, and businesses, with a total 1987 assessed value of $1,301,048,653 (Louisiana Tax Commission, 1989).

Until the 19th century, settlement of south-central Louisiana was sporadic. The population consisted entirely of Native Americans until the early 1700s. White settlers explored the Lafourche area in 1699. Throughout the 1700s, Spaniards and Germans from New Orleans and French Canadians from Nova Scotia settled the area. They sought the solitude and bountiful harvests of the bayou/marsh/swamp environment. These early settlers understood, however, the seasonal cycles of the region. Thus, they built their homes on stilts, migrating seaward and then back inland with fluctuations of the local relative sea level.

Today, 310,626 people inhabit the six-parish area of south-central Louisiana. They produce the nation's largest shrimp catch and the second largest oyster catch, and contribute substantially to the state's ranking of second in oil, first in natural gas, and first in North America's fur and hide harvest. The infrastructure to support these basic industries and their associated extraction activities is substantial. Due to the region's unstable near and subsurface conditions, the cost to construct new infrastructure and maintain existing service is high: a new four-lane, poured-concrete highway can cost in excess of $3 million per kilometer. Maintenance and protection of existing services, residents, and businesses is further complicated, since 85% of the 4,682-square-mile region is open water or wetland habitat. The remaining 15% is situated at elevations between 0.5 and 5 meters above mean sea level. Nearly half of the region's residents live in areas less than 3 meters above mean sea level. Other factors further exacerbating the effects of relative sea level rise include the leveeing of the Mississippi River and the damming of Bayou Lafourche, the uncontrolled and capricious dredging of canals for access to oil fields, the water dependency of the region's industrial and commercial base, the influx of ranch-style homes placed on a poured slab at natural ground level, and hurricanes.

One must ask, why do the people continue to stay? Is not retreat the answer? In coastal areas developed with resorts, retirement homes, and guest houses, this very well may be the answer. But, in coastal Louisiana, the majority of the residents' livelihood is directly or indirectly tied to its resource extraction and processing industries. Because of the massive size of the delta plain and the inner and outer continental shelf area, the resource extraction activities must be located within the delta itself in order to efficiently extract the resource. As long as consumers demand these resources in the market place, an abundant labor supply must likewise reside within the delta to avoid lengthy commuter trips and costly highway infrastructure to move them in and out of the delta. Similarly, and until the market dictates otherwise, selective protection of the infrastructure and the delta's productive estuary must be accommodated. Eventually, the river and the sea may very well win this battle. However, barring major catastrophes, the region's inhabitants and its industries will continue to retreat gradually, as is already the case.

PAST EFFORTS TO CONTROL FLOODING

Louisiana's first attempt to protect its people and industries began after the great Mississippi River flood of 1927, which displaced thousands of residents and destroyed many businesses. Upon surveying the damage, President Coolidge called for the construction of massive guide levees along the entire course of the Mississippi River. At the time, we did not realize that this effort triggered the massive destruction of the delta. No longer was the river to flow freely and nourish its resource-producing habitats. While the levees provided protection from riverine flooding, nothing was done to protect residents against coastal flooding until much later in the century.

Between 1927 and 1970, the U.S. Army Corps of Engineers became obsessed with controlling the river. All efforts were focused on navigation, river flooding, and backwater flooding caused by the decreasing slope of the river channel. In later years, the Corps built several diversion structures along the river's course, but these too were designed to protect against flooding, and not to enhance habitat.

Midway through the century, spurred by the development of the submersible drilling platform, the rush for black gold exploded throughout Louisiana's wetlands. With all attention focused on the oil boom, little notice was given to the initial destruction of the delta, except in close scientific circles and by residents of the lowest-lying areas. Attention was first drawn to the wetlands by the destruction caused by the now well-defined network of dredged oil and natural gas access canals. Probably not until the mid 1960s and early 1970s was the massive ongoing destruction of the wetlands and endangerment to communities beginning to receive public attention and debate.

Ultimately, as a result of the nation's Coastal Zone Management Act, by the late 1970s the state government began to examine the problems of the delta. In 1978, the Louisiana Department of Natural Resources (DNR) completed its draft Coastal Zone Management Program, including the option for local program participation by the coastal parishes. The state's program was approved in 1980. However, the local programs have been developing slowly, because the state refused to relinquish control of regulating oil and gas activities. These activities were considered uses of state concern. To date, only a few parishes of Louisiana's 19 coastal parishes have agreed to the state's regulatory role and have gained approval of their local program. In addition, the Department of Natural Resources has denied only a few applications for dredging in the wetlands. Even today, permits allowing the dredging of access canals and flow lines through the marsh are routinely approved.

As a backdrop to the rubber-stamp regulatory system of the Army Corps and the DNR, until recently lines of communication between various state and federal agencies with interests in the coast were restricted, and coordination was practically non-existent. Even within DNR, conflicts occurred between regulation and the revenue-producing benefits of exploration and production. Communication was so poor that as recently as last year, the Louisiana Department of Economic Development was heavily recruiting the location of a seafood processing plant whose fish product was currently under strict quotas by the Department of Wildlife and Fisheries.

In 1982, in response to public outcry, the Louisiana state legislature passed the state's first Coastal Environment Protection Trust Fund, which was funded with $35 million, and a project priority list was submitted. None of these projects was ever fully implemented because of heated scientific debate over the proper way to preserve and protect barrier islands and wetland habitats. In 1987, the fund was dissolved and was placed in the state's general fund to help balance the ailing budget.

Meanwhile, the Corps was catching up on research on the benefits of wetland and barrier system habitats. It proposed several wetland-nourishing freshwater diversion projects off of the Mississippi River. None of these projects was constructed, however, because of general apathy by area congressmen and the state government. Now that the projects have received congressional authorization, the state cannot meet the new requirements of local cost sharing.

While the state and federal effort stumbled along for nearly ten years, a quiet storm was brewing down in the bayous.

DESIGNING THE LOCAL PROGRAM

In the early days of Coastal Zone Management, local governments and their citizen advisory committees conducted the majority of technical research for use in the development of both the state and local plans. This early research and their knowledge of their local environment gave local governments and their citizenry an edge on what was best for their specific situations. Therefore, frustration grew over the slow and disjointed reactions of state and federal governments. Because these same coastal parishes received millions of dollars in royalties and taxes for oil and gas activities, many decided that if the problems of relative sea level rise were to be solved, they would have to go it alone, at least initially.

Terrebonne, the wealthiest parish, mounted the largest local effort. By 1980, Terrebonne funded and produced the state's first comprehensive environmental assessment and land loss study. Terrebonne's early quest for information helped spark scientific curiosity. Its research grant program helped develop the state's excellent coastal and marine research centers. Efforts were not always focused on research, however, as skirmishes with state and federal agencies were frequent. In 1983, the parish organized a monumental citizen-based attack against the Army Corps of Engineers, protesting the proposed extension of the Atchafalaya River's east guide levee. No one could believe the Corps would repeat the mistake that was made on the Mississippi River by preventing the freshwater and nutrients of the Atchafalaya River from entering Terrebonne as a result of the construction of the levee.

By 1984, Terrebonne Parish was fully aware of its problems and possessed the knowledge to solve most of them. But it knew that the resources to retard the destruction of the delta were not available unless the state and federal agencies were coordinated and properly funded. In the fall of 1984, Terrebonne officially recognized relative sea level rise as a threat to Louisiana and its people and developed a comprehensive approach to problem solving.

The key elements of the comprehensive approach are research, education and public support, lobbying, funding, and construction.

Hundreds of research papers and studies have been completed under the cooperation and coordination of local and state governments, the state universities, and the private sector. Today, this research effort continues. Armed with this research and the collective knowledge they represented, the citizens of Terrebonne recognized any effort to combat problems of such magnitude as coastal erosion, land subsidence, and sea level rise was going to be long-term and expensive. To maintain such an effort, they also realized they needed full public cooperation and support. In an effort to generate such cooperation, the Parish embarked on a major educational program.

In 1983, the Parish government developed two slide shows on the Parish's economy and the environment. These slide shows were distributed to civic organizations, schools, and congressional offices. To supplement the slide shows, the Parish developed three brochures for distribution to the general public and the public school system. Billboard posters were designed to convey the importance of preserving our barrier islands and marshes. Several of the posters were periodically displayed on area billboards. A barrier island foundation was organized to encourage and support the coordination of efforts to protect and preserve the Parish and its inhabitants. Finally, the Parish government, in cooperation with the Parish school board, developed and implemented an eighth-grade curriculum dealing with the subjects of geology, the environment, renewable and non-renewable resources, erosion problems, and solutions. The intent was that by educating our youth, they would grow and live within the Parish with a new sense of values for their environment and its productive potential. The Parish also realized the first eighth graders educated would be of voting age in ten years and might be instrumental in supporting a Parish tax for preservation purposes.

Several years later, Lafourche Parish followed suit. Like Terrebonne, it also developed brochures on the impending threats of sea level rise, and developed its own seventh grade curriculum for implementation in the school system. Today, both school boards continue to use the environmental curricula, which have proven to be very beneficial, not only to the students but to all of the residents of the region.

By 1985, Terrebonne Parish locally funded and constructed the state's first barrier island reconstruction project. The $850,000 project was designed on natural coastal processes and consisted of rebuilding 35 acres of island by reconstructing the foredunes, elevating the island, and planting natural vegetation. To date, it has survived five hurricanes and is the state's most successful and cost-effective island project.

Next, Terrebonne realized that in order to receive the millions of dollars required to correct its problems, a lobbying effort would have to be launched, demanding that state government draft and subsequently pass legislation. In the fall of 1986, the Coalition To Restore Coastal Louisiana was formed. The intent of the Coalition was to fashion a broad-based, grass-roots support mechanism to educate both the citizens and the politicians on the actions that would be required to preserve our valuable wetlands system. Terrebonne Parish provided a portion of the seed money necessary to allow the Coalition to develop, and in January 1988 the Coalition was incorporated. The Coalition immediately began working with key legislators and many friends of the coast to spearhead the passage of two environmental bills: one to establish an administrative structure to restore Louisiana's coastline, and the other to provide funding for the restoration projects.

Although in 1984 we thought by educating our seventh and eighth graders it would take ten years to win citizens' support for legislation and funding, it in fact only took five years, and both bills were passed in 1989 by the Louisiana legislature. Senate Bill 26 established the administrative structure designed to enhance coordination and cooperation among the state's various agencies. The bill created a task force of state and federal agency heads and Governor's office appointees to oversee wetland restoration efforts. It also created an executive assistant to the Governor who has the authority to coordinate efforts among the various agencies. The Office of Coastal Restoration and Management within the Department of Natural Resources will serve as the primary agency responsible for implementing the state's coastal, vegetative, wetlands, conservation, and restoration plan. Although the new law overcomes the state's past history of conflicts over agency turf battles and conflicting mission statements, the Louisiana Shore and Beach Preservation Association is disappointed with the low priority given to measures for stabilizing the beaches of the barrier islands. Efforts are currently under way to rectify this problem.

With the administrative structure in place, the next task was to secure funding. Senate Bill 25, also passed by the Louisiana legislature in 1989, submitted to the voters of Louisiana a constitutional amendment to create the Wetlands Conservation and Restoration Fund. Revenues for the fund would come from the state's mineral revenues.

On October 7, 1989, the citizens of Louisiana passed the constitutional amendment. The Restoration Fund created by the amendment will derive its funds from revenues received each fiscal year from the production and exploration of minerals, severance taxes, royalty payments, and bonus payments on rentals after previously dedicated allocations have been made. For the first year (1989), this was to be between $5 million and $40 million. Annually thereafter, the Fund will receive $10 million when the mineral revenues reach $600 million after allocations, and another $10 million when the revenues reach $650 million. The fund is not to exceed $40 million at any given time.

The final phase of the multi-pronged comprehensive approach to problem solving involved construction activities. With the passage of Senate Bill 25, the constitutional amendment, and the creation of the Wetland Conservation and

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Restoration Fund, monies were in place to begin construction phases. Initially these funds will be used as the local cost-sharing match for the U.S. Army Corps of Engineers' freshwater diversion projects along the Mississippi River. Battle lines have already been drawn, however, on the appropriate usefulness of this expenditure. Many realize that the massive costs of these diversion projects far outweigh the benefits derived. Although a small portion of the Fund will be used for marsh management practices, many feel more emphasis should be placed on barrier island stabilization projects.

CONCLUSION

In conclusion, the success of Louisiana's efforts was based on undertaking strategic planning efforts aimed at problem solving. Under a strategic planning process the following steps are followed. First compile a situation audit (assemble the data base). Next, analyze strengths, weaknesses, opportunities, and threats. Then develop action strategies to overcome weaknesses and threats and to facilitate opportunities and strengths. Within this process, ultimate success relied upon improved communications, mutual support, self help coordination, research, education, and coordinated lobbying. If local citizenry is reluctant to accept the consequences of sea level rise or fails to understand the implications, religion can be a very helpful tool. Most religions of the world have the stewardship of the earth's resources within their foundation. Use churches, mosques, synagogues, and temples to express the importance of stewardship.

Although south-central Louisiana's work has just begun, this effort has instilled hope when just a few years ago there was no hope at all in addressing the implications of sea level rise.

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TOWARD AN ANALYSIS OF POLICY, TIMING, AND THE VALUE OF INFORMATION IN THE FACE OF UNCERTAIN GREENHOUSE-INDUCED SEA LEVEL RISE[1]

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ABSTRACT

The paper has three thrusts. In the first, a methodology is constructed by which researchers can (1) evaluate the relative economic efficiency of various responses to some climate change effect based upon the best current information, (2) anticipate the most appropriate timing of those responses, given current information, and (3) assess the value of future information, which might alter both their timing and their relative social value. The second focus will highlight the preliminary results of applying the methodology to anticipating the decision of how best, if at all, to protect Long Beach Island, New Jersey. The application will rest, in part, on economic vulnerability data collected as part of a national sample. A third distinct section records comparable data from other sites taken from that sample. Concluding remarks emphasize the general insights to be drawn from the methodology and its application to Long Beach as well as the data requirements for more widespread application. Of particular note, here, is the need to move past economic vulnerability to opportunity cost in producing the requisite measure of the benefits of protection.

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Economic and Financial Implications

The effects of greenhouse warming are likely to be widespread, but our current understanding of their ultimate social, economic, and political impacts is clouded with enormous uncertainty. There is, for example, a wide range of estimates for greenhouse-induced sea level rise reported by various researchers over the past five years. In light of this disagreement, the U.S. EPA (U.S. EPA, 1988) puts our best guess for greenhouse-induced sea level rise through the year 2100 somewhere between 50 and 150 centimeters. Researcher De Q. Robin (1987) expands that range, expecting anywhere between 20 and 165 centimeters. Schneider and Rosenburg (1989) are more conservative, suggesting a range of 10 to 100 centimeters, but others still contend that a 2- to 4-meter rise cannot be ruled out (see Titus, 1989). Thus, the fundamental question in responding to sea level rise and to other dimensions of global climate change is one of determining if any response should be undertaken or even anticipated, given that we are so unsure of exactly what the future might hold -- a question of very long-term decision making and anticipation under conditions of enormous uncertainty for which we currently "have (no) workable guidelines" (White, 1989).

Response to climate change could be averting or adaptive (see Lashof and Tirpak, 1989). Evaluation of the efficacy of any averting response, even though it would have to be imposed globally, should certainly be based upon some measure of regional effects scattered around the globe, and should certainly include the potential of complementary adaptive response. Adaptive response would most likely be enacted on a local or regional level, so perhaps even more detailed measures of region-specific effects would be required. In either case, analysis of possible reaction to the threat of climate change must be soundly based on an understanding of local and regional consequences (see McCracken et al., 1989).

Returning to sea level rise, the relative merits of various adaptive responses must be evaluated on the basis of the local economic and social ramifications across the full range of possible global sea level scenarios. They should, therefore, depend upon a vector of site-specific characteristics: the geographical distribution of developed and undeveloped property, the value of that property, the potential for moving and/or protecting that property, the underlying trends in natural subsidence, and so on. They should also depend upon variables whose influence extends well beyond the boundaries of the specific site -- e.g., scientific parameters that relate concentrations to global warming, warming to climate change, and climate change to land-based ice melt and the thermal expansion of the oceans. Expressed most efficiently, the local reflection of global sea level rise should be summarized in terms of time-dependent and scenario-contingent subjective distributions of potential economic cost based upon our best <u>current</u> understanding of the underlying uncertainties and correlations.

It should be clear, however, that restricting attention to current understanding will reveal only part of the story. We will certainly learn more about what the future holds as we move forward in time, so a second, derivative question arises: one of determining the value of future information and its effect on the relative efficacy of our response options. It could be "orthogonal" (providing indirect information about a critical state variable by improving our understanding of the likely trajectories of the underlying, driving variables) or it could be "Bayesian" (providing increased understanding of a critical state variable by directly monitoring its trajectory). In either case, it should be expected that the value of such information should be different for different anticipated policies, and its assimilation could easily alter relative efficiency within the entire set of possible options.

Therefore, a thorough analysis of the response anticipation problem requires a methodology by which we can accomplish the following:

- produce a ranking of alternative response options, given current information;
- suggest the anticipated timing of those options, given current information;
- suggest how the ranking and timing results based on current information might change in the future as we learn more about what might be happening;
- evaluate the economic value of new information for each policy;
- evaluate how new information might alter the ranking and timing of potential responses; and
- suggest directions for which the results of future scientific and social scientific research might be most valuable.

Only by making progress in handling these tasks will we be able to begin to answer more fundamental questions of timing and planning. Can we, for example, wait to respond to climate change, or must we act now? If we choose to wait, what should we do in the meantime? Should we plan to deal with the extreme possibilities of climate change, or can we focus on responding to our best guess at what the future will bring? Will adaptive response be endogenous to the system, or should we anticipate a need to make conscious decisions at some point in time?

A FORMAL CHARACTERIZATION OF THE RESPONSE PROBLEM

Let the future trajectory of some vector of state variables $\mathbf{y}_t = \mathbf{y}_t(\theta_t)$ be distributed at each point in time according to $f_t[\theta_t]$, with θ_t representing a vector of random variables that produce long-term stochastic effects on $\mathbf{y}_t$. Let the cost associated over time with $\mathbf{y}_t$ be reflected by $C_t = C_t\{\mathbf{y}_t(\theta_t)\}$. Any action or sequence of actions $a_t[\mathbf{y}_t(\theta_t)]$ taken in the future in response to $\mathbf{y}_t$ will involve some stream of expenses $\phi_t\{a_t[\mathbf{y}_t(\theta_t)]\}$ and achieve a corresponding stream of benefits equal to the cost avoided at any point in time:

$$r_t\{\mathbf{y}_t(\theta_t);a_t[\mathbf{y}_t(\theta_t)]\} = C_t\{\mathbf{y}_t(\theta_t)\}-C_t\{\mathbf{y}_t(\theta_t)\,|\,a_t[\mathbf{y}_t(\theta_t)]\}.$$

The expected value of the present value of some (or series of) responses spread into the future, computed at time t_o with a social discount rate β, is then simply

$$E\{PV[a_t;f_t(\theta_t)]\} = \int_{t_o}^{\infty}\int_{t}[r\{\mathbf{y}_t;a_t\}-\phi\{a_t\}]f_t(\theta_t)d\theta_t\, e^{-\beta t}dt. \qquad (1)$$

$E\{PV[a_t]\}$ should, in principle, be the appropriate statistic with which (1) to rank potential responses to various possible trajectories for $\mathbf{y}_t$ and (2) to evaluate the best timing of those responses <u>given the best information currently available</u>.

A RANKING PROCEDURE

The expression recorded in Equation 1 is, of course, extremely general -- almost so general that it is useful only as a symbolic representation of the correct objective function. Thinking about the structure of most responses can, fortunately, produce a more illuminating formulation. To see how, recall that we are considering strategies for future responses armed only with a collection of subjective distributions of the state variables $\mathbf{y}_t$ and an imperfect understanding of how the underlying random variables θ_t will drive them into the future. Many responses will, however, be triggered in practice only when certain state variables cross specific critical thresholds. These thresholds will be crossed at time uncertain in the future, but many can be identified even now. In the case of sea level rise, the threshold for building a new bulkhead or for moving a certain structure might be an increase in the mean spring high tide of 45 cm (or 55 cm or 100 cm, depending upon the site). It makes sense, as a result, to focus on the orthogonal conditional distribution $g_c(t)$ of timing for crossing some given threshold y_c.

Returning now to the formal problem, consider a univariate vector of state variables, and let the structure of the planning process suggest a partitioning of the range of $g_c(t)$ into intervals $\{I^t_1,...I^t_n\}$. There exists a corresponding partitioning of the range of sequences of the θ_t, which bring y_t across the threshold within the specified intervals I^t_t. Let that partitioning be given by $\{{}_1\theta_t,...,{}_n\theta_t\}$. The partitioned expected present value respresented in Equation 1 can then be written

$$EP\{PV[{}_1a_t,...,{}_na_t;f_t(\theta_t)]\} = \int_{t_o}^{\infty}\int_{{}_i\theta_t} \Sigma[r\{Y_t;{}_ia_t\}-\phi\{{}_ia_t\}]f_t(\theta_t)d\theta_t\}e^{-\beta t}dt, \quad (2)$$

where ${}_{i}a_t$ represents the response that would be anticipated in partition ${}_{i}\theta_t$. For perfectly endogenous responses, there is no difference between Equations 2 and 1; the partitions simply produce a distinction with no content. For other responses whose timing and magnitude are critically dependent upon speed and momentum with which the threshold is reached and passed, however, there is a potentially significant distinction.

To see why, let some response be generically defined and represented by a_t. Implicit in the definition of a_t are issues of both timing and scope, so ${}_{i}a^*_t$ can be thought to represent the best configuration of action a_t that can currently be anticipated, given that y_t is expected to cross the threshold in interval I^t_i. If we are forced to anticipate enacting one response strategy based on current information, then we should rank each according to the discounted values of expected net welfare -- i.e., the various ${}_{i}a^*_t$ should be ranked according to

$$E_P\{{}_{i}a^*_t \mid f_t(\theta_t)\} = E_P\{PV[{}_{i}a^*_t, \ldots, {}_{i}a^*_t; f_t(\theta_t)]\}; \qquad (2a)$$

Response ${}_{i}a^{**}_t$ such that

$$E_P\{{}_{i}a^{**}_t \mid f_t(\theta_t)\} \geq E_P\{{}_{j}a^*_t \mid f_t(\theta_t)\} \text{ for all } j \qquad (2b)$$

is thus the best single option of time and scope that can be anticipated, given current information. Note, as well, that Equation 2b can define the best timing of a particular response because the various ${}_{i}a_t$ considered can represent anticipating the initiation of that response at different times.

THE VALUE OF DISCRIMINATING FUTURE INFORMATION

What of future information that allows differentiation across the range of timing intervals prior to the need to begin any response? Equation 2 provides an easy means of sorting out both its effect on the best anticipated response and its resulting economic value. Suppose, for example, future research held out the possibility of uncovering information that would allow us to tell, prior to acting, whether the threshold would be crossed in a subset of early intervals $\mathbf{I}^l = \{{}_{1}I_t, \ldots, {}_{m}I_t\}$ or in its complement set of late intervals $\mathbf{I}^h = \{{}_{m+1}I_t, \ldots, {}_{n}I_t\}$. There is, of course, an equivalent partitioning of the range of θ_t. Repeating the process just described for restricted sets of intervals $\mathbf{I}^l$ and $\mathbf{I}^h$ would then yield two best choices: ${}_{l}a^*_t$ for $\mathbf{I}^l$ and ${}_{h}a^*_t$ for $\mathbf{I}^h$. The expected present value of choosing response strategies contingent upon discovering either $\mathbf{I}^l$ or $\mathbf{I}^h$ would then be

$$E_P\{\mathbf{I}^l; \mathbf{I}^h \mid f_t(\theta_t)\} = E_P\{PV[{}_{1}a_t = {}_{l}a^*_t; \ldots; {}_{m}a_t = {}_{l}a^*_t; {}_{(m+1)}a_t = {}_{h}a^*_t; \ldots; {}_{n}a_t = {}_{h}a^*_t]\}; (3)$$

and the value of the information that provided the ability to discriminate would be

$$E_P\{I^l;I^h \mid f_t(\theta_t)\} - E_P\{_l a^*_t \mid f_t(\theta_t)\} \geq 0 \qquad (4)$$

It is, of course, possible that $_l a^{**}_t = {}_l a^*_t = {}_h a^*_t$, in which case the difference recorded in Equation 4 is exactly zero; but strict inequality should be expected whenever, as should be the rule, $_l a^{**}_t \neq {}_l a^*_t \neq {}_h a^*_t$.

Information that discriminates across the range of possible futures can have value, and it can alter the timing and character of any response that might be anticipated. Constructing a catalog of the best response strategies for a collection of possible distinguishable partitions of sets of intervals $\{I^t_1,\ldots,I^t_n\}$ would provide insight into the sensitivity of anticipated responses, including their timing and their scope, to this sort of new information. Recording, as well, the value of the information that informs those strategies would meanwhile indicate areas of research that would be most fruitful.

THE VALUE OF BAYESIAN LEARNING

The new information considered in the previous section was essentially orthogonal -- performing a discriminating function without influencing the density function $f_t(\theta_t)$. Other types of new information are, of course, possible. A Bayesian learning process could, for example, be envisioned moving along any of the trajectories of y_t that lead to crossing the threshold during some corresponding interval $_i I_t$. Such a process would not influence our current best view of the range and relative likelihoods of threshold intervals, but it would alter future subjective distributions of those intervals. This is clearly information of a different character, but the problem of estimating its value can, in the present framework, be thought of as one of estimating the value of discriminating information that is not perfectly accurate. The key is that future decisions will be based on updated information, and it is those decisions based on future information that must be evaluated, given what we know now.

To model these decisions, let $p_t(\theta_t;t_1;\theta^k_t)$ represent the posterior distribution of θ_t that would be derived in period $t_1 > t_0$, given interim experience consistent with $\theta_t \in \theta^k_t$. Evaluation of any response sequence $_i a_t$ would then, in period t_1, be based upon $E_P\{_k a_t \mid p_t(\theta_t;t_1;\theta^k_t)\}$ for any θ^k_t. Best choices $_k\hat{a}_t$ would then be characterized by

$$E_P\{_k\hat{a}_t \mid p_t(\theta_t;t_1;\theta^k_t)\} > E_P\{_k a_t \mid p_t(\theta_t;t_1;\theta^k_t)\} \text{ for all } {}_k a_t$$

and would define the anticipated response, its timing, and its scope. The current view of the expected social value of the $_k\hat{a}_t$ should, therefore, include their anticipated expected social value, given experiences consistent with $\theta_t \in \theta^k_t$, but weighted by current expectations of the relative likelihoods of the θ^k_t; i.e.,

$$_BE_P\{_k\hat{a}_t\} = \Sigma \int_{\theta^k_t} f_t(\theta_t)d\theta_t \; E_P\{_k\hat{a}_t | p_t(\theta_t;t_1;I^k)\} \qquad (5)$$

should be used to evaluate the present value of using future Bayesian information to inform response decisions.

Notice that the composite expected present value defined in Equation 5 provides direct access to a measure of the economic value of Bayesian information. Compared to Section **IvariableI** case with no extra information in which $_ia^{**}_t$ was selected as the best single option that could be anticipated with current information. The value of Bayesian information is simply $_BE_P\{_k\hat{a}_t\} - E_P\{_ia^{**}_t | f_t(\theta_t)\}$. It should be non-negative, of course, because $_ia^{**}_t$ was a choice in the decision process characterized in Equation 5. It could be zero, though, if the Bayesian process produced too little information, because the posterior distributions would then nearly match $f_t(\theta_t)$ and the $_k\hat{a}_t$ would all match $_ia^{**}_t$. It could also be zero if the cost and benefit schedules implicit in the definition of both $_BE_P\{-\}$ and $E_P\{-\}$ were linear.

Generating catalogs of the sort suggested at the end of Section III should be able to produce the same sort of sensitivity and value insight for anticipated Bayesian learning as it did for orthogonal learning. Notice that the structure created in here should also be applicable to new orthogonal information that is not perfectly discriminating. In the former instance, we glean some insight into the value of waiting (and learning while we wait); in the latter, we still gain some understanding of where we should be devoting research efforts in the meantime.

APPLICATION TO PROTECTING LONG BEACH ISLAND

Long Beach Island, a barrier island lying off the shore of New Jersey, is approximately 23 miles long and varies in width from roughly 1,000 feet to slightly more than 3,200 feet. Except for dunes on the ocean side, almost all of the island lies within 10 feet of sea level. It is, nonetheless, heavily developed, with total property value generally put in the neighborhood of $2 billion (1989$). Data have been developed reflecting both the economic vulnerability of the island in the absence of any protection (Yohe, 1989) and the cost of employing three different protection strategies (Weggel, 1989).

This section applies the analytical tools developed above to these data to evaluate the relative efficacy of two of the options investigated by the EPA: (1) raising the island as the sea level rises (an endogenous response), and (2) building a dike and associated infrastructure when the sea level rise crosses a predetermined threshold (a conscious response requiring anticipation and preparation). The rate of sea level rise will be taken to be the critical, random-state variable. The value of orthogonal and Bayesian information will be considered using a distribution of possible sea level rise scenarios drawn from current divergent opinion.

The Data

Table 1 records the total economic vulnerability data reported in Yohe (1989). Tax maps were employed to determine the current value of property (including land and structure) that would lie below the spring mean high tide for various levels of sea level rise. Property that would be in jeopardy because of beach erosion was also included, so the statistics registered in Table 1 reflect a measure of what, as the island now stands, would be "in the way" of rising seawater and its derivative effects. They will, for present purposes, also be taken as a measure of potential economic costs attributable to sea level rise. Of course this procedure will be a source of error, since it ignores the possibility of a wide range of complications: further economic development prior to inundation, property depreciation in anticipation of inundation, etc. The translation of vulnerability data to cost data has not yet been accomplished, however, so vulnerability will simply be employed here as an illustrative "first cut" at potential cost.

Weggel and his colleagues (1989) have produced estimates of the costs involved in protecting Long Beach Island. Raising the island in place given observed sea level rise has three sources of cost: fill (sand available at $6 per cubic yard along a scenario that sets greenhouse-induced sea level rise equal to a 200-cm rise in the year 2100), raising structures (at $5,000 per structure to accommodate the higher ground), and replacing roadways (which must lie on top of the new higher ground). Since these costs are correlated

Table 1. Economic Vulnerability for Long Beach Island

Sea Level Rise (cm)	Incremental Vulnerability ($ million)	Total Vulnerability ($ million)
0 - 15	15	15
15 - 30	40	55
30 - 45	225	270
45 - 60	192	462
60 - 90	381	843
90 - 120	705	1548
120 - 180	385	1932

Source: Yohe (1989)

directly with sea level rise, producing time series of costs for scenarios other than the one that produces 200 cm over 115 years is a simple matter of algebra. The only wrinkle employed in the translation involves the price of fill. A unitary short-run price elasticity of supply was employed, but only for more rapid scenarios. The price of fill would rise if demanded more quickly than anticipated along the 200-cm baseline but would not fall if demanded more slowly (i.e., $6 represents a long- run competitive price equal to a minimum sustainable average cost).

The second option considered here proposes (1) building a dike around the island when sea level rise from any source reaches 43 cm and (2) operating an interior drainage system from that time on. The dike itself was estimated to cost $285 million. Some small cost derived from raising existing bulkheads would be incurred before the dike were brought on line, and expenditures equaling $2.5 million would be required each year to maintain and operate the drainage system. Any scenario of sea level rise would, in this case, imply a planned date for constructing the dike that could be correct, early, or late. If correct, then the stream of costs would be well defined by the Weggel estimates. If the planned date turned out to be early, then policy makers would be prepared early, and could simply wait to build the dike until it became necessary. If the planned date turned out to be late, however, then inundation would occur before the construction of the dike and the drainage system. It was assumed that completion of the dike it would require at least 5 years from the recognition of immediate need, unless completion was originally planned in the interim.

Sea Level Rise Scenarios

A distribution of projected sea level rise attributable to greenhouse warming through the year 2100 was derived from the range of expert opinion reported in the introduction.[2] A log-normal distribution fit the divergence of opinion well, exhibiting a mean of 4.55 and a standard error of 0.88. The one standard error range around the mean increase of 94 cm was therefore taken to be 39 cm on the low side and 227 cm on the high side. A five-cell discrete equivalence of this distribution is provided in Section I of Table 2. For the probability values shown there, the second row shows the time coefficient α_j for each scenario, which drives total sea level rise according to the EPA functional representation:

$$SL_i(t) = .4(t-1986) + \alpha_j(t-1986)^2 \qquad (6)$$

The first term in Equation 6 reflects local subsidence for Long Beach Island of 0.4 centimeters per year, while the second term reflects greenhouse-induced sea

[2]See Nordhaus and Yohe (1983) for a discussion of this technique. It assumes implicitly that every expert estimate is sample point derived from the true distribution; as should be expected, it has been shown, at least in one case, that it tends to underestimate true variability [see Yohe (1987)].

level rise. Table 2 also indicates the year during which the 43-cm threshold for the dike would be passed.

Raising the Island

Raising the island would be a contingency response, defined by Weggel as one of raising structures, raising roads, and adding fill beneath both as needed to keep dry land approximately 40 cm higher than the mean spring high tide. Starting when total sea level rise from 1986 reaches 13 cm, Weggel et al. estimate the volume of sand (in cubic yards) required in year t along a 200-cm greenhouse-induced scenario to be

$$V_{200}(t) = 73534 + 5273(t-1986) + .427(t-1985)^2$$

The 200-cm scenario is, meanwhile, defined by

$$SL_{200}(t) = .4(t-1986) + \alpha_b(t-1986)^2,$$

where $\alpha_b = .01424$. The volume requirement along any scenario j is therefore

$$V_j(t) = 73534 + 5273(\alpha_j/\alpha_b)^{1/2}(t-1986) + .427(\alpha_j/\alpha_b)(t-1986)^2$$

Price times volume then provides the appropriate estimate of the cost of fill as a function of time along any scenario. Similar manipulation of the Weggel estimates of the cost of raising structures and replacing roads (in $ million) produces:

$$CS_j(t) = 13.65(\alpha_j/\alpha_b)^{1/2} + .01(\alpha_j/\alpha_b)(t-1986)$$
$$CT_j(t) = 2.8 + .133(\alpha_j/\alpha_b)^{1/2}(t-1986),$$

respectively. The $C_t(y_t(\theta_t)$ function required in Equation 1 is simply the sum of these three cost components for the specified scenarios.

Representing the benefit achieved by this action at any time along any scenario by the economic value of property preserved by preventing inundation, its net present value is easily computed, given $C_t(--)$. The Section II of Table 2 records these values for the five scenarios identified in Section I for a 3% social rate of discount. The final entry notes the expected net present value computed according to Equation 1. Raising the island is found to be an economically viable option that could be undertaken, depending upon stress exerted on the public budget constraint by other claims to public resources.

Constructing a Dike and Drainage System

Protecting Long Beach Island by constructing a dike and its requisite drainage system would require considerable prior planning and development, a protracted period of construction, a commitment to continuous maintenance after construction, and a future stream of enormous expenditure of public revenues.

Table 2. Expected Present Value of Raising the Island or Constructing a Dike and Drainage System

(1) Policy Description	Scenarios (2) A	(3) B	(4) C	(5) D	(6) E	(7) Expected Present Value
I. Scenario Description:						
Probability	0.1	0.2	0.4	0.2	0.1	n/a
Coefficient	.00144	.00318	.00718	.01595	.03539	n/a
Threshold	2069	2055	2039	2026	2015	n/a
II. Raising the Island	13.0	32.5	129.7	252.6	355.6	145.8
III. Anticipating a Dike in:						
2015	37.4	67.1	157.0	309.2	463.0	188.1
2026	38.7	68.9	158.9	311.9	88.8	152.5
2039	40.8	71.0	160.7	117.6	88.8	115.0
2055	42.0	72.6	52.7	117.6	88.8	72.2
2069	43.4	14.6	52.7	117.6	88.8	60.8

It would require, in short, a wide margin of preparation time. Any current consideration of the economic value of such an option must, therefore, be based upon an anticipation of exactly when a specified threshold of sea level rise will be crossed.

Section I of Table 2 shows the years during which the threshold for Long Beach Island, calculated by Weggel to be roughly 43 cm, would be achieved along five representative scenarios of sea level rise. Since the scenarios were selected to reflect a current subjective distribution of potential sea level trajectories, these years can be viewed as representing the associated distribution of dates at which construction of the dike system must be completed to adequately protect the island. They define, as a result, five representative responses that are differentiated solely on the basis of timing and that span the range suggested by the current subjective distribution of sea level rise.

Columns (2) through (6) in Section III of Table 2 record, for each scenario, the discounted net benefit of anticipating the completion of the dike system for each of the dates listed in Table 2. The diagonal, therefore, shows the maximum discounted benefit for correct timing along each scenario. Figures below the diagonal show the discounted net benefits that should be expected if the critical threshold were breached earlier than anticipated. They are all the same because the dike would be hurriedly completed in the same time frame along each scenario as soon as the threshold passed. Figures above the diagonal similarly reflect the discounted net benefit of being ready too early.

The expected discounted net benefit for each anticipated date of completion, computed from columns 2 through 6 according to Equation 2a, is provided in the final column. These are estimates currently available in the absence of any further information. Ranging from $188.11 (million) for anticipating completion of the dike system in the year 2015 down to $60.77 (million) for planning completion in 2069, they clearly show a marked dominance for planning to take early action. Building in anticipation of the extreme case depicted in Scenario E even dominates the endogenous island-raising response examined in Subsection C (by 22%). The insurance of preparing for the early completion of the dike system, even at the expense of being prepared too early and even given the subsequent expense of actually constructing the dike, is less costly in terms of expected, discounted expenditure than the continuous process of raising the island year in and year out. This relative ranking persists even when a mean preserving 50% contraction in the variance of the lognormal distribution of greenhouse-induced sea level rise through the year 2100 is imposed; it is a robust result.

The Value of Orthogonal Information

Table 3 shows the results of contemplating the discovery of some new information that will, in the future, allow policy makers to distinguish between subsets of the five threshold scenarios listed in Table 2. Each section of the table presents results for a different partitioning of the five-cell discrete distribution of sea level scenarios and records the expected discounted value of anticipating the completion of the dike system at the threshold time indicated, given that a scenario within the partition occurs. In other words, each entry shows the results of applying Equation 2a to a limited range of possible scenarios.

Before reviewing the content of Table 3, it is perhaps prudent to picture exactly what sort of information might accomplish the partitioning modeled there. Better understanding of the thermal expansion of the ocean, better estimation of the correlation between concentrations of various gases and the Earth's radiation budget, progress in identifying the "greenhouse fingerprint," etc., could all be envisioned as opportunities for new insight that would allow us to limit the range of possible sea level futures that we need to consider. That is, each has the potential to rule out certain scenarios in the future which, given today's information, are still plausible. We have no idea whether such information is forthcoming, so there is no reason to adjust the current subjective distribution of sea level scenarios. We are, quite simply, investigating how much it would be worth to us now, if it were to appear sometime prior to the need for any response.

The "Best Year" column in Table 3 shows the best contingent choices for anticipating the completion of the dike system for four partitions. Compared with the uninformed expected present value of $188.11 (million) associated with planning completion by 2015, none appears to be much of an improvement. Computed according to Equation 4, the most valuable partition distinguishes between early and late scenarios at roughly the 70th percentile, returning an expected discounted value of ($190.71 - $188.11) = $2.6 (million). Given the value of perfect discrimination $191.82 (million), though, there was not much room for improvement to begin with.

That is not, however, the entire story. Notice that the expected present value of planning the construction of the dike system changes only slightly in the 25-year period between 2015 and 2039. Information that distinguishes early from late around the 70th percentile could, therefore, ease some of the budgetary pressures that might otherwise be felt by the federal government if its share of the expense had to be committed within a more limited time frame. Devoting some effort to research that might accomplish even this sort of crude division in the potential range of sea level outcomes could, therefore, have some indirect payoff beyond its $2.6 million contribution to expected net benefit. Finally, note that Table 3 suggests a greater payoff to research designed to distinguish rapid sea level rise from slow sea level rise than to research designed to identify the extremes.

The Value of Bayesian Information

The year 2015 is the first threshold year identified above, suggesting a potential waiting period of roughly 25 years during which Bayesian learning might better inform potential response decisions. Steve Schneider has suggested that convergence in our view of the complex effects of climate change cannot be expected over the next two or three decades (Rosenburg and Schneider, 1989). In modeling a Bayesian learning process along any of the five sea level scenarios identified in Table 2, it therefore seems reasonable to assume that experience over the next 30 years can be viewed as supporting observations drawn from a lognormal distribution exhibiting the same variance as today's. Since climatologists look at 30-year intervals to assess and define changes in climate, we can also expect at most the equivalent of one such observation. Representing the current view of the distribution of the natural logarithm of sea level in the year 2100 by $\ln\{SL(2100)\} \sim N(m_o,\sigma_o)$, the result of 30 years of movement along scenario k yielding an estimated $x_k = \ln\{SL_k(2100)\}$ should therefore be a new, contingent distribution $\ln\{SL(2100)\}_k$ $N(m_k,\sigma_k)$ with $m_k = 0.5(m_o + x_k)$ and $\sigma^2_k = (\sigma^2_o\sigma^2_o)/(\sigma^2_o+\sigma^2_o) = 0.5\sigma^2_o$. If the x_k are taken to equal the natural log of the 2100 values indicated in Table 2 and $\sigma_o = 0.88$, then each of the five scenarios must be assigned different discrete probability values consistent with $N(m_k,\sigma_k)$ and contingent upon which scenario defined the 30-year experience from 1986 through 2015.

Table 4 indicates the resulting expected discount values of all six options (raising the island and constructing a dike during the five alternative years) contingent upon the learning that would occur in the first 30 years along each scenario in columns 2 through 6. Each has been computed according to Equation 5a. The final column records the current view of their expected discounted net benefit based on Equation 5b. The figures recorded in column 7 of Table 4 reflect, when matched against the comparable figures in Table 2, our best idea

Table 3. Expected Present Values for Constructing a Dike-Differentiating Information

	Anticipated Year for Completing the Dike					Best Year	Expected Present Value
	2015	2026	2039	2055	2069		
{A} from (B,C,D,E}:							$188.7
{A}	37.4	38.7	40.8	42.0	43.4	2069	
{B,C,D,E}	204.9	165.1	123.2	75.6	62.7	2015	
{A,B} from {C,D,E}:							$189.7
{A,B}	57.2	58.9	60.9	62.4	24.2	2055	
{C,D,E}	244.2	192.6	138.1	76.4	76.4	2015	
{D,E} from {A,B,C}:							$190.7
{A,B,C}	114.2	116.0	117.9	56.9	40.5	2039	
{D,E}	360.5	237.5	108.0	108.0	108.0	2015	
{E} from {A,B,C,D}:							$189.9
{A,B,C,D}	157.6	159.5	117.9	70.4	57.7	2026	
{E}	463.0	88.8	88.8	88.8	88.8	2015	
Complete	43.4	72.6	160.7	311.9	463.0	exact	$191.8

Table 4. Expected Present Value of Response Options After Bayesian Learning

(1) Policy Description	Scenarios (2) A	(3) B	(4) C	(5) D	(6) E	(7) Expected Present Value
I. Raising the Island	64.5	99.1	138.4	195.5	249.4	145.8
II. Anticipating a Dike in:						
2015	96.7	135.5	175.7	248.3	317.9	188.5
2026	90.8	125.7	150.5	184.8	173.2	152.7
2039	79.3	98.5	125.5	115.5	109.6	115.2
2055	60.1	69.1	65.4	85.6	90.4	72.4
2069	41.2	47.9	57.4	76.9	86.3	60.9

of how much Bayesian learning would be worth for each policy, given our current subjective distribution across the trajectories that will be doing the "Bayesian teaching." The differences representing that value, defined by Equation 5c, are small; but that again is a function of both the effective contingency response that was assumed when the dike was anticipated too early or too late and the linearity of the resulting net benefit schedule. The real news buried in Table 4 can be uncovered by noticing that the variation in expected net benefit shown across the rows in columns 2 through 6 is much smaller than the corresponding variation in net benefit of the uninformed decisions of Table 2. An objective function displaying any sort of risk aversion would therefore applaud the results of the Bayesian process.

ECONOMIC VULNERABILITY ELSEWHERE AROUND THE U.S. COASTLINE

Coastal sampling by Park et al. (1989) has resulted in computer-based mapping capability within which the inundation effects of various sea level rise scenarios can be uncovered. Each site in the Park sample is partitioned into square grid quadrants measuring 500 meters (sometimes 250 meters) on each side. A computer run for any site provides, therefore, quadrant-specific effects in 5-year intervals for each scenario, defined not only by an assumed contribution in sea level rise from greenhouse warming (50 cm, 100 cm, etc., through 300 cm), but also by the underlying rate of natural subsidence (recall Equation 6).

Figure 1 shows, as an illustration, the computer maps for Charleston, South Carolina. Panel A depicts the area in its current configuration, while Panel

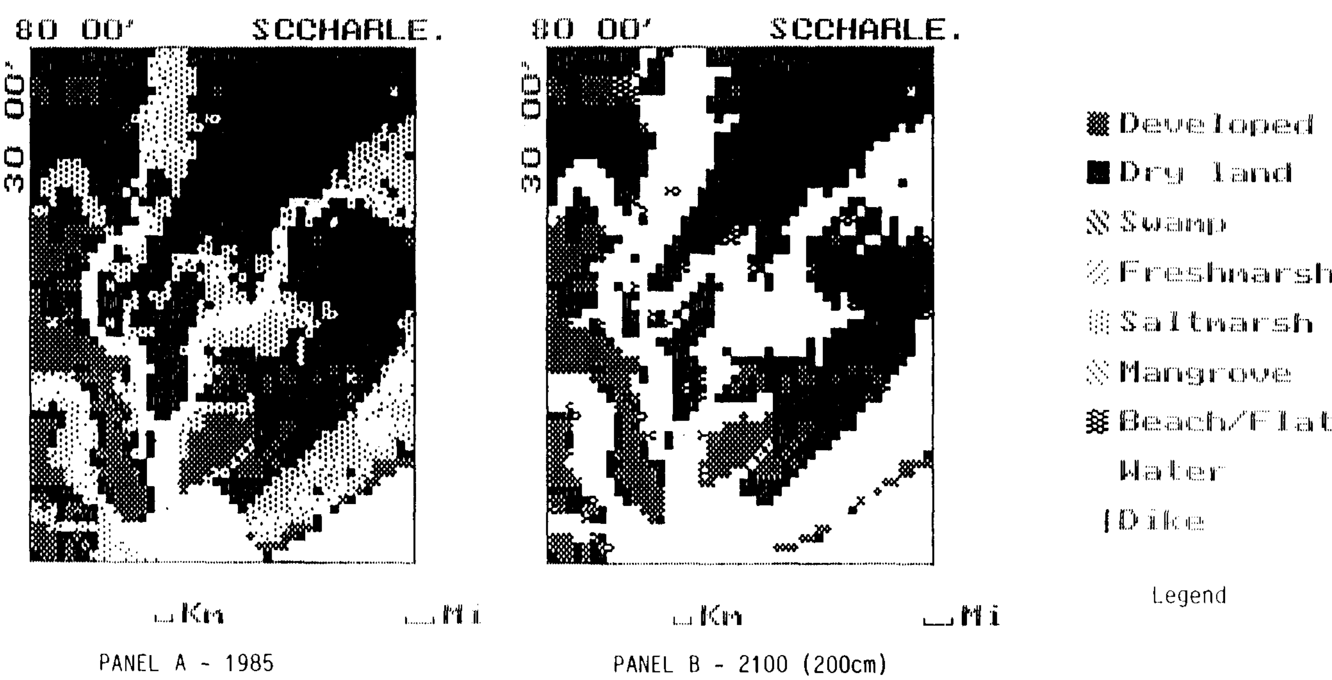

Figure 1. Computer map of Charleston, South Carolina (U.S) showing (A) current configuration and (B) configuration with a 200-cm sea level rise.

Table 5. Economic Vulnerability[a] and Wetland Loss[b] for Selected Sample Sites

Site[c]	0-15	15-30	30-45	45-60	60-90	90-120	120-180	180-240
TXPORTLA (3mm)								
Econ	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11.2
Wetland	0	0	0	0	0	0	0	0
TXPALACI (3mm)								
Econ	0.0	0.0	0.0	0.0	1.3	0.0	0.0	0.0
Wetland	10	80	0	0	5	2	3**	0
LAGRANDC (8mm)								
Econ	0.0	1.4	1.4	4.1	5.4	5.4	1.4**	0.0
Wetland	0	5	10	10	5	10	60**	0.0
LABARATA (9mm)								
Econ	6.1	6.1	9.2	6.1	6.1	6.1	18.4	3.1**
Wetland	0	30	5	5	5	5	40	10**
MSPASSCH (1mm)								
Econ	1.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Wetland	40	60**	0	0	0	0	0	0
FLSTJOSE (1mm)								
Econ	0.0	0.0	0.0	0.0	0.0	0.0	1.6	4.8
Wetland	none							
FLPORTRI (1mm)								
Econ	26.3	0.0	0.0	0.0	0.0	26.1	131	183
Wetland	add	add	10	60	5	25**	0	0
FLMIAMI (1mm)								
Econ	148	295	592	811	1260	1770	7530	4130
Wetland	none							
FLSTAUGU (1mm)								
Econ	2.5	1.1	2.5	15.3	16.5	5.0	24.2	24.5
Wetland	0	5	5	10	80**	0	0	0
STCHARLE (2mm)								
Econ	26.1	34.8	8.7	8.7	34.9	78.6	39.1	65.6
Wetland	10	5	5	75	5**	0	0	0
NCLONGBA (1mm)								
Econ	0.0	1.1	3.4	7.9	0.0	6.7	2.3	1.1
Wetland	0	10	20	65	5**	0	0	0

Notes: [a] In millions of dollars (1989). [b] In percent of current wetlands.
[c] Local subsidence recorded in (parentheses). ** Totally inundated.

B shows the effect of 200-cm greenhouse-induced sea level rise superimposed through the year 2100 upon a 0.2-cm per year natural subsidence. Economic vulnerability, the current value of property which might be in the way of the rising sea, is then accessible for each site from a procedure that computes the average property value for each affected quadrant from tax maps and/or housing and business census data. Table 5 registers the resulting data for a subsample of the Park sites; Table 6 shows our nationwide estimates.

Table 6. National Cumulative Economic Vulnerability to Sea Level Rise ($ billions)

Sea level rise	25th percentile	Best estimate	75th percentile
50 cm	78.4	133.2	188.1
100 cm	165.8	308.7	451.6
200 cm	411.3	909.4	1407.6

CONCLUDING REMARKS

The problem of analyzing the economic value of potential responses to the effects of global climate change is a problem that lies at the heart of decision making under enormous long-term uncertainty. The methodology outlined in Sections I through IV is advanced as a first step in confronting that problem. It appeals to well-established economc tools to provide a means of organizing one's thoughts in face of uncertainty, taking into account not only what we know now but also what we might know in the future, and how we might, in the normal course of events, react to that growing base of knowledge.

Only two new wrinkles in existing theory were employed. It was, first of all, noted that the usual representation of uncertainty with subjective distributions of future state variables at some point in time can, in many cases, be replaced profitably in our thinking by the corresponding orthogonal distributions of time when certain specific threshold values in those state variables might be crossed. In that context, one can investigate the best anticipated timing of some potential response, given the current subjective view of the future, by taking advantage of the second wrinkle: defining a set of derivative responses differentiated only by the time in which they would be enacted. The best anticipated response then defines the best anticipated timing.

The application of the methodology to Long Beach Island also provided some general insight. To the extent that communities can correct any error in anticipating exactly when a given response might be required, new information that can differentiate future states of nature prior to the need to respond will be less or more valuable. That point notwithstanding, however, it is quite possible that the best anticipated response might be to guard against the potential effects of scenarios at the extremes of current subjective distributions. If the cost of being prepared too early is small, then planning as if the future will unfold showing the maximum rate of sea level rise is the best choice.

Finally, the notion that communities will learn about the future as it is revealed should also be considered. This sort of Bayesian learning may provide more or less extra in net expected benefit, depending upon the communities' abilities to correct for errors in anticipation. Nevertheless, it can always be expected to reduce the variance of possible futures at the time of actually initiating a response. Any degree of risk aversion in the evaluation function will, as a result, welcome the opportunity for such learning.

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RISK-COST ASPECTS OF SEA LEVEL RISE AND CLIMATE CHANGE IN THE EVALUATION OF COASTAL PROTECTION PROJECTS

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ABSTRACT

Planning for federal projects designed to protect the U.S. coast can incorporate forecasts of sea level rise and storm frequency changes due to climate change by applying risk and uncertainty analysis techniques. Incorporating future sea level rise and climate change into current projects implies building projects that are too large for existing conditions. In addition, changed future conditions that increase recurring project maintenance costs tend to favor structural-type projects. In terms of planning current projects, the adverse impacts of sea level rise and climate change occur too slowly and too far into the future to have much influence on the choice of the type and scale of coastal protection project. This is especially true given the higher interest rate used in present-value calculations. Therefore, the U.S. is likely to rely on nonstructural, land use management solutions administered by state and local agencies.

INTRODUCTION

The impending threat of climate change and sea level rise has brought calls from various sectors for government institutions to prepare for this creeping natural hazard. The U.S. Army Corps of Engineers is one such federal agency that is responsible for various aspects of a diverse program responsible for water resources and shoreline protection. The Corps recognizes that its activities are likely to be affected by the hydrologic, meteorologic, and oceanographic consequences of global warming and expected climate changes. One response has been the explicit introduction of risk analysis to aid in the evaluation and selection of alternative plans and project components to deal with natural hazard extremes and the mitigation of their social and economic consequences. This formal risk analysis is merely an addition to existing multiobjective evaluation procedures that guide federal water resources development. These procedures are based on a body of social, economic, environmental, planning, and decision theory literature that has been developed over the last 50 years.

Many uncertainties and unknowns are associated with the physical effects of greenhouse warming and anticipated sea level rise. These compound the existing difficulties of planning under conditions of uncertainty regarding future growth, economic development, and environmental effects. The key risk and uncertainty issues facing present-day coastal protection projects are the following:

1. Establishing the proper baseline for evaluating the physical and socioeconomic impacts of sea level rise,

2. the rate and magnitude of sea level rise,

3. the uncertainty of storm frequency and wave regimes under climate change, and

4. the dominant effect of the discount rate.

Sea level rise alone, even with the present weather regime, will logically cause the landward retreat of the shoreline following the Bruun rule (Schwartz, 1967). Weather changes associated with global warming could imply increased variability and intensity of individual coastal storm events, further exacerbating the present conditions of beach erosion and property damage in coastal areas. However, the direction of the intensity and frequency of storm events, is still largely speculative. An additional factor in the proper selection of strategies for societal adaptation to sea level rise and storm frequency is their rates of change. The immediacy of the consequences to shorelines and coastal development will influence the choice of action.

A fundamental question that climate change and sea level rise pose for society is how to effectively cope with the changes that appear irreversible. Many federal, state, and local institutions are currently debating the possible strategies and specific measures for anticipating the most severe consequences and adapting to the inevitable changes. The Corps of Engineers, as one of these institutions, can effectively deal only with protective measures. This paper deals with how the Corps' economic evaluation principles and decision rules influence the choice of a particular shore protection measure in a risk analysis framework. There are many other effective alternative management measures, residing within the responsibilities of the states and local communities, that should be strongly considered in adapting to sea level rise. The range of public measures to mitigate the potential hazards to life and property from sea level rise and climate change will be the same as those available today under "normal" conditions. The probable difference will be that the emphasis on alternative management strategies will change to reflect the reality that the baseline condition is changing. Thus, it is likely that shore protection strategies would shift from protective measures such as groins, bulkheads, seawalls, and beach nourishment to land use modification measures, which limit investments in and subsidies to hazard-prone areas through regulation and disinvestment strategies, such as transferable development rights and the use of financial incentives and tax deductions.

AN OVERVIEW OF ECONOMIC EVALUATION PRINCIPLES

The federal government has a long history of planning coastal protection projects. By providing protection against the hazard, efficiency gains can be achieved that result in an increase in the national output of goods and services. There are also additional regional and local economic gains that result from the transfer of economic activity from some other location. The identification and measurement of the national efficiency gains follows benefit-cost analysis procedures developed, to a significant extent, to evaluate the national economic implications of federal investments in what are inherently local water resource projects. These procedures are codified in the "Economic and Environmental Principles and Guidelines for Water and Related Land Resources Implementation Studies (Principles and Guidelines)" (Water Resources Council, 1983).

Adaptive responses to sea level rise are generally the same as those considered for existing coastal erosion problems. These can be classified into four approaches or options:

1. Hard engineering options -- bulkheads, groin fields, seawalls, revetments, and the elevation of the shoreline and structures;

2. soft engineering options -- beach nourishment and dune stabilization;

3. management options -- set-back requirements, restrictions on land development and land use; and

4. passive options -- no systematic response, allowing the coast to erode, with private attempts to protect individual property.

Coastal protection projects, like all investments, involve spending money today to gain predicted benefits in the future. In addition, many types of projects, particularly the beach nourishment, maintenance type, require the commitment to future spending to maintain the project. This future aspect requires that the current and future dollar costs and benefits must be compared in a common unit of measurement. This is typically in terms of their present values or the average annual equivalent of their present values. Therefore, the discount rate used to determine the present values influences the economic feasibility of alternative projects. It is well known that large discount rates reduce the influence of future benefits and costs on present values: High interest rates generally favor the selection of projects with low first costs but relatively high planned future maintenance expenditures over those with high first costs but low future maintenance expenditures.

Economic and Financial Implications

The standard for identifying and measuring the economic benefits from investment in a water resources project is each individual's willingness to pay for that project. For coastal protection projects, this value can be generated by a reduction in the cost to a current land use activity or the increase in net income possible at a given site. A project generates these values by reducing the risk of storm damage to coastal development. Conceptually, the risk from storms can be viewed as incurring a cost to development -- i.e., capital investment -- at hazardous locations. Thus, the cost per unit of capital invested at risky locations is higher than at risk-free locations. Economic theory predicts that the risk of storm damage in a given location results in less intensive development and lower land value in that location as compared with development and values if the same location had a lower risk as compared with otherwise equivalent, risk-free locations. The risk component of the marginal cost of capital is composed of the expected value of the per unit storm damages plus a premium for risk. This risk premium results from the attitudes or preferences of the individual decisionmaker toward risk. If the individual is averse to risk, the risk premium is positive, indicating that capital must earn a return not only to cover expected storm damages but also to compensate the investor for taking the risk.

NATURAL SOURCES OF RISK AND UNCERTAINTY

Storms damage coastal property in several ways. In addition to direct wind-related damage, which is ignored here, a storm typically produces a surge that raises the water surface elevation well above the mean high tide level. This wind-driven surge may be sufficient, even in the absence of waves, to flood low-lying areas. In addition to the surge, storms also produce larger waves. Property subject to direct wave attack can suffer extensive damage to the structure and contents as well as erosion of the foundation, threatening the stability of the entire structure. Storms also produce at least temporary physical changes at the land-water boundary by eroding the natural beach and dune that serve to buffer and protect the shore and property from the effects of storms. Increased wave energy during storms erodes the beach and carries the sand offshore. At the same time, the storm surge pushes the zone of direct wave attack higher up the beach and can subject the dune and structures to direct wave action.

Several components of coastal project evaluation are stochastic, so that the evaluation can be computationally complicated. For instance, the damages from storms are dependent on characteristics described in probabilistic terms, such as intensity, duration, wind direction, and diurnal tide level. Since these characteristics, in turn, influence the level of storm surge and significant wave height, these two direct factors in storm damage are also stochastic. Sea level rise can be considered as a shift in the base elevation for measuring storm surge and wave height.

THE EVALUATION FRAMEWORK

The first step in an evaluation is to assess the baseline conditions, that is, what will happen without the project being evaluated. In the deterministic approach, a single forecast defines physical, developmental, cultural, environmental, and other changes. These changes are considered to occur with certainty in the absence of any systematic adaptive measure. This approach does allow, however, for individual property owners to respond to storm and erosion threats by constructing protective measures or by abandoning property. The baseline requires assumptions to determine when these responses occur. In the risk analysis approach, this simplistic determination of the "without" condition is modified to incorporate uncertainties about storm frequencies, the distribution of wave heights, and the geomorphologic changes and property losses produced by storms and waves.

The variable <u>sea state</u> is measured as the sum of the level of storm surge plus the significant wave height. The level of storm surge is a function of the storm characteristics, so that the annual probability of storm surge exceeding some level depends on the annual probability of storms that can generate a surge of that level or greater. The distribution of wave heights from a storm is not independent of the level of storm surge (Bakker and Vrijling, 1981). One can consider the storm surge to shift the probability density function for significant wave heights.

The final component for incorporating classical risk-analysis techniques within the benefit evaluation framework for storm protection, as specified by the <u>Principle and Guidelines</u>, is to compare the future economic development and land values if the project is implemented with the baseline values. Without a public coastal protection project, property owners are presumed to repair structural losses with the damages from storms presumed to be capitalized into the value of the land. In addition, property owners are assumed to construct individual protective structures when the costs are less than the value of the preserved property and the avoided expected damages to improvements. With the project, landowners realize increases in economic rental values of land at protected locations. This rental value increase is typically considered to be equivalent to the annualized expected present value of avoided property losses with the project or the avoided costs of individual protective structures. The time stream of these benefits will reflect the stochastic nature of storm events. An important additional consideration stems from the chronological order of storms and damages. A large storm may result in damages that are so extensive that the buildings are not or cannot be rebuilt. Therefore, succeeding storms will inflict smaller losses if preceded by large storms.

The general description of the evaluation framework does not explicitly incorporate long-term shoreline erosion. In many situations, the observed shoreline retreat is simply the by-product of the storm history at a particular location, perhaps in combination with relative sea level rise. In other special cases, coastal structures such as groins and jetties may induce sand starvation in down-drift areas. Typically, these are incorporated in project evaluation, based on the average rate of historical shoreline retreat. For purposes here, any shoreline retreat is treated as storm-induced.

The increase in rental value of land is location-based, resulting from a reduction in the external costs imposed by storms. The increase represents a national economic development benefit, as required under the Principles and Guidelines. It is this type of economic benefit that is compared to project costs to determine the economic feasibility of any proposed federal project.[1]

Benefits produced by a project depend on the project's type and scale. Even where two alternative projects have the same scale, as defined by the design level of storm protection (e.g., 100-year storm or probable maximum hurricane), the impact on benefits will differ, depending on the magnitude of residual losses from storms that exceed the level of protection. For example, for a given level of protection, a sea-wall is likely to result in different residual storm losses as compared with beach and dune restoration, stabilization, and nourishment.

In addition to national economic development benefits, a second major consideration in applying benefit-cost analysis in choosing a project and its level of protection is the stream of future project costs. The appropriate costs used in the analysis should provide a measure of all the opportunity costs incurred to produce the project outputs. These national economic development costs may differ from the expenses of constructing and maintaining the project. For coastal protection projects, expenses would include the first costs of project construction, any periodic maintenance costs, and future rehabilitation costs. In addition, the project may incur environmental or other non-market costs whose monetary value can be imputed. The nature of the stream of future costs depends on the type of project. For instance, a structural-type project typically has high first costs and high future rehabilitation costs but low future periodic maintenance costs. On the other hand, a maintenance-type project is composed of relatively low first costs but with larger recurring future maintenance costs.

Each of the time streams of costs must be converted into present-value terms using the prevailing federal discount rate. Note that the stream of future costs for both types of projects, but especially the maintenance, must be defined in probabilistic terms. The realized amount and timing of maintenance and rehabilitation expenditures depends on the number and severity of storms experienced at the project site in the future. Thus, the expected future cost stream is based on the estimated probability density function for sea states.

Once the alternative formulated plans are evaluated in economic terms, the expected net benefits can be calculated. Following the project selection

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[1]In some cases, it may be determined that there is "no federal interest" and no federal project. This may be the case where a "few" large identifiable beneficiaries could organize to pay for their own protection financed out of increased land values.

criteria in the <u>Principles and Guidelines</u>, the recommended type and scale of plan should be the one that "reasonably maximizes" net national economic development benefits. This is a key conceptual point in risk analysis: the net benefits decision rule for selecting the economically optimal project simultaneously selects the degree of protection and level of residual risk bearing. Thus, by varying the scale each type of project, we can derive a benefit function for each type of project. Deviations from the national economic development plan can be recommended to incorporate risk and uncertainty considerations in addition to the explicit risk analysis used in the economic evaluation. These could be considerations for human health and safety or non-monetized environmental concerns.

CLIMATE CHANGE AND SEA LEVEL RISE

Thus far, the evaluation and selection of federal coastal protection investments has assumed that climate and mean sea level will not change; the underlying physical parameters and relationships yielding the historically observed distribution of sea states have been assumed to be constant. Most forecasts for sea level rise suggest that it is not an immediate problem for coastal development. In addition, there is a wide variation in the estimates of the rate of sea level rise.

For instance, a recent National Research Council report notes that relative sea level rise is composed of two components: (1) the localized land subsidence or uplift, and (2) a world-wide rise in mean sea level. (NCR, 1987). The report adopted equations resulting in the following relationship to forecast total relative sea level rise:

$$RSLR(t) = (0.0012 + M/1000) \cdot t + b \cdot t^2$$

where:

RSLR = relative sea level rise by year t above the 1986 level
M = the local subsidence or uplift rate in mm/year, and
b = the eustatic component of relative sea level rise by the year 2100 in m/year.

The value of M is fairly well established for many coastal locations: the value of b, however, is subject to wide forecast differences. Table 1 shows the estimates of the total relative sea level rise at Hampton, Virginia, and Grand Isle, Louisiana, for the three scenarios adopted in the NRC report. The variability in the predicted sea level rise offers a case for the application of sensitivity analysis in the evaluation of project scale. In addition, the disagreement over the eustatic component of relative sea level rise argues for projects whose scale can be staged to account for sea level rise as it occurs.

Sea level rise can be included in the evaluation of planning alternatives as a shift in the probability density function of storm surge in which the variance remains constant but the mean increases by the amount of sea level rise. This results in an increase in the site cost of capital "with" and "without" each alternative. Note that a rise in sea level will most likely have different impacts on the site cost of capital for different types of planning alternatives. The incorporation of higher future sea levels in project evaluation will favor the recommendation of larger, structural-type projects over maintenance projects. Two additional considerations temper this conclusion, however. First, building higher levels of protection than are economically efficient given the current mean sea level implies that current net benefits are sacrificed. The higher levels of protection are economically efficient only at higher mean sea levels that may or may not occur in the future. Second, since the increase in net benefits for a larger scale project occur in the future, the discounting process necessary to determine the present values of benefits and costs will reduce the influence of these future benefits on the determination of the appropriate project scale.

One way of presenting the economic tradeoffs between design project scales that have different time streams of future net benefits is to determine the break-even discount rate for the projects. The break-even discount rate is the interest rate that equates the present values of two streams of future net benefits. The present value of net benefits as a function of the discount rate is shown in Figure 1 for two alternative projects, A and B. Project A provides the economically efficient level of protection today ignoring sea level rise, while B provides a higher level of protection in anticipation of climate change and sea level rise. Notice that the present value of future net benefits for project B exceeds the present value of future net benefits for project A if the discount rate is less than approximately 3.2 %. This compares to the 1989 U.S. federal discount rate of 8 7/8% used for project evaluation. In general, because sea level rise and its effects occur relatively far in the future, incorporating even a high forecast of future sea levels in the evaluation of project scale will have little impact on the economically efficient project design when high discount rates are employed. Nevertheless, the uncertain prospect of the amount of sea level rise may support projects that are more flexible and that can easily incorporate staging of project increments as sea levels change.

Similar to the above analysis, project evaluation could incorporate the effects of forecasted climate change, expressed as a change in the frequency of storm events, through the calculation of expected values and sensitivity analysis. One hypothesis about the effect of climate change is that in many locations the frequency of severe storms will increase over time. Since recurring maintenance expenditures depend primarily on the frequency of storms, climate change that increases storm frequency will shorten the time period between these expenditures. This would tend to favor structural-type projects, since they have lower maintenance costs. Again, a perhaps overriding consideration for federal projects is the impact of discounting on these future costs and their influence on project type and scale. Thus, even though climate change may result in a dramatic increase in total lifetime project costs, most of the increase occurs beyond the first 15 to 20 years of project life, which

Table 1. Total Relative Sea Level Risk Forecasts in Meters

Year	Hampton, VA			Grand Isle, LA		
t	I	II	III	I	II	III
1985	0.0	0.0	0.0	0.0	0.0	0.0
1990	0.0	0.0	0.0	0.1	0.1	0.1
1995	0.0	0.0	0.1	0.1	0.1	0.1
2000	0.1	0.1	0.1	0.2	0.2	0.2
2005	0.1	0.1	0.1	0.2	0.2	0.2
2010	0.1	0.1	0.2	0.3	0.3	0.3
2015	0.2	0.2	0.2	0.3	0.4	0.4
2020	0.2	0.2	0.3	0.4	0.4	0.5
2025	0.2	0.3	0.3	0.4	0.5	0.6
2030	0.3	0.3	0.4	0.5	0.6	0.7
2035	0.3	0.4	0.5	0.6	0.7	0.8
2040	0.3	0.4	0.6	0.6	0.8	0.9
2045	0.4	0.5	0.6	0.7	0.8	1.0
2050	0.4	0.6	0.7	0.8	0.9	1.1
2055	0.4	0.6	0.8	0.8	1.0	1.2
2060	0.5	0.7	0.9	0.9	1.1	1.3
2065	0.5	0.8	1.0	1.0	1.2	1.5
2070	0.6	0.8	1.1	1.1	1.3	1.6
2075	0.6	0.9	1.2	1.1	1.4	1.8
2080	0.7	1.0	1.4	1.2	1.6	1.9
2085	0.7	1.1	1.5	1.3	1.7	2.1
2090	0.8	1.2	1.6	1.4	1.8	2.2
2095	0.8	1.3	1.7	1.4	1.9	2.4
2100	0.9	1.4	1.9	1.5	2.0	2.6

Scenario	Coefficient	Implied Sea Level Rise by 2100
I	0.000028	0.5
II	0.000066	1.0
III	0.000105	1.5

RSLR = $(0.0012 + M/1000)\cdot t + b\cdot t^2$
M = Rate of subsidence or uplift in mm/yr
= 3.1 for Hampton, VA
= 8.9 for Grand Isle, LA
b = The rate of change in rate of growth in eustatic sea level rise for scenarios I, II, and III.
Source: Based on NRC (1987).

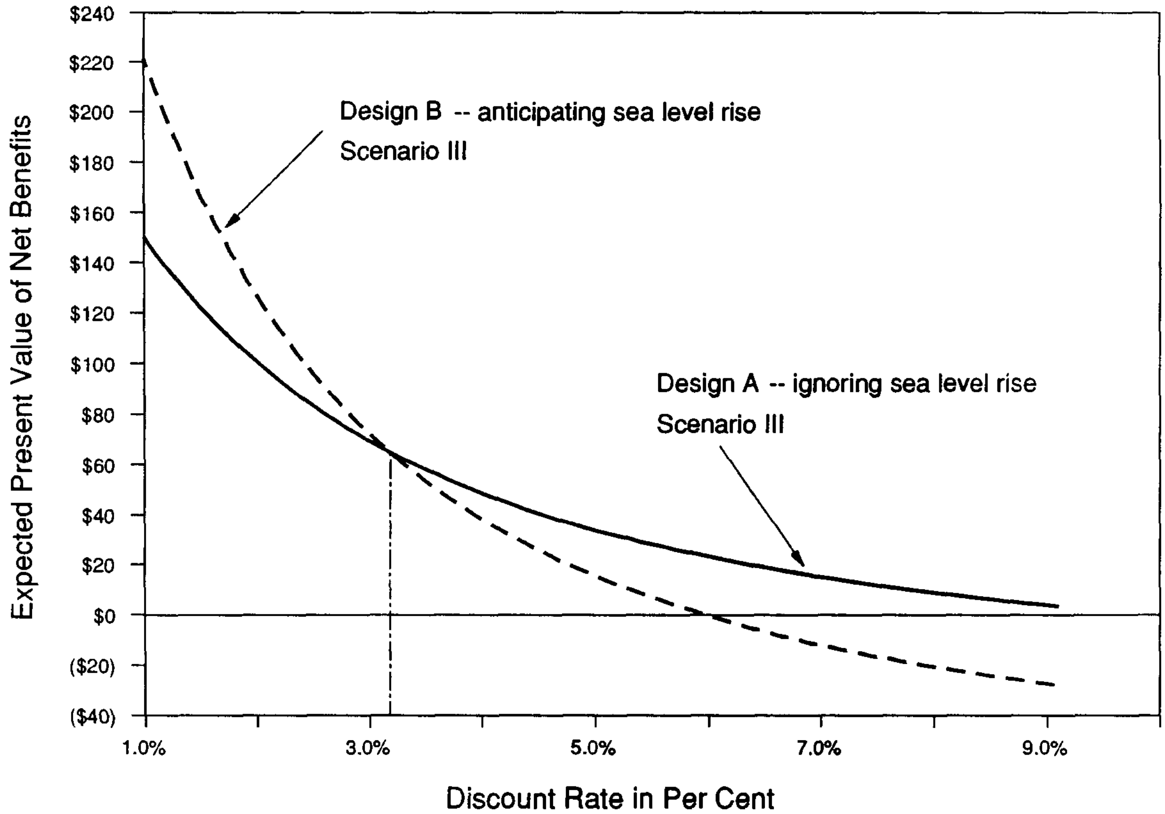

Figure 1. Expected present value of net benefits as a function of discount rate.

has little influence on the present value of net benefits. (See the economic section of the conference report for a further discussion on discounting.)

CONCLUSIONS

Coastal protection projects can incorporate forecasts of sea level rise and storm frequency changes due to climate change through the application of risk and uncertainty analysis techniques. The incorporation of these forecasts is not a trivial matter, but well within the probabilistic analyses currently employed to estimate project benefits and costs for coastal projects. When the effects of sea level rise and climate change occur in the future, in-place structural projects of larger scale than those warranted under the current sea level and storm frequencies would offer greater benefits than those designed for the current conditions. In addition, sea level rise and climate change, which increase recurring project maintenance costs, tend to favor structural-type projects.

Risk-cost analysis is not likely to yield definitive answers to the problem of choosing adaptive measures to cope with the risk of sea level rise. Other considerations that incorporate cultural, social, or environmental aspects related to sea level rise may be more important in choosing adaptive measures. Risk-based approaches remind the analyst, however, that hard engineering options may exacerbate losses by encouraging development and fostering a false sense of security. Hard engineering adaptations to sea level rise, particularly the barrier type, have the potential for disaster should natural events exceed their designed level of protection. Therefore, decision-makers should be wary of engineering solutions with high residual risks.

At present, there is considerable disagreement over the degree of sea level rise and the impact of climate change on storm frequency. More important, the adverse impacts on storm damages occur too far into the future, given the nature of discounting and the level of the federal discount rate, to have much influence on the economically efficient type and scale of project recommended today. There is likely to be a greater reliance on nonstructural, land use management solutions that require state and local regulatory controls. The uncertainties about the magnitude and rate of change in sea level rise emphasize the need to maintain flexibility and emphasizes the adoption of an incremental approach that preserves options.

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SPEECHES

GLOBAL PARTNERSHIPS FOR ADAPTING TO GLOBAL CHANGE

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I am pleased to join you this morning here in Miami. Whoever chose this site for a workshop on Adaptive Options and Policy Implications of Sea Level Rise certainly chose well. Here we see a prime example of a fragile coastal environment; a heavily built up coastal area; an excellent example of the possible costs and dislocations associated with a significant rise in sea level.

You are here to take on a significant challenge -- how to respond to potential major changes in our global environment. The purpose of this workshop is to gather information and exchange views on adaptive options -- to learn how to protect resources and minimize economic disruption resulting from a potential rise in sea level.

For those of you, like myself, who have long been concerned with environmental issues, these last few months have been almost breathtaking. Environmental issues, in particular, the possibility of human-induced global change, have reached center stage in much of the world. The global environment has become a priority issue in summit discussions. For example, fully one third of the summary communique that came out of the economic summit, the G-7 conference in Paris this past summer, was devoted to environmental issues. Prime Minister Thatcher's recent speech to the United Nations General Assembly was devoted entirely to environmental matters. Here in the U.S., President Bush has placed environmental concerns near the top of his agenda.

In the past year, the Intergovernmental Panel on Climate Change (IPCC), created by the World Meteorological Organization (WMO) and the U.N. Environment Programme in 1988 to address the serious potential consequences of climate change, has become a dominant international force. Three working groups under the IPCC focus on various aspects of climate change.

Working Group 1 is examining the state of the science: What do we know and what don't we know?; How can we gather more information?; How can we be sure about the various aspects of climate change, particularly the role of man in generating those changes? Working Group 2 is investigating the socioeconomic and environmental impacts of climate change. For example, if there is climate change, there will be more rainfall in one region than in another; what impacts will that have? There also will be warming of the oceans; what impact will this have on fisheries? Working Group 3 is focusing on response strategies to climate change. It is under the auspices of this third working group that the U.S. is hosting this conference.

The Netherlands was a member of the U.S. delegation to the Ministerial Conference on Atmospheric Pollution and Climate Change. At that conference, there was agreement to use the results of the IPCC deliberations, including the results of workshops such as this, as the basis for a framework convention on global change. Such a convention probably will be negotiated in the next two to three years. The negotiations and the decisions concerning any frame-work convention on global change and its subsequent protocols will be strongly influenced by the work of the IPCC; and by extension, will be strongly influenced by your deliberations this week.

We're here to discuss sea level rise. What about sea level rise? What do we know about it? Geologists have long known that most shoreline areas change constantly, because of silting, shoaling, and flooding, and because of changes in sea level, caused either by a change in the ocean volume, or by a subsidence or rise in the coastal land area.

Over geological time scales the shoreline is a very dynamic feature. Even on a scale of decades, we have often seen significant changes in the shoreline -- much of those changes caused by either the sinking or rising of the land. In much of Scandinavia, for example, sea level is dropping -- not because there is less water in the ocean but because the earth is rising, at a rate of about 1 cm a year. This rise in the Earth's surface, also occurring in Canada and much of the polar regions of the Northern Hemisphere, is due to the isostatic adjustment that occurred after the disappearance of the glaciers some 10,000 years ago. In Japan, one of the more tectonically active regions of the earth, depending on which part of the country you're in, sea level is either sinking or rising, at rates of from 0.5 to 2 cm per year. Again, this is due to land changes, not changes in sea level.

So, how should we respond to shoreline changes? One might argue that a prudent nation would build back from the shore, and leave the dynamic, constantly changing shoreline alone. If we all did this, there would be no need for workshops such as this one. However, we must have our coastal ports. Many of the great cities of the world began as ocean ports -- New York, Venice, Rio de Janero, Rotterdam. Are they to be abandoned because of rising sea level? Yet, some island nations, such as the Maldives and the Trust Territories in the Pacific, could lose much of their total land as a result of a significant rise in sea level. Nations such as Bangladesh could suffer significant loss of land area because they are built on a coastal plain, as could some of the U.S. Gulf Coast states (e.g., Louisiana and Texas), which are geologically similar.

Coping with rising sea level, or sinking land level, is not a new phenomenon. Venice, which has been grappling with this problem for years, has been sinking into the ocean at about 20 m a century. The Netherlands decided long ago that if they were to provide enough land for their citizens, much of it would have to be below sea level. More than 50 percent of the Netherlands is now below sea level. Here in the United States, the great port city of New Orleans is some number of feet below the Mississippi River, which flows alongside.

Thus, while the risks of living on the shore may be high, the benefits, and often the necessity, of coastal living usually predominate.

Given the fact that this is not a new problem, why the increased interest in sea level rise? There are at least two reasons. One is that what we are facing is a global issue, not a regional one, not a local one. A rise in sea level due to melting of glaciers and expansion of sea water will have a worldwide impact. Second, and more important, particularly in a political sense, this change in sea level will be human-induced. If our activities cause an increase in global temperature, then we are responsible for a rise in sea level, because one consequence of global warming is an increase in the volume of the ocean and a consequent worldwide rise in sea level.

The issues of climate change and sea level rise, therefore, are much more than fodder for scientific discussion. They are truly global issues that affect us all. The diversity of the attendance here -- scientists, policy-makers, diplomats, academicians from 38 countries -- reflects both the global nature and the importance of these matters.

How much do we know about climate change and sea level rise? To a large degree, our decisions in the future will be based on our knowledge about the risks involved. To support the decisions we have to make, we must improve our ability to understand and to forecast trends in climate change and sea level rise. Part of our strategy to address global change must include improving the data and information we have available.

As the Administrator of the National Oceanic and Atmospheric Administration (NOAA), this is a particularly important issue to me personally, and to my agency. And as a scientist, I must acknowledge that the present data and information base is not as robust as many of us would like. On the other hand, what we do know is sufficiently compelling to generate wide concern. There is a growing sense that we cannot wait until we are absolutely certain before we begin to take at least limited action, and under any circumstances, prepare for what might follow.

What we do know is that atmospheric concentrations of carbon dioxide have increased nearly 30% within the last 100 years and are now higher than at any time in the last 40,000 years. While we have not been measuring carbon dioxide for 40,000 years, we can get some estimate of what CO_2 concentrations were back then by measuring the air trapped in ice cores where the ice was deposited 20,000 to 100,000 years ago. It is quite clear there is more CO_2 in the atmosphere now. And the concentration of CO_2 has been increasing at a rate of about 4% per decade. There is no doubt that human activities are generating enormous amounts of carbon dioxide and other radiatively important gases, such as methane and chlorofluorocarbons (CFCs). We are affecting Earth's heat budget as a consequence. How the global climate will respond to these changes in the heat budget is still a matter of debate.

A second debatable issue is whether or not we have already seen global warming as a result of increased carbon dioxide. There are various opinions. At least some studies for which long-term temperature records were examined indicate that present global temperatures are the highest ever recorded and still rising. For example, one analysis of temperature from land-based sites has documented an observed worldwide increase in temperature of 0.4°C since the start of the industrial revolution. On the other hand, two recent articles published by NOAA scientists have shown that there has been no significant increase in temperatures over the contiguous U.S. in the last 100 years.

These two seemingly disparate results are not necessarily in conflict. We can indeed have a worldwide warming that will not be uniform. We can be <u>almost certain</u> it will not be uniform; some areas might even cool. But the <u>average</u> temperature of the Earth will rise.

Projecting the change in sea level from global warming is equally complex and uncertain. There is general agreement in the scientific community that a rapid sea level rise, projected by some a few years ago, is rather unlikely. It is generally accepted that global sea level has increased at a rate of 1-2 m per year over the last century. But even here, the uncertainty is great. Detecting that small of a change is not easy. In many parts of the world, the tectonic movement of the land is 5 to 10 times greater. Furthermore, the present worldwide network of tide gauges for measuring sea level was established primarily for purposes of maritime safety, and not for the purpose of determining the rise and fall of sea level. The distribution is not ideal for attacking this problem. Many of my colleagues would not be too surprised to find that when all the data is in and analyzed, it will not be possible to say whether or not there has been a rise in sea level in the last 100 years.

As for the future, in spite of all the well-publicized concern about global warming, we must understand that there is still considerable uncertainty among scientific experts about a number of the most critical factors that determine global warming and, as a consequence, global sea level. We remain uncertain about the magnitude and the timing of such changes, as well as about the specific impacts in different regions of the world.

The Earth system is composed of a variety of interactive parts, These climate interactions include cloud cover, snow and ice, hydrology, and ocean circulation, amongst others. Key scientific questions focus on the processes that tie the system together.

One of the biggest areas of uncertainty is the role of the oceans in climate change. Although the sun drives the system, the ocean serves as a somewhat erratic "fly wheel" that mitigates the sharp seasonal changes and interannual variations. We must improve our understanding of ocean variability and how the ocean interacts with the atmosphere on a global basis. That point has been stressed recently.

The World Meteorological Organization noted in June 1989 that existing ocean observing networks generally are not adequate to meet the international scientific requirements for climate monitoring, research, and prediction. A month later, in July, the IOC determined that there is an urgent need to substantially modernize and expand the existing global ocean observing systems. I agree. But monitoring the oceans is difficult because of the vast expanse, the diversity of ocean processes, and quite frankly, because there is still much that is poorly understood.

There currently exists a surface-based observational network that is a mixture of hundreds of various ocean measurement systems and platforms; in addition, there are nearly 8,000 worldwide volunteer observing ships. Some of these programs are operational, while others support research programs. They are managed by an equally varied group of more than 100 nations, plus intergovernmental bodies and agencies, many with different missions and objectives. The systems are often incompatible in type, location, data format, and communication links. That existing network, such as it is, is an unfinished patchwork quilt; many pieces are in place, some are not. Before we <u>truly</u> understand the ocean's role in global warming, we will need to pull all the existing pieces together and begin "sewing" the quilt. We are on our way to doing just this.

Major international programs such as the Tropical Ocean Global Atmosphere (TOGA), and the World Ocean Circulation Experiment (WOCE), have begun to provide the needed scientific bases for defining the network. And they have begun to assemble some preliminary pieces. But there is still much to be done. Satellites, for example, can only do part of the job. They are wonderful for looking at the atmosphere; satellites cannot be used to penetrate the ocean -- they can only look at the surface of the ocean. For example, satellite measurements cannot tell us anything significant about the movement of heat from one ocean basin to another.

Once the observational network is complete, we must identify the intergovernmental mechanisms needed to maintain it.

As the U.S. Earth systems agency, we at NOAA have the responsibility for monitoring and predicting environmental change. We have a major role in the scientific examination of global warming and attendant sea level rise. NOAA has already begun a comprehensive effort to improve the global ocean-observing system. One part of that task is to improve our tide gauge network so we can better monitor changes in sea level.

NOAA has been in the business of measuring tides and water levels for more than 140 years. Our longest continuous series of measurements began at San Francisco in 1854. And, of course, compared to some of our European colleagues, we are rather "Johnny-come-latelys" in the business of measuring sea level.

Sea level measurement is going through a revolutionary change at present. Because of recent advances in geodetic positioning, it is now possible to measure the true sea level with a precision never before possible. That is, we can distinguish the movement of the tide gauge caused by the land from movement caused by actual change in sea level.

In summary, understanding and predicting global change requires a truly global partnership. International organizations are defining the requirements for a global ocean observing system and will play a pivotal role in maintaining that observing system over the long term.

It is a challenge for each of us personally to work within our country for increased scientific research and intergovernmental support for a global observation network.

Your task this week is to consider the consequences of sea level rise resulting from global change, to identify rational approaches to climate change and sea level rise, and to consider the policy implications of such responses. If we think that solving the scientific riddle is a challenge, I expect that the search for responses and solutions will be even more of a challenge. It is a process that we need to begin now.

It may be the task of science to provide us with high-quality information and predictions that can guide our efforts, but we cannot wait for science to give us definitive answers before we get on with the planning and the assessing of our options.

LUNCHEON REMARKS

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It is a distinct pleasure for me to represent the Assistant Secretary of the Army for Civil Works and, with my co-hosts from NOAA and U.S. EPA, to welcome this distinguished body of international delegates and to participate with you in the exchange of information and ideas at this IPCC Sea Level Rise Workshop.

Let me begin by explaining that my office oversees the civil-oriented work of the U.S. Army Corps of Engineers which is the principal U.S. agency for development of water resources projects throughout the United States. The Army has been doing such work since 1824, when it had the country's only organized group of engineers and was charged by the Congress to develop navigation projects.

Since 1824, the Army's responsibilities have been expanded by the Congress to encompass virtually all types of water resources development projects including single purpose navigation, flood control, and coastal projects. Multipurpose projects also include features that provide for industrial and municipal water supply, hydroelectric power production, irrigation, resource conservation, and recreation. We also have regulatory responsibilities, which include management of the nations' waters, including controls associated with tidal and non-tidal wetlands.

I must emphasize that in the process of executing our water resources development and regulatory responsibilities, the Department of the Army, through the Corps of Engineers, works with a wide spectrum of other federal agencies, as well as state and local governments, and public interest groups. Through this cooperative and collaborative process we in effect, join in multiple partnerships with others to evaluate and decide on the broad social, economic and environmental implications of alternative public investment options related to water resources development and conservation. Hence, we and our companion agencies of the U.S. Government find the IPCC a familiar and comfortable forum in which to participate and to join with you as partners in formulating solutions to problems that could arise in the event of human-induced climate change.

With that brief background, I would now like to share with you the views of the U.S. Department of the Army concerning the implications of a possible future accelerated rise in sea level, and what we are doing at present to address the consequences of that potential phenomenon in terms of planning adaptive options.

First, we do not view the potential for accelerated sea level rise with either alarm or complacency. In general, there does not appear to be a substantive basis for broad and immediate emergency action. Moreover, in many situations in the United States and throughout the world, the effects of an increase in the level of the seas could be accommodated in the normal course of maintaining or replacing existing facilities or protective structures without extraordinary added costs related to sea level rise. However, near-term action may be warranted in limited geographic areas having low topographic elevations and/or significant land subsidence rates.

The options available for adapting to sea level rise with respect to developed areas are those traditionally used for responding to threats of storm tides and wave action in coastal and estuarial zones, namely: (1) stabilization measures, such as seawalls, bulkheads, revetments, beach fills, groins, breakwaters, flood walls, levees, and estuarial or sea-entrance tidal barriers; (2) elevating of lands and facilities usually with the application of stabilization measures; and (3) retreat from hazardous or threatened areas. Advanced measures such as land use management can be employed in areas which are presently extremely hazardous or would become so in the event of a marked rise in sea level.

In regard to the choice of an option or set of options, most developed areas that would be exposed to the impacts of a rising sea level possess their own singular mixes of physical, social, economic, political and environmental characteristics. These composite characteristics would, case by case, govern the choice, initiation, and phasing-in of an adaptive response or set of responses to a rise of sea level. Doubtless, the implementation of responses, from national or global perspectives, would be a slowly evolving process following the anticipated gradual rise in sea level, should enhanced greenhouse effects occur.

In any case, those charged with planning, design, or management responsibilities in the coastal and estuarial zones should be aware of and sensitized to the possibilities and quantitative uncertainties pertaining to future sea level rise. It may be some time before we know what changes, if any, are taking place in the levels of the seas vis-a-vis climate change. Moreover, if this phenomenon does occur and is detected, additional time will transpire before definite rates and trends of the rise are established relative to land surfaces in specific areas of concern.

In the meantime, we should, wherever possible, conduct our activities so as to leave options open for the most appropriate future response without undue current investments, social and economic disruption, or environmental damage. I realize that this is not an easy task, even when the involved institutional establishment has a common viewpoint on the potential problem. Certain realities and constraints must be recognized. For example, traditional benefit-cost analyses, with the high discount rates currently in use, do not generate significant benefit values for the prevention of damage events that are expected to occur 35 to 50 years in the future -- even when the likelihood of such events can be strongly supported by past events and statistical analyses. Thus, water resources projects for which benefits are long term are normally deferred in favor of more certain, near-term benefits.

Nevertheless, something can be done to prepare for potential future problems. As an illustration, many protective structures such as levees, seawalls, and breakwaters can be planned and designed with features that allow for future incremental additions that, if needed, could accommodate increased water levels and wave action. This can be done, in many cases, without significant additional costs in the initial investments.

Other actions can be taken now, or strategies and technologies developed, that require little investment and can in fact, reduce current operating expenditures. One important example that comes to mind is the beneficial use of material dredged from navigation projects in the creation of tidal wetland habitats. We are vigorously pursuing this option at both the research and the field application levels. This use of dredged material can, in proper circumstances, reduce the costs of disposal of the material while offsetting wetland losses due to sea level rise or other causes.

Though sea level rise would seemingly reduce navigation dredging requirements by naturally providing deeper waters, such an effect would, if at all, be short lived. In this connection, one has only to consider that vertical shoaling rates of one meter per year are extremely common, and that little advantage to navigation would be gained by a 1- to 2-meter rise in sea level over a 100-year period. In any case, we expect that overall navigation dredging demands will not be significantly affected by changing sea level, albeit, long-term changes in areal distributions of shoaling may attend a gradual rise in sea level.

In this country, the possibility of a large-scale program to create tidal wetlands with dredged material is evident in considering that over the past decade, the Army Corps of Engineers has excavated an <u>average annual</u> quantity of 250 million cubic meters of uncontaminated dredged material from navigation projects. Moreover, most of this material is removed from channels and harbors in the coastal and Great Lakes regions. If placed to a thickness of 1 cm, 250 million cubic meters of dredged material <u>each year</u> would cover an area of about 25,000 hectares. Admittedly, all uncontaminated dredged material could not be effectively used for purposes of wetland creation, but a substantial amount could be applied in that way and would significantly offset loss of tidal wetland due to sea level rise.

Now a few words about what we are doing to address the basis issue.

To assure a consistent approach to considerations of possible accelerated sea level rise, the Army Corps of Engineers has adopted uniform planning procedures. The procedures require that potential sea level change be considered in every project feasibility study undertaken within the coastal and estuarial zones. Study areas are to extend as far inland as the potential future limits of tidal influence. This applies primarily to the study and formulation of shore protection, flood control, and navigation projects.