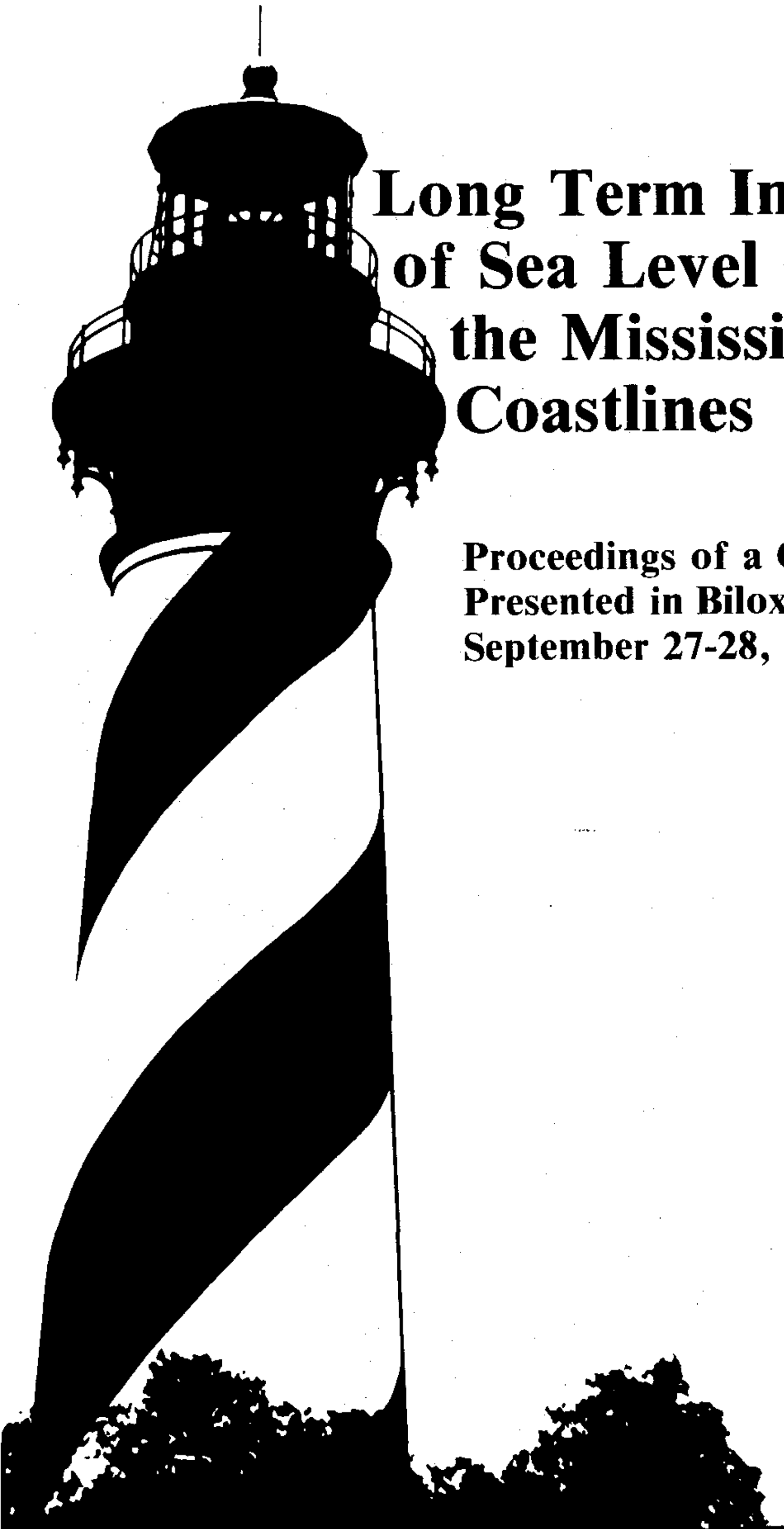

Long Term Implications of Sea Level Change for the Mississippi and Alabama Coastlines

Proceedings of a Conference
Presented in Biloxi, Mississippi
September 27-28, 1990.

MISSISSIPPI-ALABAMA SEA GRANT CONSORTIUM; MISSISSIPPI DEPARTMENT OF WILDLIFE, FISHERIES AND PARKS; BUREAU OF MARINE RESOURCES; MISSISSIPPI STATE UNIVERSITY COASTAL RESEARCH AND EXTENSION CENTER; ALABAMA DEPARTMENT OF ECONOMIC AND COMMUNITY AFFAIRS

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Foreword

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One of the foremost issues that has received considerable attention in recent years is the likelihood of an accelerated sea level rise. This issue is of critical importance to coastal residents, developers, and coastal managers along the northern Gulf of Mexico since small rises in sea level can have far-reaching impacts on the region's generally flat coastal profiles. In some areas of the Mississippi/Alabama coast, small rises in sea level could cause a large horizontal displacement of the apparent shoreline, resulting in new shoreline formation hundreds of feet inland.

Prior development of many coastal areas has disrupted natural processes, resulting in increased shoreline erosion, loss of coastal flora and fauna, as well as increased exposure to hurricanes, flooding, and loss of property and life. Continued development in the coastal zone, coupled with the possibility of elevated water levels, may serve to only magnify the consequences of man's activities. Future development in the coastal zone must take into consideration the impacts associated with accelerated sea level rise.

It is imperative that decision-makers develop an appropriate management strategy to minimize the effects sea level rise may have on our fragile coastal resources. The strategy must include efforts in the areas of research to monitor sea level changes and rates of erosion; regulations that address construction standards and setback zones; and projects that protect the shoreline and slow coastal erosion. Public education relating to this critical issue is also important to the management strategy, because without public support, management strategies cannot be implemented.

It is within this framework that the Mississippi Bureau of Marine Resources, along with the Mississippi-Alabama Sea Grant Consortium, Mississippi State University Coastal Research and Extension Center, and the Alabama Department of Economic and Community Affairs, resolved to examine the present and future trend of sea level along the Mississippi and Alabama coastlines. A decision was made to host a conference and invite local, state, and federal experts to present papers examining the sea level rise phenomenon.

These proceedings represent the information shared during the 2-day conference. This is by no means an exhaustive compilation of information about sea level trends; however, it does provide a comprehensive overview of our current understanding of the issue as it relates to Mississippi and Alabama. Undoubtedly, the dominant variable shaping future coastal management decisions is the rate of sea level change. Until this critical variable is known, we must strive to adopt flexible management plans that incorporate various scenarios of sea level change as we try to cope with the dynamics of the coastal zone.

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Welcome and Introductory Remarks

James I. Jones, Director
Mississippi-Alabama Sea Grant Consortium
Ocean Springs, Mississippi

It is both my duty and pleasure to welcome you on behalf of the Mississippi-Alabama Sea Grant Consortium, a cosponsor of this conference. About 2 years ago, Larry Lewis called me to see if our two agencies could cooperate to develop this meeting. I am delighted to now be able to experience the results of our mutual efforts, and am highly pleased that the Alabama Department of Economic and Community Affairs and Mississippi State University have joined us. It is clear to me that the myriad coastal environmental problems facing this region and the nation cannot be resolved through individual action by any single organization. Whatever optimism we may muster requires that cooperative actions be taken. This conference is one small step in that direction.

For those of you who wish to know more about Sea Grant, and even for the rest of you, the Mississippi-Alabama Sea Grant Consortium is comprised of eight institutions of higher learning located in the two states. These include the University of Mississippi, Mississippi State University, the University of Southern Mississippi, and the Gulf Coast Research Laboratory in Mississippi; and the University of Alabama, University of Alabama at Birmingham, Auburn University, and the University of South Alabama, in Alabama. Thus, Sea Grant has the intellectual resources of eight institutions of higher learning to draw upon. These institutions, through Sea Grant, are ideally suited to initiate and develop selected, intensive cooperative research programs of the dimensions necessary to address the major facets of coastal change. Sea Grant has the proven infrastructure and broad base of experienced academic researchers and other professionals who comprehend the magnitude of the problem and who can readily collaborate in efforts to reduce the impacts on coastal resources and residents.

Sea Grant is uniquely qualified to organize, develop, and conduct studies of coastal change. All the necessary administrative mechanisms are in place, and equally important, paid for. The availability of the region's finest research scientists is assured, and the mechanisms for public outreach, education, and technology transfer are both available and well proven. The extension of Sea Grant's activities to more effectively address the most significant problems of this coastal region is both logical and necessary. No other governmental or nongovernmental organization has the documented ability to work as efficiently or as cost-effectively throughout the required range of research, education, and outreach activities, utilizing a national network of public and private organizations, academia, and local, state, and federal agencies.

The coastal ocean is a unique region, which simultaneously impacts on and is impacted upon by man. A significant segment of the world's population derives its livelihood from this region, while many others utilize it for recreational and leisure time activities, a consequence of the fact that most of our major population centers are adjacent to it. The coastal ocean and its adjacent land area constitute a homogenous ecosystem. As such, a delicate balance exists among its many attributes, characteristics, and resources. As a result of man's ever-increasing requirements, combined with natural processes such as sea level rise, a very real potential exists to further disturb and eventually destroy this delicate ecological balance. In this century, for the first time in human history, mankind has achieved the ability to impact very large marine and coastal ecosystems at a level sufficient to effectively destroy their natural productivity.

It has been estimated that within this decade nearly 75 percent of the population of this country will live within 50 miles of the coast. That population level is expected to continue increasing rapidly into the next century and for the foreseeable future. In order to support that population increase, a wide range of new or increased facilities, businesses, and industries will be necessary to provide the required services and to contribute to an effective economic/environmental balance. One consequence of this population shift will be the increased destruction of estuarine habitats. This destruction will degrade both estuarine water quality and coastal ground water. Ultimately, significant decreases in coastal biological productivity will result. This continued degradation and destruction of our coastal and ocean environment, through both natural and anthropogenic factors, will generate severe social and economic costs. Many human activities create impacts that are severely detrimental to the coastal economy and injurious to the health and well being of coastal inhabitants. When combined with natural factors, such as sea level rise, they may become compounded many times over, producing major environmental and economic dislocations.

The primary factors affecting the coastal ocean environment are: (1) coastal water quality, (2) wetland habitat loss, and (3) coastal marine productivity. Water quality is affected by a variety of industrial, agricultural and domestic activities, which may be located on or near the coast or more distantly, in the heartland of the continent. Innovative processes and techniques are needed to improve and maintain both the quality and the quantity of water, to preserve and restore the integrity of the coastal ecosystem, and to provide an abundant supply of high quality water for human and other needs. Sea level rise, whatever its magnitude, will increase salinities in rivers, bays, and estuaries; exacerbate salt water intrusion into aquifers; drown existing stands of highly productive coastal emergent and submergent vegetation; and markedly increase coastal erosion and land loss. It is critical that the timing and magnitude of these events be determined to the best of our ability to provide maximum time to prepare for them and ameliorate their impacts where possible.

Wetland loss is a function not only of natural processes such as sea level rise, but also of man's developmental activities. The coastal wetlands, in their role as nursery or hatchery areas, are known to be major contributors to the productivity of the many marine species that occur there, or that occur there only during a part of their life cycle. This area, through its "buffering" capability, also serves a major role in lessening the on-shore impact of major storms.

Many differing approaches and mechanisms are needed to preserve, enhance, and re-establish the wetlands in order to maintain the many functions they perform. The very real potential for their significant loss through sea level rise requires even more concern for those man-induced losses which may be reversible or lessened. While there is relatively little that can be done to impact the "natural" process of sea level rise we can concentrate our efforts on those aspects upon which we **can** impact.

This conference represents our best effort to bring together in a single forum the principal scientists, managers, legislators, administrators, private sector professionals, and concerned citizens who have responsibilities or concerns regarding sea level rise and its effects upon this region. We hope that through this mechanism you will define the scope of the problem, as it relates to our coastal area, and recommend ameliorative or other actions, which will lessen the economic, social, and environmental impacts of this process. This is a daunting challenge, but one that must be accepted for the benefit of all of us. The participants in this seminar have the knowledge, experience, and capability to educate the rest of us. You, with your peers, can uniquely develop the definitive recommendations for those actions that will allow us to plan for and limit, to the best of our ability, the negative effects of sea level rise. Good luck and Godspeed in this critical endeavor.

Public Trust Tidelands Issues in Mississippi

The Honorable Dick Molpus
Mississippi Secretary of State
Jackson, Mississippi

Good morning. It is a pleasure to be here this morning to talk with you about a subject that is extremely important to me–public trust tidelands issues in Mississippi. It is not often that I have the opportunity to discuss tidelands issues with a group that is so concerned and knowledgeable about the subject.

There is a tendency for people in public office to deal with the problem that is facing them that afternoon, or if they want to consider long-range planning, the problem they may face next week. So I'm delighted to be with who would come and deal with a problem that is going to occur over the next several decades. It is reassuring to me that we have public officials and public servants with that type vision.

Before I discuss the more hotly debated and litigated public trust issues, I'll let the cat out of the bag and tell you that in Mississippi, rising sea levels increase public trust ownership. This is one area that appears to be viewed harmoniously by our supreme court and our legislature. I'll explain further when I return to this issue later in my remarks.

First, perhaps a little history of the tidelands question in this state would be helpful to those of you whose expertise is in other areas, be it coastal management, geology, law, or port development. Two and a half years ago, in February 1988, the U.S. Supreme Court affirmed the Mississippi Supreme Court's unanimous decision of 1986 that the State of Mississippi owns in trust for the public, and has owned since statehood in 1817, all lands subject to the ebb and flow of the tide, up to the line of mean high tide and regardless of the navigability of the waters over them. This state court decision is referred to as the *Bambini* case. Following the 1988 U.S. Supreme Court affirmation of *Bambini,* I appointed a Blue Ribbon Commission of coast residents to address tidelands issues. We also opened a coast office and staffed it with an attorney to provide local assistance to coast citizens and officials.

The Commission studied five areas of tidelands concerns: the boundary question, conservation and development, lease program management, littoral and riparian rights, and taxation. They met over a period of 6 months in open meetings in each of the coast counties. Every meeting was advertised to the public and the media, and at every meeting, every citizen who wished to speak was heard. Some members of the public never missed a meeting, whether it was held in Pascagoula, Bay St. Louis, or places in between.

The Commission faced the tears of woman who couldn't hold them back when she understood her property **wouldn't** be affected. The Commission also heard the threat of a man who said he'd die before he'd pay a penny. As you can tell, some of the meetings became pretty emotional. Law enforcement officers were called in at one crowded meeting in Bay St. Louis; one Commission member had to be escorted to the bathroom by a policeman. The weather didn't cooperate either; several times meetings were cancelled because of hurricane warnings. I hope it's a sign of the wisdom of the Commission's recommendations that we've had no threat of hurricanes in the 2 years since that time.

In any event, the Commission diligently continued to meet and study. Within 6 months, their recommendations concerning each of the five areas of scrutiny were compiled into a comprehensive report, which I adopted in its entirety and made available to the Legislature when it convened in January 1989.

The Legislature studied the tidelands subject, and passed a bill during that 1989 session which responsibly incorporated most of the Commission's recommendations. Even those legislative hearings had some tense moments. I remember being called arrogant for seeking legislative resolution to the issue by a respected lawyer who said that only the judiciary could decide the matter. He had represented the losing party in the *Bambini* case. I would have thought he understood the judiciary **had** decided the matter.

But to return to the Tidelands Act, which was eventually passed: it included a direction to the Secretary of State to prepare a preliminary map of public trust tidelands. The Tidelands Act directed me to depict the boundary on the preliminary maps, "as the current mean high water line where shoreline is undeveloped." However, (and this is what I was referring to when I said the Legislature took **most** of the Commission's suggestions) the Legislature departed from Commission recommendations concerning the boundary in developed or filled areas. The Commission had advised that the boundary be fixed at the mean high water line immediately prior to the time of development or filling. But, the Tidelands Act provides that "in developed areas or where there have been encroachments," the maps "shall depict the boundary as the determinable mean high water line nearest the effective date of the Coastal Wetlands Protection Act," which was in 1973. The result of this provision is, of course, to grandfather all filled tidelands, regardless of whether the fill was authorized, as long as the filling was accomplished prior to 1973. After publication of the preliminary map, the Tidelands Act calls for a 60-day comment period, after which the Secretary of State can in his discretion revise the maps "accordingly" and publish final maps.

Immediately after that 1989 legislative session, I filed suit in Jackson for a declaratory judgment that the portion of the Tidelands Act, which I just quoted, violates our state constitution by making a gift, a donation, of public lands. But during the legislative session, a suit had been filed here in Harrison County to confirm title to a parcel of filled property south of the seawall in Biloxi. Many of you may be familiar with the Bill Byrd Honda suit, as it is known locally. After the enactment of the Tidelands Act, the Byrd suit was amended to seek declaratory judgment of the constitutional issue. The Hinds County suit has been held in abeyance while the issue is decided in the local suit.

As many of you know, the Chancery Court in Biloxi has declared the Tidelands Act constitutional, has said it does not amount to a donation, has even said that at Eastertime when the case was heard, we "should heed the admonition of those who advocate forgiveness." We have appealed that judgment to the Mississippi Supreme Court. The *Bambini* decision clearly held that "lands brought within the ebb and flow of the tide by avulsion or by artificial or non-natural means" are not a part of the trust tidelands. We are firmly convinced that while the *Bambini* court didn't specifically say so, the converse is also true, that lands removed from tidal influence by filling remain public trust lands. I agree with the Commission's finding. It is my belief as trustee that what is public should remain public and the historical line should be used in determining the boundary. We look forward to the Supreme Court's resolution of this issue. We believe it will conform with its earlier decision in the *Bambini* case.

The preliminary maps called for by the Tidelands Act have been published. They show 20 areas in the three coast counties that are filled tidelands, areas that were once subject to the ebb and flow of the tide, but which are now high and dry because of the fill material which was placed upon them. The maps indicate that artificially created or re-nourished beaches below the various seawalls are public trust lands. The maps also show where dredging has expanded tidal influence; trust ownership in these areas is disclaimed, in conformance with the *Bambini* decision. With a relatively minor exceptions, in all other areas, the current mean high water line is designated the boundary between public trust tidelands and privately owned lands. I read in the *Clarion Ledger* the day after the maps were published that I was a communist. Mr. Joe Baricev said the state coming and taking land away is just like communism. What is it called when an individual preempts the public's right to its own property?

The 60-day comment period has run; our tidelands office has received and reviewed about 85 comments. The tidelands office has also ceased to hear on a regular basis from several vocal citizens who have learned they will not be affected after all. Publication of the final map, however, has been enjoined pending resolution of the Bill Byrd appeal. We won't know until then whether the filled areas remain trust property or are donated to their current occupants.

Most of the acreage involved in the 20 areas was developed pursuant to statutory authority and will be exempt from the requirement of a lease regardless of the outcome of the current litigation. These areas include the public ports in the coast communities, the area occupied by Ingalls in Jackson County and several county industrial parks.

We have told private occupants in the nonexempt areas who have approached us that we will work with them during the pendency of the Byrd appeal. If an occupant needs financing, but cannot obtain it because of the uncertainty regarding title to the property, we will enter a long-term lease with him which would guarantee his right to occupy the property, but which would be canceled in the event we receive an unfavorable ruling from the Court.

Related to boundary issues is our very successful program for expedited boundary determinations for properties outside the 20 contested areas: they can apply to our office for a letter verifying that the public trust boundary is the current mean high water line. If the property borders tidal waters that were created by dredging, our letter will state that the property is not affected by public trust tidelands considerations. Because this letter is relied upon by financial institutions and title insurance companies, the sale and improvement of these properties proceeds smoothly. To date, we have issued boundary letters for more than 100 properties. We feel we have a very good relationship with coast realtors and real estate lawyers who have utilized this service.

Additionally, we have in place a leasing program for tidelands and submerged lands that last year produced revenues in excess of $43,000. As we expand our lease program to include nonexempt occupants in uncontested areas, we expect the amount of those revenues to increase. More than half the funds collected during the past fiscal year for tidelands and submerged lands leases, about $29,000, was presented in a check we sent to the Bureau of Marine Resources last month. Pursuant to the statutory mandate of the Tidelands Act, which incorporated the suggestions of the Blue Ribbon Commission, these funds are to be used by the BMR for new and extra programs of tidelands management, such as conservation, reclamation, preservation, acquisition, education, or the enhancement of public access to the public trust tidelands, or for public improvement projects relative to tidelands. We can't undo what has been done but we can initiate programs and policies that will guard against future destruction and degradation.

Returning finally to the question that is the topic of this conference, (that is, the implications of sea level changes for the Mississippi and Alabama coastlines), as I stated earlier, rising sea levels increase the area subject to the trust in Mississippi. In the *Bambini* decision, the Mississippi Court specifically addressed rising sea levels: "The geophysical tidal experience may enlarge trust properties. If over decades, epochs or even centuries 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. . . .The new tidelands so affected accrete to the trust." Our legislature agreed with this position when it enacted the 1989 tidelands bill, which sets out that, "the state recognizes that the boundary of the public trust tidelands is ambulatory and that the natural inland expansion of tide water over land not previously subject to the ebb and flow of the tide increases the land subject to the public trust."

The answer, then, is simple. In its practical and technical and legal implementation, however, I'm sure it will not be. I believe that throughout the rest of the day, and tomorrow, you will gain insight into the issues we face and sharpen the tools you need to meet the challenges presented by these issues.

This brings me to my final point and I hope you don't mind me expanding the focus here to take a brief look at the big picture. Today we are facing enormous pressures not only on the public trust tidelands, but also on all of these fragile wetland ecosystems. We read about our increasing coastal populations, the increasing amounts of marine trash and pollution, oil spills, loss of wetlands, dredging and filling, overfishing, and now, with the Persian Gulf crisis, increasing pressures to return to the old days of unrestrained oil and gas exploration, drilling and canal dredging associated with those operations. We read about the drying up of the everglades in Florida and the loss of wetlands at staggering rates in Louisiana.

Wetlands managers feel the pressures, too. Because of these pressures we are surely standing at a crossroads - all of us, academicians, marine biologists, scientists, land managers, water resources managers, conservationists, sports enthusiasts, businessmen, and politicians. We stand at this crossroads and we must make decisions which will affect the course of these ecosystems today and for hundreds of years in the future. We can choose to stand up to those seeking short-term objectives and profits; stand up to those who would have us diminish these lands; or we can give in and watch as the wetlands slowly disappear.

All of you know what I'm talking about too. All of you have felt the pressures in your positions as managers, protectors, and even scientists. Some of the pressures have been subtle and some not so subtle. In my role as trustee of the public trust tidelands, I have been accused of single-handedly destroying the economy of the Mississippi Gulf Coast and certainly the real estate market, despite the fact that professionals in the legal and banking community knew of the tidelands issue for decades. Those of you charged with enforcing the various regulatory laws have been asked to look the other way at an illegal catch or an obvious pollution or marine trash violation. The scientists have been asked to ignore test results on occasion, just for this one permit or just for this one industry. The compound result of all of these seemingly insignificant or one-time relaxations of rules and standards will doom these lands for all time and our gift to our children will diminished.

You are the front line. You fight for generations yet unborn. You have a sometimes thankless job. But you are the only hope for the future. Stay committed. Stay strong. Godspeed to you.

Responding to Global Warming Along the U.S. Coast

Jim Titus
U.S. Environmental Protection Agency
Washington, DC

Introduction

The process of responding to accelerated sea level rise in the United States is well underway, at least for a phenomenon that is not expected for several decades. Over the last 7 years, almost all of the coastal states have held at least one major conference on the subject, and a few of them have altered coastal development policies to accommodate a future rise. Public officials are generally familiar with the issue, as are representatives of the press, nongovernmental organizations, and coastal investors. The federal government has conducted assessments of possible nationwide responses, as well as implications for specific types of decisions such as the design of coastal drainage systems, maintaining recreational beaches, and protecting coastal wetlands. In Mississippi, the Secretary of State and legal scholars are clearly aware that a recent law governing the public trust lands may unconstitutionally give away far more land than was originally intended, if sea level rises as expected.

This paper examines possible responses to sea level rise in the United States, partly because the author has limited knowledge about the situation in Mississippi and partly because those who know what is happening there may benefit from a consideration of how the problem plays nationally. Because the most important question is what we should actually do in response to rising sea level, we focus primarily on the planning and engineering strategies that will determine how activities on the coast eventually change.

Future Responses: Shoreline Retreat and Flooding

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

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

Barrier Islands and the Open Coast

Oceanfront communities could respond to sea level rise protecting developed areas with dikes, pumping sand onto the beach and other low areas, or retreating from the shore. Along mainland beaches, the latter option generally implies no coastal protection; in barrier islands, however, it would also be possible to engineer a landward retreat of the entire island, creating new land on the bayside to offset that lost to oceanside erosion. The four options are illustrated in Figure 1.

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

Engineering a retreat would also be much less expensive than raising the island in place, because the latter option would require more (and higher quality) sand. However, this option would be vigorously opposed by the oceanfront owners who would have to move their houses to the bay side, as well as bayfront owners who might lose their access to the water. Moreover, filling new bayside land would disrupt back-bay ecosystems unless the estuary was also allowed to migrate landward onto the mainland (which we discuss later). As Table 2 shows, island raising would

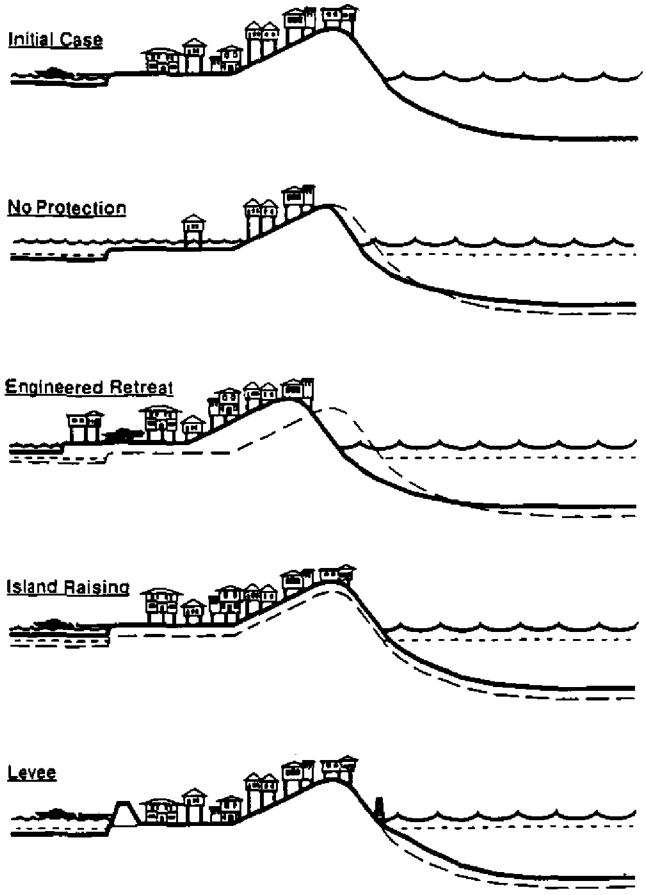

Figure 1. Response to sea level rise for developed barrier islands.

cost less than $600 per house per year until after sea level had risen more than 60 cm, which would be less than the rent for one week. Thus, we suspect that the more expensive but less disruptive approach of pumping sand onto beaches and the low bay sides of barrier islands would be the most commonplace, at least in the beginning.

Table 3 compares the ability of the four options to satisfy various desirable criteria. (Most of the rationale for this table is found in Titus, 1991). An important lesson from the Long Beach Island study is that the least expensive solutions are not always the most likely; dikes are culturally unacceptable and an engineered retreat is administratively difficult. Nevertheless, the noneconomic criteria should not always outweigh economics.

Leatherman (1989) estimated the quantity of sand necessary to hold back the sea for every coastal state but Alaska, and estimated the cost assuming that sand does not become more expensive. Titus et al. (1991) adjusted those cost estimates on the assumption that as least-cost supplies are exhausted, it will be necessary to go farther out to sea for suitable sand. Table 4 illustrates the resulting estimates of dredging costs for current trends and rises in sea level of 50, 100, and 200 cm. Titus et al. also estimated the cost of elevating buildings and utilities as sea level rises.

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

Sheltered Waters

Americans' affinity for beaches and concern for the environment have created a strong constituency

Table 1. Cost of sea level rise for four alternative options at Long Beach Island, NJ (millions of $U.S.).

Sea Level Rise (cm)	Total Cost: Dike with Beach	Raise Island	Island Retreat	No Protection
30	52	105	41	55
60	434	285	109	462
90	509	522	178	843
120	584	786	247	1,548
150	659	1,048	308	1,740
180	734	1,310	371	1,932
210	809	1,574	431	total loss
240	884	1,835	492	total loss

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

Source: Weggel et al. (1989): Dike Cost Yohe (1989): No Protection Source: Titus (1990)

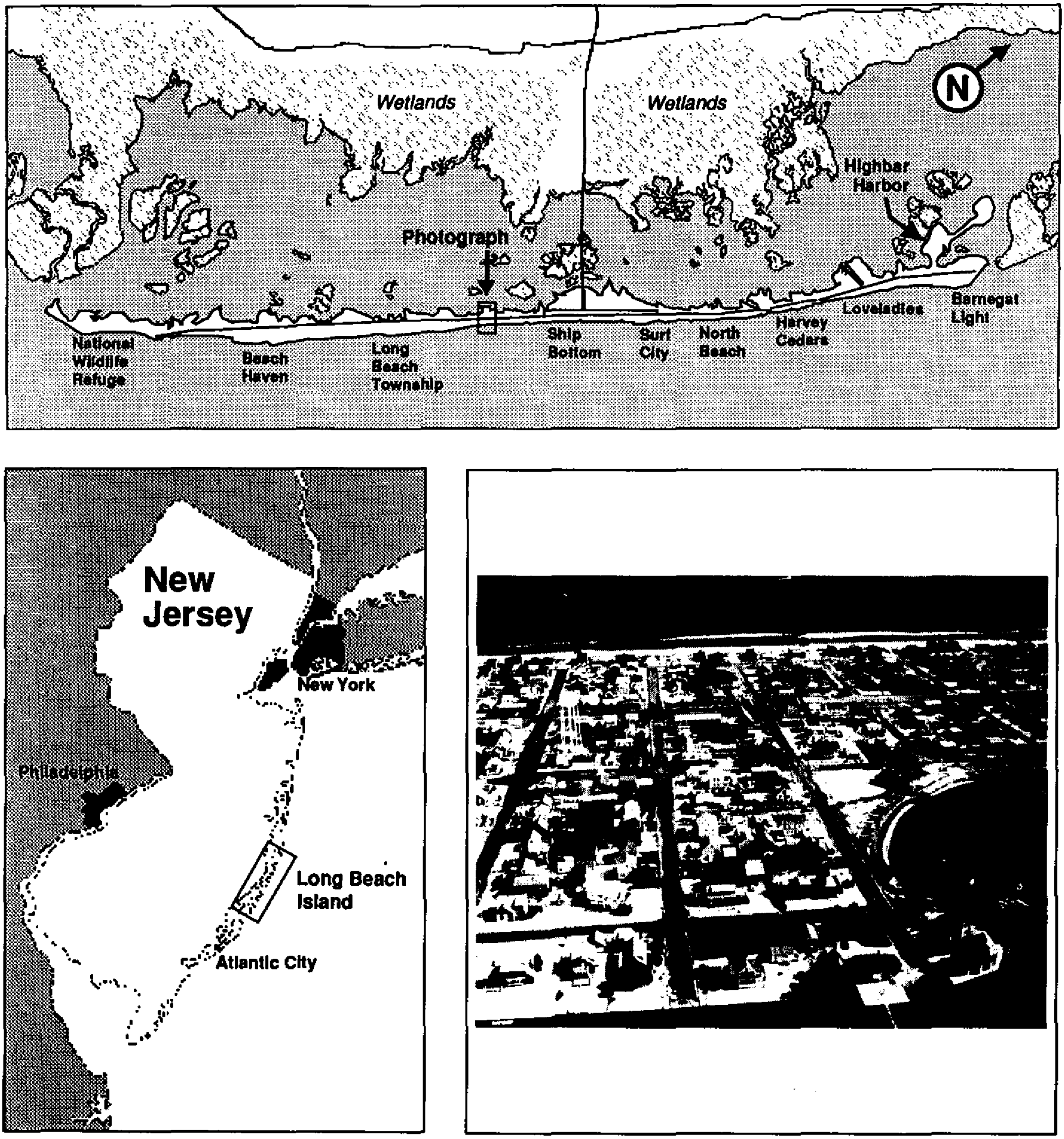

Figure 2. Long Beach Island, New York.

Table 2. Evolution over time of the relative costs of retreat Island raising, Long Beach Island, NJ.

Sea level above 1986 (cm)	Year*	Years it will take sea to rise 15 centimters	Cost (millions) Retreat	Cost (millions) Raise island	Cost ($/yr/house) Retreat	Cost ($/yr/house) Raise Island
15	2013	18	20	57	77	219
30	2031	14	34	85	168	420
45	2045	12	34	95	196	548
60	2057	11	34	110	214	692
75	2068	10	34	127	235	879
90	2078	9	34	132	261	1,015
105	2087	9	34	132	261	1,015
120	2096	8	34	132	294	1,142
135	2112	7	30	132	296	1,305
150	2126	6.5	30	132	319	1,406
165	2139	6	30	132	346	1,523

* Assuming global sea level rises one meter by the year 2100.
NOTE: All costs assume that until the particular year, the community has responded to sea level rise by raising the island in place.
Source: Titus (1990)

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

In a recent EPA report to Congress on the implications of global warming, Park et al. (1989) examined the potential loss of wetlands and dry land for a sample of 46 sites comprising 10 percent of the U.S. coastal zone, for three alternative responses: no protection, protecting areas that are densely developed today with dikes and bulkheads, and protecting all shores. For each site, Weggel et al. (1989) estimated the cost of protecting developed areas from a 2-meter rise. Titus et al. (1991) used cost functions suggested by Weggel et al. and estimates of inundated land from Park et al. to interpolate the cost estimates, and developed confidence intervals for the estimates of lost land.

Table 4 illustrates the nationwide results (the source studies provide regional detail). For a one-meter rise, the cost of protecting the most densely developed 1,000 square miles of coastal lowlands would work out to $3,000 per acre per year, which would generally warrant protection. However, such protection would increase the loss of wetlands by 300-500 square miles, and reduce the area of shallow water for submerged

Table 3. Ability of alternative responses to satisfy desirable criteria, Long Beach Island, NJ (assuming one-m rise by 2100).

Criteria	Policy: Dikes	Policy: Rise Islands	Policy: Engineered Retreat	Policy: Abandonment Forced	Policy: Abandonment Unplanned
Social Cost					
Cumulative ($ millions)	584	786	247	1,548	1,548
Present Value ($ millions, 3%)	115	130	46	170	170
Environmentally acceptable	No	Usually	Usually	Yes	Yes
Culturally acceptable	No	Yes	Yes	No	Maybe
Legal	Yes	Yes	Maybe	Maybe	Yes
Constitutional	Yes	Yes	Yes	Maybe	Yes
Institutionally feasible	Yes	Yes	Maybe	Maybe	Yes
Performs under uncertainty	Poor	Good	Good	Good	Good
Immmune to backsliding	Yes	Mostly	Somewhat	No	Mostly

Source: Titus (1990).

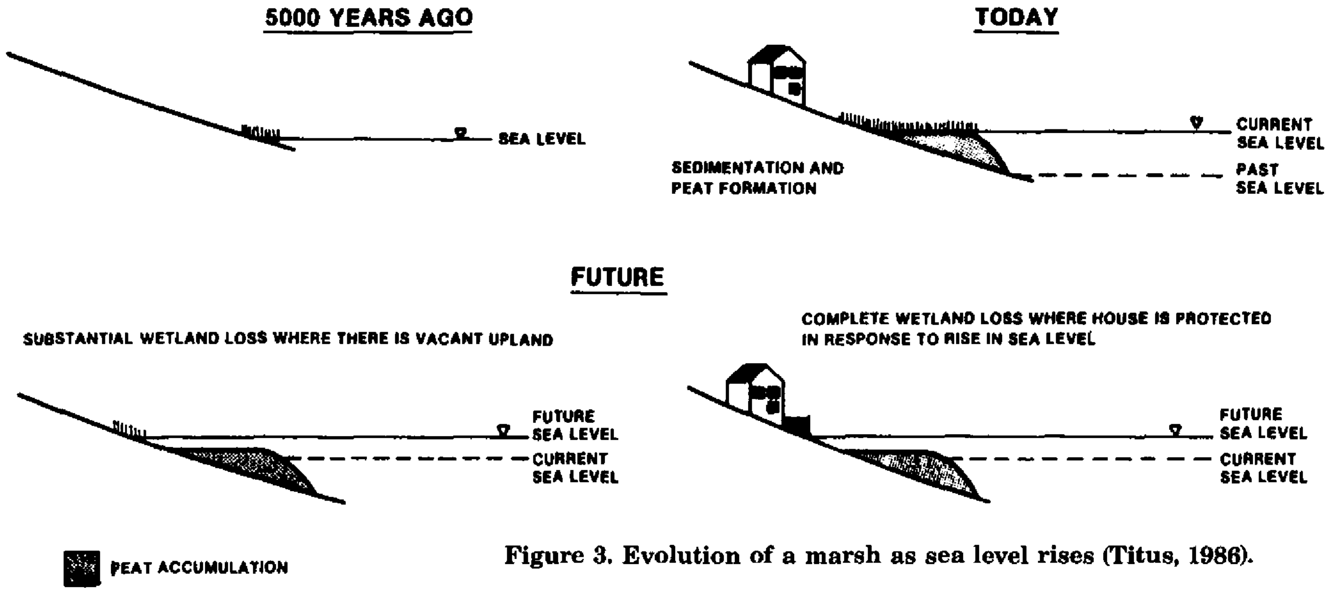

Figure 3. Evolution of a marsh as sea level rises (Titus, 1986).

vegetation by another 500-700 square miles. Moreover, many vacant areas are being rapidly developed. If all areas must be protected, the additional loss of wetlands would be 1,800-2,700 square miles, and another 3,000-7,000 square miles of shallow waters would be lost.

The political process will have to decide whether to abandon coastal lowlands to protect the environment. To help the necessary discussions get underway, we are circulating a draft that investigates seven options for enabling coastal wetlands to migrate landward (Titus 1991). The first two apply only to undeveloped areas: prohibiting development and purchasing coastal lowlands. The next three involve doing nothing today and purchasing land and structures when inundation is imminent; forcing people to move out when inundation is imminent; or hoping that protection will prove to be uneconomic. The final two options, which we call "presumed mobility," allow people to use their property as they choose, but on the condition that they will eventually abandon it if and when sea level rise threatens it with inundation; presumed

Table 4. Nationwide impact of sea level rise on the United States (billions of dollars unless otherwise stated).

	Baseline	50 cm	100 cm	200 cm
If No Shores Are Protected				
Dryland Lost (sq mi)	N.C.	3,315-7,311	5,123-10,330	8,191-15,394
Wetlands Lost (%)	N.C.	17-43	26-66	29-76
If Developed Areas Are Protected				
Dryland Lost (sq mi)	1,470-4,686	2,200-6,100	4,100-9,200	6,400-13,500
Wetlands Lost (%)	9-25	20-45	29-69	33-80
Value of Lost Land		52-130	86-212	112-297
Wetlands	5-43	11-82	17-128	19-144
Undeveloped Land	6-19	13-34	21-71	29-121
Land for Dikes	16-47	9-33	14-48	22-74
Cost of Coastal Defense		55-123	143-305	402-645
Open Coast:				
Sand	4	15-81	27-146	59-284
Elevate Structures	0	29-36	62-170	257-316
Sheltered Shores				
Dike Construction	0	5-13	11-33	30-101
Total Cost of Inundation and Erosion	20-51	128-232	270-475	576-880
If All Shores Are Protected				
Wetlands Lost (%)	N.C.	38-61	50-82	66-90

Source: Titus et al. 1991

mobility could be implemented whether by prohibiting construction of bulkheads and dikes, or by converting property ownership to long-term or conditional leases that expire when sea level rises a particular amount.

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

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

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

When Will A Response Be Necessary?

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

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

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

Future Responses: Mississippi Delta

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

As with other coastal areas, dikes and abandonment are both possible. However, there is a general consensus that these options should be avoided if possible because in either event, most of the delta's wetlands

Table 5. Alternative strategies for protecting natural shoreline areas that have not yet been developed.

Policy	Cost to public	Social Cost (vs. no sea level rise): present value	Social Cost (vs. no sea level rise): cumulative	Economic Efficiency	Performance Under Uncertainty: Sea Level	Performance Under Uncertainty: Economics	Constitutional	Equitable	Political feasibility	Risk of Backsliding
1. Prohibit Development	None None	Speculative Premium + <1% of base value	Land	Poor	No	Yes	No	No	None	Possibly
2. Buy Coastal Land	Speculative Premium	Speculative Premium + <1% of base value	Land	Poor	No	Yes	Yes	Yes	None	Possibly
Defer Action										
3. Order people out later	none	<1% of land and structures	Land and Structures	Fair	Yes	Perhaps	Maybe	Doubtful	Low	Very Likely
4. Buy out later	land and structures	<1% of land and structures	Land and structures	Fair	Yes	No	Yes	Yes	Low	Very Likely
5. Rely on elements/ economics	none	<1% of land and structures	Land and Structures	Fair (if it works)	Yes	Useless	Yes	Yes	Good	Low
Presumed Mobility										
6. No bulkheads	None	<1% of land value	Land + residual value of structures	Optimal	Yes	Yes	Probably	Usually	Good	Likely
7. Leases	<1% of land & residual of structures	<1% of land value	Land + residual value of structures	Optimal	Yes	Yes	Yes	Yes	Fair	Very unlikely

Source: Titus (1991)

would be lost, and those wetlands support 50 percent of the nation's shellfish and 25 percent of its fish catch. Thus, federal and state officials are focusing primarily on options to restore natural processes, which would enable at least a large fraction of the delta to survive even an accelerated rise in sea level. The U.S. Congress has authorized a number of projects to divert freshwater and sediment to wetlands by effectively cutting holes in the dikes. Under current policies, however, only a small fraction of the river water is likely to be diverted by such projects to avoid siltation of shipping lanes.

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

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

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

Future Responses: Saltwater Intrusion

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

Preventing Salinity Increases

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

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

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

Although dams can be useful, one must understand abandon the river as a supply of freshwater. Many argue that the river is polluted enough to view such a situation as a "blessing in disguise," and have suggested that the groundwater under Lake Pontchartraine would be a suitable source (Louisiana Wetland Protection Panel, 1987). Nevertheless, alternative supplies are finite, and may become increasingly scarce as the economy grows, especially in areas where the greenhouse effect fails to increase precipitation enough to offset the increased evaporation that warmer temperatures invariably imply.

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

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

The Need for Near-Term Action

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

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

Conclusion

No one would accuse the United States of overreacting to the prospect of a rise in sea level from the greenhouse effect; the process has been slow, but steady. After 7 years, we have reached the point where the relevant disciplines and the relevant government agencies are considering the issue and looking for opportunities to respond. Everyone realizes that it is difficult to convince politicians to make short-term sacrifices for the long-term good, but we have a public that is concerned about environmental quality in general and the greenhouse effect in particular.

Is action more urgent or less urgent in Mississippi than in other states? Along the open coast, it seems less urgent: you haven't developed your barrier islands. Moreover, the Sound's shoreline is so extensively developed that it will almost certainly be able to economically justify the cost of erecting any necessary dikes and renourishing the beaches. Given the ability to undertake these measures with relatively short notice, there is no reason to start **building** them today.

On the other hand, the need to undertake **institutional** measures may be greater here than elsewhere. As discussed in other articles in this proceedings, a literal interpretation of the tidelands act fixes the legal tidal boundary at a particular location, regardless of changes in the tides themselves. The net effect of such a law is that the state gives away its right to take over newly flooded lands. The original intent of the law was probably primarily administrative ease. It is a nuisance to continually remap property lines. Had they considered current sea level trends or the prospect of an accelerated rise, they would have realized that the effect of this law would be to give away the state's right to tidelands. Thus, it seems reasonable to argue that the law was an unconstitutional granting of public lands without compensation. Nevertheless, if this law is not corrected soon, people may gradually become accustomed to it and make decisions based on the assumption of its validity, which in time, might make future courts sympathetic.

There is little doubt that laws governing tidelands will have to be modified in most coastal states to explicitly address sea level rise. When the Mississippi Legislature next examines this issue—probably in response to pending court rulings—it should ensure that it not only addresses the narrow issues required to meet the Court's constitutional objections; it should also design a law that will leave future generations happy with the way it anticipated accelerated sea level rise. The easiest time to fix institutions to take sea level rise into account is when we are fixing it anyway.

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Sea Level Rise:
Policy Implications for the Mississippi Coast

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The Houses are All Gone under the Sea. (T.S. Eliot).

Introduction

For ages, the strong lure of the sea has attracted man, pulling him to that fragile area between the ocean and the land. This is no less true in 1990–in fact, a well-documented statistic is that in this decade, 50 percent of all Americans will live within 50 miles of the coastline.[1] Not only does this population shift mean additional stress on a delicate and important ecosystem, it also means added burdens on existing infrastructure.

An increasing coastal population presents a number of problems to policymakers and coastal managers. Finding a workable balance between growing development and the need to protect against the destruction of critical habitat have always been difficult issues to resolve, but are intensified by the growing numbers of people who want to be near the ocean and take advantage of its resources. However, as if the problems of serving greater numbers of people while protecting the environment were not enough of a challenge, there is a new problem on the horizon that further complicates coastal planning. Although it is known that the level of the sea changes over time, many researchers now believe that, due to global warming, the sea level is rising at an accelerated rate.

Recently, the possibility of global climate change has been the focus of a great deal of attention.[2] Although scientists have differing opinions about the extent to which the world's climate can be expected to change, as well as exactly what impacts any changes may bring, one thing is certain: if temperatures do rise, the environment will be affected in a variety of ways. Furthermore, it is clear that some of the most detrimental effects will be felt by coastal areas in the form of a rapidly rising sea level.

Although future planning for something with such a speculative nature is difficult, this paper proposes that it is not too soon for Mississippi to begin considering the regulatory implications that a sea level rise could bring. In fact, by implementing a management structure to prepare for the adverse effects of a rising sea level, the state could be strengthening its ability to address some of the more immediate concerns facing the Mississippi coast today.

The following discussion describes some of the existing federal authority that currently responds to the types of problems that would be intensified by sea level rise. It will also summarize the types of responses that have been made at the state or local level. Additionally, it will describe briefly some of the potential impacts the state is likely to see as a result of a sea level rise. Finally, it will suggest actions the state could take to improve its capacity to deal with this pending problem.

The Federal Government

While the number of federal laws that relate to the coastal zone and the agencies responsible for carrying them out are numerous, those with policies directly applicable to sea level rise are not. Nevertheless, several agencies are beginning to address the issue. For example, the U.S. Army Corps of Engineers (Corps) has perhaps the longest record of overseeing coastal development. Beginning with the Rivers and Harbors Act of 1899,[3] and continuing through other public work laws, the Corps has the authority to regulate development affecting America's navigable waters. Although it has not expressed a formal policy on sea level rise, it is currently reassessing the design of its coastal protection structures to accommodate for that eventuality.[4]

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Another federal agency directly involved in addressing coastal zone issues relevant to a sea level rise is the Environmental Protection Agency (EPA). The Clean Water Act[5] charges EPA to protect the United States' water resources, and in connection with this responsibility, EPA has been on the forefront in gathering information on sea level rise. Much of the research sponsored by EPA has discussed the implications of such changes and has suggested alternatives for policymakers to consider in preparation.[6]

The Federal Emergency Management Agency administers the National Flood Insurance Program,[7] which provides that the federal government bear some of the risk of flood loss in order to encourage sound land use.[8] This program also covers damage caused by erosion of the shoreline.[9] In the past, this program has been criticized for encouraging development by providing subsidized flood insurance in high hazard areas. However, the program has been reevaluated, and in the future, property owners will have to bear the majority of the costs from building in hazardous areas.[10] Obviously, a rising sea level would have an impact on the operation of this program.

The Coastal Barrier Resource Act also deserves mention in this context.[11] This Act creates the Coastal Barrier Resource System, made up of undeveloped coastal barriers on the Atlantic and Gulf Coasts.[12] Federal subsidies for hazard insurance and infrastuctural development are prohibited within these areas.[13] Because barrier islands stand to bear a major portion of the brunt from a sea level rise, any law or regulation controlling their management would be affected.

Although the above-mentioned federal legislation is relevant, certainly the legislation that provides the most comprehensive scheme of managing the coastal zone is the Coastal Zone Management Act.[14] This act creates a partnership between the federal and state governments to manage coastal areas. By developing federally approved coastal management programs, states are eligible to receive financial and technical assistance from the federal government. The states are also given the promise that all federal activities conducted within their coastal zone will be consistent with its approved coastal management program.

In furtherance of its goals of protecting coastal resources through a cooperative federal-state effort, the recently passed Coastal Zone Act Reauthorization Amendments of 1990[15] addresses sea level rise. With the creation of "Coastal Zone Enhancement Grants" the Act establishes a program to encourage improvements of state management programs in eight specified areas. One of these specified areas for which a state may apply and receive assistance is for "anticipating and managing the effects of potential sea level rise..."[16]

State Responses

According to a recent article by Paul Klarin and Marc Hershman,[17] the different state coastal management plans show various reactions to the threat of a rapid sea level rise.[18] The state responses can be grouped into four categories: (1) those that have shown no official recognition of sea level rise as a problem; (2) those that have expressed recognition and have taken initial steps to consider alternative responses to the threat; (3) those that have adopted new regulations or have modified existing regulations to accommodate the issue; and (4) those that have adopted an express policy and regulations geared at responding to sea level rise.[19]

It is not difficult to articulate reasons why the responses from coastal managers vary on this issue. Many commentators have noted the constraints involved in initiating a policy response to sea level rise.[20] It is always difficult to encourage proactive planning for future events, particularly when current scientific projections are uncertain. Political willingness to support changes that may be unpopular is especially difficult to generate, and the ever-present problem of limited finances makes it hard to devote fiscal resources to problems beyond the ones government faces daily. Nevertheless, these are not insurmountable obstacles. Creative and responsible planning for a sea level rise can be accomplished, and for Mississippi, its Coastal Program[21] is an appropriate vehicle for instituting workable policies. However, no planning can take place without an analysis of the problems sea level rise may bring. The following describes some of the types of impacts that are likely to be felt on the Mississippi coast. Many of the impacts described are already problems the area must deal with, which will only be intensified by a sea level rise.

Potential Impacts

(1) Increased Flooding. Flooding is always a problem in low lying areas like the Mississippi coast. Obviously, because of its low, flat terrain, the area can expect increased flooding as a result of sea level rise. Warmer temperatures would mean an increased frequency and intensity of storms, and higher tides would cause greater storm surges. Additionally, higher water tables would decrease storage capacity and cause slower water drainage.[22]

(2) Wetland Destruction and Saltwater Intrusion. Much has been written lately about the alarming rate of destruction of wetlands and the many reasons for their loss.[23] While historically, wetlands (particularly in undeveloped areas) have been able to keep pace with the rising sea level, a rapid rise will likely outpace many wetlands. Furthermore, in many instances, wetlands would not be allowed to retreat inland, because development would prevent migration.

Increased salinity would be an additional problem. The introduction of higher levels of saltwater would have a detrimental impact on the delicate nature of coastal wetland ecosystems, and would also threaten ground and surface water supplies.[28]

(3) Fisheries Degradation. A change in sea level will bring about a number of changes to fish habitat, with corresponding impacts on industries that depend on healthy, vital fish stocks. The destruction of wetlands will mean a loss of valuable breeding ground. Additionally, warming temperatures and changing currents will cause stresses on species that may be even more disruptive than the insults they currently face from pollution and over-fishing.

Detriment to fisheries would add further burdens to an already troubled fishing industry. Additionally, the support facilities for the fishing industry can expect degradation of their own: docks, marinas, and other facilities currently built immediately adjacent to the water's edge will be subjected to increased tidal and wave inundation.[25]

(4) Increased Beach Erosion. Beach erosion is a continual problem for Mississippi. A major portion of the state's sandy beaches are manmade: constructed to protect existing seawalls, to enhance the scenic quality of the area, and to provide recreational areas.[26] However, because of wind and tidal conditions, these beaches require constant renourishment to maintain their existence. The increased height of tidal crests that a sea level rise would bring would cause even greater beach erosion. Obviously, such erosion would have a negative impact on the tourist industry, which relies on drawing the public to the sandy beaches.

More importantly, erosion may diminish the beaches' important function as buffers against storm inundation. Research suggests that the beaches may erode more quickly in the underwater portion than the visible portion. This phenomenon, known to as "profile steepening," lessens the beach's ability to protect upland areas from storms.[27]

(7) Barrier Island Migration. Mississippi's barrier islands are primarily undeveloped, and as such have the potential to respond to a sea level rise naturally, either by "washing over" (caused as the island washes on the ocean side, and is built up on the Sound side by the storm pushing sand onto the shore), or by breaking up and drowning in place.[28] In either case, changes to the barrier islands would have an impact on the Mississippi Sound as well as the mainland. The islands offer protection from storms by bearing the brunt of wave action. They also contribute to the ecosystem of the Sound. Since the barrier islands absorb most of the impact of waves coming in from the open waters of the Gulf of Mexico, the Sound remains a relatively calm body of water.

Responses for Mississippi

According to the categories developed by Klarin and Hershman, Mississippi falls into that group of states whose coastal programs have recognized the need to implement policy, but as of yet have made no efforts beyond initial discussion stages.[29] However, Mississippi could easily move out of this category and into the one consisting of programs that have modified existing regulations to accommodate for a potential sea level rise.

Obviously, government officials are always reticent to propose any policies that appear to discourage development, especially in a state like Mississippi, which is currently experiencing a period of static growth[30]. The key is to implement policies that accommodate for sea level rise by promoting "sustainable development."[31] The idea is not to discourage development, but instead to encourage the type of development that is both ecologically and economically sound in light of the threat it faces from an impending sea level rise.

To this end, several options are available to state and local governments. These governments can revise zoning ordinances to mandate set backs and restrict development in flood prone areas, implement building codes that restrict size or impose certain engineering standards, or employ other land use mechanisms to discourage inappropriate development in hazardous areas.[32] Additionally, property tax structure can be used to control development. For example, incentives could be offered for property owners who develop for uses that are compatible with beach protection, or who choose to relocate structures currently situated in high-hazard areas.[33]

Authority granted to these entities can also be used to redesign the existing flood control and drainage systems to accommodate a sea level rise, or to preserve aquifers or other groundwater resources. Nonstructural, or "soft," engineering techniques—such as beach replenishment, bluff and wetland revegetation, or creation of buffer areas around critical areas—could be used to combat adverse effects of erosion or bluff destablization. Existing post storm policies can be reevaluated to restrict redevelopment in hazard-prone areas.[34] Finally, the state could consider the possibility of acquiring land and placing it in a conservancy program.[35]

Conclusion

Although it may be too early to know all of the consequences that may accompany a sea level rise, it is not too early to prepare. In fact, there is a strong argument that much of the needed planning for a sea level rise would be useful today. Since many of the ill effects of a sea level rise will be the exacerbation of existing problems, modifications to address sea level rise would not be merely an exercise in future planning. By using sea level rise as an "excuse" for strengthening Mississippi's Coastal Program, coastal managers would have an improved set of tools for handling today's problems, while putting the state in a position to respond to effects that are likely to be felt in the future. With some responsible and innovative planning, Mississippi's houses, unlike Eliot's, do not have to go under the sea.

Endnotes

1. *Committee On Merchant Marine And Fisheries, Oversight Report - Coastal Waters In Jeopardy: Reversing the Decline and Protecting America's Coastal Resources,* (1988). This statistic is also included in the Reauthorization Amendments of 1990 to the Coastal Zone Management Act. Pub. L. No.____ (1990).
2. Miller, *Policy Responses to Global Warming,* 14 S. Ill. L.J. 87, 229 (1990).
3. River and Harbor Act of 1899, 33 U.S.C. §401 *et seq.* (1982).
4. Meo, *Climate Change Impacts On Coastal Environments: Implications for Strategic Planning,* Coastal Zone '89 1384, 1386 (O.T. Magoon, *et al.* eds. 1989).
5. Federal Water Pollution Control Act, 33 U.S.C. § 1251 et seq. (1986).
6. *See* Office of Policy, Planning and Evaluation, Office of Research and Development, (Draft Report, 1988) *The Potential Effects of Global Change in the United States. Titus, Planning for Sea Level Rise before After a Coastal Disaster, in* **Greenhouse Effect and Sea Level Rise: A Challenge for This Generation** (M. Barth and J. Titus, ed. 1984); Titus, Greenhouse Effect, Sea Level Rise, and Barrier Islands: Case Study of Long Beach Island, New Jersey, 18 Coastal Mgmt. 65 (1990).
7. National Flood Insurance Act, 42 U.S.C. § 4001 *et seq.* (1976).
8. 42 U.S.C. § 4001 (1976).
9. 42 U.S.C § 4001 (9)(a)(c).
10. Tsai, *Coastal Barrier Resources Act and The National Flood Insurance Program Six Years After,* 4 Coastal Zone '89 3430, 3434 (1989).
11. Coastal Barrier Resource Act, 16 U.S.C. § 3501 *et seq.* (1982).
12. 16 U.S.C. § 3503 (1982). In the 101st Congress, Senator John H. Chafee (R.I.) proposed an amendment to the CBRA which would have also included 58,000 acres along the Great Lakes. However, this proposed amendment died on the calendar.
13. 16 U.S.C. § 3504 (1982). Many of Mississippi's coastal barriers, such as Round Island, Belle Fontaine Point, and Deer Island, are a part of the Coastal Barrier Resource System. United States Dept. of the Interior, Report to Congress: Coastal Barrier Resource System, Vol. 17 (1988).
14. Coastal Zone Management Act, 16 U.S.C. §§ 1451 - 1464 (1976 and Supp. III. 1979).
15. Coastal Zone Act Reauthorization Amendments, Pub. L. No____ (1990).
16. *Id.*
17. Klarin and Hershman, *Response of the Coastal Zone Management Programs to Sea Level Rise in the United States.* 18 Coastal Mgmt. 143 (1990).
18. *Id.* at 146.
19. *Id.*
20. *See* Klarin, *Response of the Coastal Zone Management Programs to Sea Level Rise in the United States, supra* note 17, at 156; Titus, *Planning for a Sea Level Rise Before and After a Coastal Disaster, supra* note 6, at 263.
21. Bureau of Marine Resources, Dept. of Wildlife, Fisheries and Parks, **Mississippi Coastal Program** (Revised 1988).
22. Titus, *Greenhouse Effect, Sea Level Rise, and Barrier Islands: Case Study of Long Beach Island, New Jersey, supra* note 6, at 67.
23. *See* Southworth, *Conserving Southeastern Coastal Wetlands,* 1990 Audubon Wildlife Rep. 223.
24. Environmental Protection Agency, Office of Policy, Planning and Evaluation, Office of Research and Development, (Draft Report), *The Potential Effects of Global Climate Change in the United States,* at 9-10 (1988).
25. Bigford, *Sea Level Change, Fisheries, and Coastal Planning,* 2 Coastal Zone, 1333, 1334-38 (1988).
26. Bureau of Marine Resources, Dep't of Wildlife, Fisheries and Parks. **Mississippi Coastal Program** (Revised 1988) at VI-10.
27. Titus, *Planning for Sea Level Rise Before and After a Coastal Disaster, supra* note 6, at 254.
28. Titus, *Greenhouse Effect, Sea Level Rise, and Barrier Islands: Case Study of Long Beach Island, New Jersey, supra* note 6, at 68.
29. In September 1990, MS's Bureau of Marine Resources, Alabama Department of Economic and Community Affairs, Mississippi State University, and the MS-AL Sea Grant Consortium sponsored the "Conference on the Long Term Effects of Sea Level Change for the Mississippi and Alabama Coastlines." At this conference, scientists, attorneys, coastal planners, policymakers, and concerned citizens discussed potential effects of sea level rise and policy options.
30. From 1987 to 1988, there was only a 3.5 percent change in the nonagricultural wage and salary employment in Mississippi. **Mississippi Statistical Abstract** at 226 (1989).
31. *See* **Sustaining Tomorrow: A Strategy for World Conservation and Development**, (F. Thibodeau & H. Field, ed. 1984).
32. An example might be to limit the availability of infrastructure. States with such limitations are: Florida, Maine, South Carolina and North Carolina. See Beach and Shore Preservation, Fla. Stat. Ann. § 161.011 *et seq.* (West 1990); Protection of Natural Resources, Me. Rev. Stat. Ann. tit. 38 § 480-A *et seq.* (1974 & Supp. 1990); Coastal Tidelands and Wetlands, S.C. Code Ann. § 48-39-10 *et seq.* (Law, Co-op 1976 & Supp. 1983).
33. Amendments to the Beach Preservation Act of 1972, Del. Stat. tit. 7 ch. 68 (1972).
34. *See* South Carolina Press Blue Ribbon Committee on Beachfront Management. 1987. "Report of the South Carolina Blue Ribbon Committee on Beachfront Management;" Use and Maintenance of Public Beaches, Tex. Nat. Res. Code Ann. § 61.001 *et seq.* (Vernon 1977).
35. *See* State Coastal Conservancy, Cal. Pub. Res. Code § 31000 *et seq.* (Deering, 1986); Coastal Wetland Acquisition, Tex. Nat. Res. Code Ann. § 33.231-33.238 (Vernon, 1977 & Supp. 1990).

Trace Gases, Equal Footing, and the Public Trust:

Ownership of Coastal Properties after the Greenhouse Effect

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Introduction

Every day the industrialized world pumps great quantities of contaminants into the air. Carbon dioxide and nitrous oxide, mainly from fossil fuel combustion and the burning of rain forests; methane, mainly from natural gas production, landfills, and farm animals; and chlorofluorocarbons, mainly from aerosol propellants, refrigeration, and automotive air conditioners, are collecting in the atmosphere. Because these gases take up only a small percentage of the air, they are known as "trace gases." The collection of trace gases is causing the atmosphere to trap more and more of the sun's heat. The likely result is a gradual warming that could lead to worldwide climatic change.[1]

The effects of a general increase in temperatures on a global scale would be dramatic. They could include: changes in cloud cover; increased vegetation growth; increased biological decay; and a reduction of the polar ice pack.[2] The "most pervasive and certain" impact of rising greenhouse temperatures, however, is the thermal expansion of the oceans and the melting glaciers, which "are likely to raise sea levels by 0.5 to 2.0 meters by the year 2100."[3] Such a dramatic shift in water levels would threaten major cities, destroy wetlands,[4] and completely reshape the world's coastal areas. Estuaries, coastal aquifers, and other water reserves will likely become more salty,[5] and rivers will also suffer as salt concentrations migrate upstream.[6] This, in turn, will make these areas less attractive breeding grounds for aquatic life and less fit for many human purposes.

The primary concern that coastal property owners have about a greenhouse-induced tidal rise is loss of their land and the improvements on that land due to flooding. Expensive homes and hotels that are now on the beachfront may one day be inundated, or at least partially flooded. As the water approaches these properties, the beachfront itself will also be lost.[7] In Mississippi, because of its simple geography, a simple one foot rise in sea level could erode the shore from 50 to 400 feet.[8] Coastal property owners, however, face a legal problem that may be as worrisome as the water itself. When their property becomes subject to tidal influences, they will lose title to it. Title will revert to the state, as trustee for the people of the state, under the public trust doctrine.

The public trust doctrine dates back at least to the sixth century and is well entrenched in the English common law.[9] It is based on the proposition that certain interests, such as navigation and fishing, are so intrinsically important to every citizen that their free availability is necessary if the society is ever to develop and prosper.[10] Private ownership of these waters would therefore conflict with the needs of society.[11] The United States Supreme Court has held it "inconceivable" that any person would claim a private property interest in the navigable waters of this country.[12] As the Mississippi Supreme Court has declared "fee simple title to all lands naturally subject to tidal influence, inland to today's mean high water mark, is held by the State of Mississippi in trust [for the public good]."[13]

The Mississippi public trust was formed in 1817, at the time of Mississippi's admission to the Union. After the Revolutionary War, the colonies retained their navigable waters and submerged coastal lands, to be held in trust for their people.[14] As new states were admitted to the Union, they were given an "equal footing" with the other states, so each new state received property to be held in trust for public purposes.[15] In this trust, was the fee simple title to the tidelands and navigable waters of the state.[16] These lands were to be held in the public trust for various purposes. Over the years, Mississippi law has recognized those purposes as including fishing,[17] navigation and transportation,[18] commerce,[19] bathing, swimming and other recreational activities,[20] development of mineral resources,[21] environmental protection and preservation,[22] the enhancement of aquatic, avarian and marine life, sea agriculture, and other purposes.[23]

Rising Water Levels and the Public Trust Boundary

Since the boundary of the public trust is defined by the ebb and flow of the tide, one issue that will emerge in the next century is whether the state takes control of property that had been in private hands, but which has become subject to the ebb and flow of the tide due to higher water levels caused by the greenhouse effect.[24] The Gulf's high tide mark "in theory, at least – [is] ascertainable as of 1817."[25] However, because water boundaries shift, the 1817 boundaries are not the ones of import for determining which lands are held in trust by the state today. The Mississippi Supreme Court has held that:

> Where the forces of nature — gradually and imperceptibly — have operated to expand or enlarge the inland reach of the ebb and flow of the tide, the new tidelands so affected accrete to the trust. Put otherwise, state law decrees that the surveyable outer boundary of the trust . . . is **today's** mean high water line, regardless of the absence of a tidal influence in 1817...[26]

Thus, under traditional public trust law, current property owners will lose their title to the state if their land becomes subject to tidal influence due to a gradual, greenhouse induced rise in water levels.[27] Moreover, the state would be able to claim not only a right of way on the water and tidal lands, but mineral rights would also accrete to the state (including the right to drill for oil and to grant oil exploration leases).[28]

If land formerly held in private ownership were, over the relatively short period of a few decades, transferred to state ownership due to the greenhouse effect, particularly where the property could still be of value to the private owner, one might expect the state to accommodate the prior owner by refusing to assert authority over the property, by selling the property back to the former owner, or by granting the former owner a long-term lease at a favorable price. There will certainly be political pressure for such a solution. Because legislatures often receive pressure from landowners, and because individual states have the authority to define the boundaries of the public trust,[29] legislatures have often succumbed to public pressure to give up trust lands, but courts have jealously guarded the trust.[30]

The most celebrated public trust case in American law is *Illinois Central Railroad Company v. Illinois*.[31] In 1869, the Illinois Legislature made an extensive grant of submerged lands to the Illinois Central Railroad. That grant included all the land underlying Lake Michigan for one mile out from the shoreline and extending one mile in length along the central business district of Chicago–more than 1,000 acres of land.[32] The Supreme Court declared the grant invalid.[33] The rationale underlying this holding is that the government operates in order to provide widely available public services, such as schools, police protection, libraries, and parks. While there may be valid reasons to benefit some small discrete group, there is usually some relatively obvious reason for doing so, such as a need to assist the poor. However, when a program benefits a certain group and there is no obvious reason for singling out this group, suspicions should be aroused.[34] Any such conveyance should be viewed with great skepticism.[35]

The Mississippi Legislature has received political pressure from coastal property owners, and in 1989 it responded with the Public Trust Tidelands Legislation.[36] That legislation directs the Secretary of State to prepare a map of Public Trust Tidelands.[37] After the map is completed and approved, trust boundaries will be fixed, and property owners will be issued certificates indicating that their property is not part of the trust.[38] The legislation, in essence, fixes trust boundaries at their 1973 location and prohibits them from moving with the tide.[39] This legislation is obviously intended to protect landowners who might otherwise lose title to their land. However, it is at odds with the purposes of the Public Trust.

Although the Act purports to recognize the importance of the Public Trust and purports to adhere to the common law doctrine,[40] it departs dramatically from the common law rule that boundaries move with the ebb and flow of the tide.[41] The Secretary of State's interpretation of the Act is that:

> This law requires the line of public trust tidelands in developed areas to be placed at the mean high water line as of July 1, 1973...to be revised only if more accurate information with respect to the line of mean high water at that date is received during the ensuing 60 days.[42]

Thus, the legislation certifies that the state will not claim dominion over property which would otherwise accrete to the trust. The Secretary has challenged the Act, claiming that it amounts to a donation in violation of the Mississippi Constitution, which provides: "Lands belonging to, or under the control of, the state shall never be donated, directly or indirectly, to private corporations or individuals..."[43]

The constitutionality of this legislation has been put at issue in *Byrd v. Mississippi*.[44] That case is currently under appeal to the Mississippi Supreme Court, but the lower chancery court has upheld the legislation. The primary concern of the chancery court seems to have been the confusion, difficulty, and expense that is involved with surveying the trust's boundary line. The chancery court held that:

> There was no attempt by the legislature . . . to **change** the boundary for it cannot be changed. It is the same as

it was in 1817. However, a procedure was enacted which will facilitate the **location** of the boundary, for it must be remembered that the 1817 boundary is elusive and there are no photographs or known physical surveys which can precisely locate it as it actually existed in 1817.[45]

The chancery court is wrong. The trust boundary can change, and it does change. The location of the 1817 boundary is irrelevant. The Mississippi Supreme Court's boundary definition, which is in accord with public trust law in almost every other state, places the boundary at **today's** mean high tide line, not the 1817 high tide line.[46]

The *Byrd v. Mississippi* case is now on appeal and should come before the Mississippi Supreme Court within the year. The Supreme Court has some very important decisions to make. If the greenhouse effect causes a general one foot increase in water levels, the Mississippi shoreline will move in some areas by as much as 400 feet.[47] A larger increase in water levels will shift the shoreline even further. If these lands are held as private property, and the boundaries of the trust are not allowed to shift with the coast, the public may be denied access to these waters and effectively denied all of the rights that the public trust has protected over the centuries.[48] For instance, if submerged land is held in private ownership 400 feet out into the water then people might be prohibited from fishing or swimming in those waters all up and down the coast. The Public Trust has protected individuals and individual rights in the past, but if the new legislation is allowed to stand, these rights may be lost, along with numerous other rights.

As noted earlier, this legislation has the effect of conveying trust property to private ownership. Such conveyances conflict with the restrictions placed on governmental authority over trust land and have been universally condemned. The public trust doctrine requires that trust property be held available for use by the general public and not be sold, even for a fair market price.[49] It is possible for the state to convey some interest, but only if the public's rights are protected.[50] For example, most property owners on the coast own only a part of their property. The public at large still holds the right to use the waters and submerged lands in keeping with the trust purposes. That is the typical rule when trust lands are conveyed into private ownership.[51] The Mississippi legislation, however, will have the effect of transferring complete title to private owners, to the exclusion of the general public.

Until this recent legislation, Mississippi law had been clear. Mississippi public trust law prohibits disposition or use of trust property except in furtherance of public purposes, and then only by approval of the legislature.[52] The Mississippi Constitution also prohibits the state from donating property under its control to private interests.[53] These prohibitions have been held to preclude the sale of trust property at prices below the fair market value.[54] Long-term leases at less than fair market prices are also prohibited.[55] The state, acting as trustee, has a duty to manage the trust so as to reasonably maximize the income from it. Thus, any benefit bestowed on a private entity at the expense of the general public violates the state's duty.[56] The 1989 Mississippi legislation does just that.

Conclusion

If the greenhouse effect does actually lead to dramatic shifts in water levels, the Public Trust Doctrine will emerge as a critical legal issue for the next century. Steps may be taken today to help minimize adverse greenhouse effects and to prepare for the new waterlines, but the state should not let property ownership concerns infringe on the public's right to use these properties.

The 1989 Public Trust Tidelands legislation should be overturned. It is not surprising that the Mississippi Legislature gave in to political pressure from coastal property owners; however, the Mississippi Supreme Court should not allow this legislation to stand. Although individuals may lose property due to a greenhouse induced tidal change, the superior right of the public should not be defeated. Navigable and coastal waters have long held positions of extreme importance to the public in general. The public's right to use and enjoy tidally affected coastal waters should be recognized as paramount to concerns over boundaries. Those who now own property that may become subject to tidal influences have sufficient time to prepare. They should recognize that their property may gradually – imperceptibly – be encroached upon by water. They should also realize that this may cause them to lose title to their property. This does not mean that they need to sell their property tomorrow. Their land will remain usable and enjoyable for decades to come. It might, however, one day begin to decrease in value. That is true of any real estate.

This is but one factor that should weigh in the calculation of whether to build, buy, or sell coastal property. If concessions must be provided to current property owners, they should be granted monetary compensation or the limited subservient interest, at most, while the public retains the right to use use and enjoy navigable and coastal waters.

In place of the 1989 Public Trust Tidelands Legislation, the Mississippi Legislature could enact legislation similar to that in Maine, which requires the removal of manmade obstructions as the water rises and wetlands migrate inward.[57] Additionally, the state could benefit from legislation requiring tidal changes to be considered before any new construction is begun in coastal areas.[58] And even though Mississippi has few air pollution problems, compared to other states, it certainly would not hurt to focus on reducing the production of trace gases and try to lessen the greenhouse effect.[59] Any of these enactments would be far more welcome than the 1989 legislation. The Public Trust has protected the public's right to use and enjoy the world's waters and coastlines for centuries. It should be allowed to remain a vital and useful means of protecting such rights as we enter into the next century.

Endnotes

1. *See generally* S. Schneider, *Global Warming: Are We Entering the Greenhouse Century?* (1989); S. Roan, *Ozone Crisis* (1989). It must be noted that not all scientific evidence supports the theory. At least one theory suggests that the effect will lead to more cloud cover, reducing temperatures. Moreover, with any issue as political as the environment, political posturing may sometimes distort a true picture. Consider the following statement by Stephen Schneider of the National Center for Atmospheric Research and author of the book, *Global Warming: Are We Entering the Greenhouse Century?*:

   > On the one hand, as scientists, we are ethically bound to the scientific method, in effect promising to tell the truth, the whole truth, and nothing but - which means that we must include all the doubts, the caveats, the ifs, ands, and buts. On the other hand, we are not just scientists, but human beings as well. And like most people we'd like to see the world a better place, which in this context translates into our working to reduce the risk of potentially disastrous climatic change. To do that **we need to get some broad based support, to capture the public's imagination. That, of course, entails getting loads of media coverage. So we have to offer up scary scenarios, make simplified, dramatic statements, and make little mention of any doubts we might have.** This "double ethical bind" we frequently find ourselves in cannot be solved by any formula. Each of us has to decide what the right balance is between being effective and being honest. I hope that means being both.

   Schell, *Our Fragile Earth*, Discover, Oct., 1989, 44, 47 (emphasis added). Schneider's remarks have led one conservative commentator to charge that what is written and stated on global warming "is almost always from environment fanatics more interested in dramatic statements than in being honest." Paul Harvey, syndicated column, *reprinted in* The Oxford [Mississippi] Eagle under the headline "Confessions of an Alarmist," Jan. 25, 1990, p. 4, col. 1. Nonetheless, the weight of the evidence and expert opinion suggests that if present trends continue the earth will experience a general increase in temperatures. In fact, the earth may have already experienced a slight increase in temperatures due to greenhouse gases. The 1980s were the warmest decade in human history. Miller, *Policy Responses to Global Warming*, 14 So. Ill. U.L. Rev. 187, 194 (1990). *See also* Solomon and Freedberg, *The Greenhouse Effect: A Legal and Policy Analysis*, 20 Environmental Law 83, 89 (1990) ("scientists have concluded that global temperatures have increased from 0.5 to 0.7 degrees C over the last century").
2. Shabecoff, Global Warming: Experts Ponder Bewildering Feedback Effects, N.Y. Times, Jan. 17, 1989, at C1, col. 1.
3. Solomon and Freedberg, *supra* note 1, at 93; Miller, *supra* note 1, at 190 ("models currently predict a rise of 0.5 to 1.5 meters during the next 50 to 100 years"); Titus, *Greenhouse Effect, Sea Level Rise, and Barrier Islands: Case Study of Long Beach Island, New Jersey*, 18 Coastal Management 65, 65 (1990) ("the greenhouse effect is likely to raise sea level a few feet in the next 100 years"). The level of the increase, however, is subject to dispute. *Id.* at 66.
4. The importance of wetlands was recognized only in fairly recent times. In the mid-1800s, the federal government viewed wetlands mainly as a health menace and a hindrance to land development. President's Council on Environmental Quality, *Fifteenth Annual Report of the Council on Environmental Policy* 274 (1984). That perception continued more or less unchanged until a 1956 publication, entitled *Wetlands of the United States*, was issued to set forth the value of wetlands to wildlife. *Id.* at 275. Since 1956, a number of environmental studies have been published that document the ecological value of these unique land-water environments. *Id.*

   Mississippi's Yazoo Basin contains numerous wetlands which serve as nurseries and breeding grounds for fish and wildlife. These animals depend on the swampy ecosystems for food and shelter. These extremely valuable natural resources are also among the prime wintering areas for migratory waterfowl in Mississippi. Loss of these wetlands could seriously impact on wildlife populations.
5. Solomon and Freedberg, *supra* note 1, at 96.
6. *Id.* at 98.
7. Some states are taking steps to assure that the beaches will not be lost by requiring removal of any building seaward of the vegetation line and by requiring new construction to be set far enough back from the waterline to offset any foreseeable water level increase. Titus, *supra* note 3, at 70-1.
8. *Id.* at 66.
9. For a thorough account of the ancient history of the Public Trust Doctrine, *see* Sax, *The Public Trust Doctrine in Natural Resource Law: Effective Judicial Intervention*, 68 Mich. L.Rev. 471, 475-78 (1970). *See also* J. Kalo, *Coastal and Ocean Law* 73 (1990) (tracing the history back to ancient Romans and noting renewed interest in the doctrine following the signing of the Magna Carta).
10. Martin v. Lessee of Waddell, 41 U.S. (16 Pet.) 367, 414 (1842).
11. *See* Rychlak, *Society's Moral Right to Punish: A Further Exploration of the Denunciation Theory of Punishment*, ____ Tulane L.Rev. ____ (Dec. 1990) (discussing the needs of society and the reasons for its formation).
12. United States v. Chandler-Dunbar Water Power Co., 229 U.S. 53, 69 (1913).
13. Clinque Bambini Partnership v. State, 491 So. 2d 508, 510-11 (Miss. 1986), *aff'd sub nom.* Phillips Petroleum Co. v Mississippi, 484 U.S. 469 (1988).
14. United States v. California, 332 U.S. 19, 30 (1947); Martin v. Lessee of Waddell,

41 U.S. (16 Pet.) at 410; Pollard v. Hagan, 44 U.S. (3 How.) 212 (1845).

15. Cinque Bambini Partnership v. State, 491 So. 2d at 511. Those public purposes include navigation and transportation, commerce, bathing, swimming and other recreational activities, development of mineral resources, environmental protection and preservation, the enhancement of aquatic, avarian and marine life, sea agriculture and other purposes. *Id.* at 512.
16. *Id.* By contrast, although navigable fresh water is held in public trust, the land underneath navigable freshwater rivers, lakes and streams can be privately owned. Dycus v. Sillers, 557 So.2d 486, 498 (Miss. 1990). As the Mississippi Supreme Court has explained:

    "Upon the admission of the state into the Union, there became invested in the state, as trustee, the title to all the land under tidewater, including the spaces between ordinary high and low water marks; this title of the state being held for public purposes, chief among which purposes, is that of commerce and navigation...").

    Rouse v. Saucier's Heirs, 166 Miss. 704, 713, 146 So. 291, 291)92 (1933). *See also* State *ex rel.* Rice v. Steward, 184 Miss. 202, 230-31, 184 So. 44 (1938) ("[W]e hold the State of Mississippi to be the absolute owner of the title of the soil, and of the minerals contained therein...wherever the tide ebbs and flows, as trustee for the people of the State"); *id.* at 222, 184 So. at 50 ("[T]he state holds the ties to the land beneath tidewaters, as trustee for the people, subject only to the paramount right of the United States to control commerce and navigation").
17. State *ex rel.* Rice v. Stewart, 184 Miss. at 231, 184 So. at 50.
18. Rouse v. Saucier's Heirs, 166 Miss. 704, 146 So. 291, 192 (1933); Martin v. O'Brien, 34 Miss. 21 (1857).
19. Rouse v. Saucier's Heirs, 146 So. at 292.
20. Treuting v. Bridge & Park Com., 199 So. 2d 627, 632-33 (Miss. 1967) (recreational activities recognized as included within public trust rights). *See also* Miss. Code Ann. 49-27-1 *et seq*; Miss. Code Ann. 15-1-4 (Supp. 1988) ("Public waterways" defined and the right of free transport, fishing and water sports reserved to the public).
21. Treuting v. Bridge & Park Com. 199 Soi. 2d at 633; Cinque Bambini Partnership v. State, 491 So 2d at 512.
22. Miss. Code Ann., §§ 49-27-and -5(a) (Supp. 1985).
23. Cinque Bambini Partnership v. State, 491 So. 2d at 512; Dycus v. Sillers, 557 So. 2d at 498 (containing an essay on the joys of fishing).
24. This matter is governed by state law. Oregon *ex rel.* State Land Board v. Corvallis Sand and Gravel Co., 429 U.S. 363 (1977). *See also* Cinque Bambini Partnership v. State 491 So. 2d at 519. *Cf.* Hughes v. Washington, 389 U.S. 290 (1967) (federal law controls ownership of land gradually deposited by the ocean on adjoining upland property conveyed by the United States prior to statehood).
25. Cinque Bambini Partnership v. State, 491 So. 2d at 515. *But see* Byrd v. Mississippi, No. 17,879, slip op. at 7-8 (Chancery Ct. of Harrison Co., Miss., 2d Jud. Dist. 1990) (noting the difficulty of actually determining the 1817 boundary).
26. Cinque Bambini Partnership v. State, 491 So. 2d at 520 (emphasis in original) (footnotes omitted) (citing O'Neill v. State Highway Department, 50 N.J. 307, 235 A.2d 1, 9-12 (1967). *See also* Maloney and Ausness, *The Use and Legal Significance of the Mean High Water Line in Coastal Boundary Mapping*, 53 N.C. L. Rev. 185 (1974). *But see* Byrd v. Mississippi, *supra* note 25 (indicating that the boundary does not move).
27. Hilt v. Weber, 252 Mich. 198, 219, 233 N.W. 159, 165-66 (1930) (noting that this is a "general-perhaps universal" rule). *But see* Miss. Code Ann. 29-15-1 (Supp. 1989) (fixing trust boundaries at their 1973 location).
28. *See generally* Cinque Bambini Partnership v. State, 491 So. 2d at 511 (involving the right to grant oil leases); Treuting v. Bridge & Park Com., 199 So. 2d at 633.
29. Phillips Petroleum Co. v. Mississippi, 484 U.S. at 479.
30. *See, e.g.,* Illinois Central Railroad Company v. Illinois 146 U.S. 387 (1892) (legislature gave trust property to railroad, but court voided the conveyance).
31. 146 U.S. 387 (1892).
32. J. Kalo, *supra* note 9, at 73.
33. The Supreme Court decision was a four to three split. Chief Justice fuller disqualified himself because he had represented the railroad in the lower courts, and Justice Blatchford disqualified himself because he held stock in the railroad. *Id.*
34. *See* Martin v. Lessee of Wadell, 41 U.S. (16 Pet.) at 411 (conveyances of trust property are "construed strictly").
35. State *ex rel.* Haman v. Fox, 100 Idaho 140, 594 P.2d 1093, 9 Envtl. L. Rep. 20,507 (1979) (quoting Sax, *supra* note 9, at 490); People *ex rel.* Scott v. Chicago Park Dist., 66 Ill. 2d 65, 360 N.E.2d 773, 7 Envtl. L. Rep. 20, 346 (1976) (same). *See also* Rychlak, *Thermal Expansion, Melting Glaciers, and Rising Tides: The Public Trust in Mississippi ____ Miss. Col. L.Rev. ____ (1990).*
36. *See* Miss. Cod Ann. SS 29-15-1 *et seq.* (Supp. 1989).
37. *Id.* § 29-24-7 (1).
38. *Id.* § 29-25-7 (4).
39. *Id.*
40. *Id.* § 29-15-7 (2).
41. The common law approach is that accretions to the shores of the sea belong to the riparian or littoral owner of the land bordering the sea. *See, e.g.,* Humble Oil & Refining Co. v. Sun Oil Co., 190 F.2d 191 (5th Cir. 1951), *cert. denied*, 342 U.S. 920 (1952); Jackson v. United States, 56 F.2d 340 (9th Cir. 1932). Mississippi public trust law is in accord and holds that the owner of land bounded by water is entitled to accretions thereto. Cinque Bambini Partnership v. State 491 So. 2d at 519; H.K. Porter Co. v. Board of Supervisors, 324 So. 2d 746, 751 (Miss. 1975); Paepcke v. Kirkman, 55 F.2d 814, 815 (5th Cir. 1932); Anderson)Tully Co. v. Franklin, 307 F. Supp. 539, 542 (N.D. Miss. 1969).
42. Byrd v. Mississippi, *supra* note 25, slip op. at 11 (quoting the reply brief of the Secretary of State).
43. Byrd v. Mississippi, *supra* note 25, slip op. at 1. Section 95 of the Mississippi Constitution states as follows:

    "Lands belonging to, or under the control of, the state shall never be donated, directly or indirectly, to private corporations or individuals, or to railroad companies. Nor shall such land be sold to corporations or associations for a less price than that for which it is subject to sale to individuals. This, however, shall not prevent the legislature from granting a right of way, not exceeding one hundred feet in width, as a mere easement, to railroads across state land, and the legislature shall never dispose of the land covered by such right of way so long as such easement exists."
44. *Supra* note 25.
45. *Id.* at 6.
46. Cinque Bambini Partnership v. State, 491 So.2d at 520 (emphasis in original) (footnotes omitted) (citing O'Neill v. State Highway Department, 50 N.J. 307, 235 A.2d 1, 9-12, 1967). The chancery court wrote that, "some compromise must be effected between the purity of the [Supreme Court's] boundary definition and the needs of the people of the State of Mississippi." Byrd v. Mississippi, *supra* note 25, slip op. at 8. *See also* Maloney and Ausness, *The Use and Legal Significance of the Mean High*

Water Line in Coastal Boundary Mapping, 53 N.C. L. Rev. 185 (1974).

47. Titus, *supra* note 3, at 66.

48. *But see* 31:32 Ocean Science News 2, 3 (Nov. 15, 1989) (reporting on a presentation made by David D. Caron, acting Professor of Law at the University of California, Berkley, identifying advantages of fixed *national* boundaries).

49. Sax, *supra* note 9, at 477. *See, e.g.*, Hayes v. Bowman, 91 So. 2d 795, 799 (Fla. 1957) (state cannot make conveyance of trust property if doing so would interfere with the public's enjoyment). The last requirement is expressed in two ways. Either it is urged that the resource must be held available for certain traditional uses, such as navigation, recreation, or fishery, or it is said that the uses which are made of the property must be in some sense related to the natural uses peculiar to that resource. As an example of the latter view, a beachfront in Biloxi might be said to have a trust imposed upon it so that it may be used for only water-related commercial or amenity uses. A dock or marina might be an appropriate use, but it would be inappropriate to fill the area for trash disposal or for a housing project. Sax, *supra* note 9, at 477.

50. A few courts have denied completely the power of the state to alienate trust property. *See Waters and Water Rights* Vol. 1, p. 197, 36.4(A) (R. Clark ed., 1967) (citing People *ex rel.* Harbor Comrs. v. Kerber, 152 Cal. 731, 93 P. 878 (1908) (following Cal. Const., Art. XV, 3)); Northern P. R. Co. v. Hirzel, 29 Idaho 438, 161 P. 854, 860 (1916) (railroad not permitted to take title to trust property); Milne v. Girodeau, 12 La. 324, 325 (1838) (land below the high water mark cannot be privately owned); Hodges v. Williams, 95 N.C. 331 (1886); State *ex rel.* Cates v. West Tennessee Land Co., 127 Tenn. 575, 158 S.W. 746, 747 (1913).

51. Bychlak, *supra* note 35; *Waters and Water Rights, supra* note 50, at Vol. 1, p. 197, § 36.4(A).

52. Cinque Bambini Partnership v. State, 491 So. 2d at 513. *But see* Miss. Code Ann, 29-15-1 *et seq.* (Supp. 1989); Byrd v. Mississippi, *supra* note 25 (slip op.) (upholding the Mississippi legislation; case currently under appeal). Thus, the state may not convey fee simple title to trust property unless it is for a higher public purpose and the legislature has approved. Cinque Bambini Partnership v. State, 491 So. 2d at 513. Moreover, such lands are not subject to claims of adverse possession. *Id.* at 521; Miss. Const. Art. 4, 104 (1890); Board of Education v. Loague, 405 So. 2d 122, 124-25 (Miss. 1981); Gibson v. State Land Comm'r, 374 So.2d 212, 217 (Miss. 1979). Public use can, however, cause private lands to be claimed by the state through adverse possession. Dycus v. Sillers, 557 So. 2d at 501. *See also* O'Dell and Howorth, *Alabama Tidelands After Phillips Petroleum v. Mississippi: Time to Reinvigorate the Public Trust*, 20 Cumberland L. Rev. 365, 387 (citing University of South Alabama v. Alabama, No. 83-1242, slip op. at 1 (Ala., filed July 19, 1984)). *But see* Board of Trustees v. Rye, 521 So. 2d 900, 908 (Miss. 1988) (upholding the tax sale of school trust property and holding that even if the sale had not been effective, plaintiffs would have had an adverse possession claim).

53. Miss. Const. Art. 4, 95 (1890). *But see* Board of Trustees v. Rye, 521 So. 2d at 908 (upholding the tax sale of school trust property).

54. Koonce v. Board of Supervisors, 202 Miss. 473, 477-78, 32 So. 2d 264, 265 (1947) (involving the sale of school trust land). *See also* State *ex rel* Kyle v. Dear, 209 Miss. 268, 279, 46 So. 2d 100, 104 (1950) (involving the sale of timber at below market prices); State *ex rel.* Coleman v. Dear, 212 Miss. 620, 630-31, 55 So. 2d 370, 374-75 (1951) (same).

55. Hill v. Thompson, No. 07-58509, slip op. at 9 (Miss. 1989) (holding a lease of school trust land void where the trustee had leased it for a period of 99 years for a price of $7.50).

56. *Id.* Tally v. Board of Supervisors, 323 So.2d at 550 ("where the consideration paid for a lease is so small as to amount to a donation of the property, the lease is void"). *See also* Saxon v. Harvey, 190 So.2d 901 (Miss. 1966) (superseded by statute as stated in Canton Farm Equipment, Inc. v Richardson, 501 So. 2d 1098 (Miss 1987)); Coleman v. Shipp, 223 Miss. 516, 78 So. 2d 778 (1955) (involving the public maintenance of private roads).

57. *See* Solomon and Freedberg, *supra* note 1, at 105 n.121 (discussing Maine's regulations).

58. Titus, *supra* note 3, at 70-1 (discussing a similar rule in Texas, which requires that tidal changes be considered before new construction is begun).

59. Miller, *supra* note 1, at 228-29 (discussing legislation to reduce trace gas emissions).

The Mississippi Legislative Perspective

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As a public official, I would like to welcome those of you who are visiting our state from Alabama and Louisiana. We're happy to have you here. There was an interesting discussion I had with one of my colleagues yesterday about back in the territorial days when they were cutting up the Mississippi territory. There was a lot of discussion about whether it should be drawn north-south so that we have the two states (Alabama and Mississippi) we have right now, or drawn east-west to form a North Mississippi territory and a South Mississippi territory. I think the general conclusion was that, in retrospect, our brethren in the northern part of the state and we down here probably would have been happier with the latter cut rather than what we ended up with merely because of cultural, geographical, and other similarities.

I want to mention that I will be talking about our perspective on the **effects** of sea level rise, not on the **causes**. Those are two separate issues. I don't want to set aside the fact that we, as a matter of public policy, need to be concerned about those things exacerbating our sea level rise problems, but I want to talk primarily on the effects.

The legislative perspective is necessarily one that asks the question, "What should we do about the rules by which our society is going to govern itself?" The legislature is used to thinking in the rather short-term. I think the remark was made earlier this morning that the long-term sometimes is next week. We're not real good at thinking about long-term problems, so it is kind of tough to figure out what we should be doing.

I want to contrast the sea level rise issue with other water-related geological events. We, in this state, and many of our sister states, are very familiar with changes to riverine shorelines when you have massive, avulsive-type events. For example, we have towns that have completely been obliterated by changes in the course of the Mississippi River. And we see were it not for the Corps of Engineers' efforts and the old river control structure, we would have had a different Mississippi River today. We are somewhat familiar with those avulsive type events. While we're not very good at dealing with them, we do have experience with them.

The sea level rise is a whole different ballgame. It is very slow in terms of our perspective here in society, certainly not slow in geological time, but it is not something you can go out and watch. Because of this difference, the inexorable but slow rise in sea level, our response is necessarily going to be a little different than what it would be with more sudden events. Our response is inherently more diffuse and I want to address a few of the issues.

We need to realize that sea level rise is not something that is **going** to happen, it is something that **is** happening. It is an interesting perspective when you realize a lot of times we talk about it in the future tense. It is not in the future, it has been occurring in the past, is ongoing today, and will continue, apparently at a faster rate, in the future. We need to be thinking about what we are doing today and the effects of that 10, 15, 20, and 100 years down the road.

When we look at legislation, I generally tote up before the legislature a series of things we can do about a problem. We can first ignore it (and we're quite good at that); we can study it (we're also pretty good at that); we love to tax it; we can prohibit it; we can spend on it; we can regulate it; and can delegate it to local government.

Now, of those choices we have, ignoring it, studying it, taxing it, or prohibiting it won't work very well. Obviously we shouldn't ignore it, although we would like to. It is not a whole lot of use from the state legislative perspective to study it. The federal government handles that rather nicely. In terms of any new state initiatives necessary to study the problem, I don't think we have an issue there. We have a lot more thinking to do about the effects of sea level rise, but as far as major new studies that are going to uncover things that we don't understand right now, I don't think we contribute a lot to that from the state level. I think a lot can be contributed at the **federal** level by looking at the greenhouse effect.

I can't think of a more stable and sure way of getting revenue than taxing sea level rise, but I don't think we can do that, nor can we prohibit it, although I think the legislature may at times wish they could.

One of my colleagues told me a story yesterday that the legislature some years back by decree was going to decide where Desoto found the Mississippi River. I guess if we feel like we can legislate historical facts, there is no reason why we can't prohibit natural effects. But I don't think that will work even in our wildest imagination. That leaves three things that I want to address: spending, regulating, and delegating.

The state needs to think about its capital investments in public infrastructure and public facilities and realize that when we make those investments, we need to think in the long-term about where they should be located. The sea level rise issue for our public infrastructure investment is inherently a geographic problem.

When you stop to think about it there's not a whole lot the state does **directly** that gets affected by sea level rise, perhaps with the exception of port development. A lot of **indirect** investments do need to take it into account. An example is highways. Our major artery here on the Gulf Coast is Highway 90. It is located directly on the coast and there is no question that in the long-run, the ability to maintain that road, and any other beachfront road, is going to be affected significantly by sea level rise. At some point, we will have to make a decision whether is it worthwhile maintaining it at that current location or make an investment decision to move it. There are some parts of our major highways, particularly the beachfront roads in south Hancock County and some areas of Jackson County, where **today** it is hard for those roads to hang onto that little coastal fringe. It will be nearly impossible in the long-run.

Similarly, we are making major investment decisions in public facilities, state parks, new state office buildings, new university campuses, and that type of thing. If you're going to be losing your waterfront, you need to worry about where you put them. I think we need to adopt a long-term perspective, because the public facilities we build, in some form or another, are going stay there for long periods of time. It has been only in the last century or so that the government has really spent large sums of money on major physical public facilities, so we don't always think that what we're building right now is something that people 200, 300, or 400 years from now will still be using.

We don't do much at the state level on structural measures for shorefront protection. Thankfully, we've gotten out of that. Earlier in the century, we built an awfully lot of seawalls down here. Modern studies and modern thought tell us that was probably an exercise in futility. Now we use shorefront replenishment and beach nourishment; that is probably cheaper and every bit as effective as "hardening up" the coast. I think we need to understand from the policy-making level that whatever we do about our coastline has to respect the natural forces.

That covers some of the spending issues. The fact that we don't spend a lot of money on shorefront hardening, and the fact that we already have the legal mechanisms in place for making decisions about where we invest our money in highways and public facilities, tell me that legislative changes are not needed as much as just making smarter decisions about those facilities and those investments as we make them.

Let's look at the issue of regulating. I will include in this the state laws as they regulate shorefront property rights. I think there is an issue there. Our legal system and our laws are set up in large measure to resolve disputes. I would submit to you that we already have an adequate legal framework for resolving any land disputes. Some people might not like the results. A private owner on the shoreline probably doesn't like the fact that the law says when the tide moves in, his property line moves in with it. But we don't have a **legal** issue there as much as we have a **policy** issue.

Is that the result we as a society think ought to happen? My gut feeling is that, except in very rare circumstances, it is probably a good policy.

If you look at shorefront property as having an attribute of an ambulatory boundary at the water line, those who own the property have bought it with the full understanding that its boundary is not fixed, and that they are at risk of that shoreline moving inland.

When the recent tidelands legislation was put together, the issue of where the line is, and the issue of defining that line, were concerns in already developed areas where filling had proceeded from the shoreline out into the public trust. Somewhere in that new piece of land, we had to find the underlying property boundary to know who owned what.

That was really the concern. I don't think we ever thought through what happens in what I'll call the "virgin territory": undeveloped land where the line **is** moving and **has been** moving and may now, through the legislation, get frozen in time. Freezing the boundary can't be done by mere legislation. We're going to have to go into some constitutional issues. Thankfully, in my view, our constitution says that you can't just give away the public trust lands. I think we would be in a much worse situation today were it not for that constitutional prohibition.

We talked about the Illinois Central case earlier on, but we actually have a more outrageous situation here in Mississippi. Back in the 1880's, the Legislature granted the Gulf and Ship Island Railroad "for the private profit and use of the railroad" a full 6 square miles of our Mississippi Sound, an area now occupied by the Port of Gulfport. We may poke fun at Illinois, but we certainly have our skeletons in the closet too.

The basic policy of who should get tidelands is a public policy issue requiring a constitutional change in Mississippi. I personally don't think that it should change, but like all constitutional issues, the proper forum for that to be debated is public; it is a real, live public policy question. It is not something with an easy solution. We have to decide as a society where we're going to allocate the rights.

A related, but slightly different problem (and I think from an economic standpoint the bigger issue as the tidal regime moves), is the issue of oil and gas rights. Under today's regulatory environment, the cost of hardening up the coast and developing in low-lying areas is simply not cost effective. In the undeveloped areas right now, I don't think we will see a lot of pressure to develop, except for the areas that are already developed. But as the tidelands boundaries move, and as oil and gas get more developed, who gets the rights to oil and gas will be an economic issue.

It is clearly settled law that the state will get those oil and gas rights as the tide moves in, but that again becomes a public policy question. In the larger scheme of things, the issue of who gets the oil and gas rights does not impinge on the traditional public access and navigability rights to the surface waters. It's a situation where you can accommodate both interests, and the only cost to the state is the loss of potential oil and gas revenues. That has to be balanced by traditional notions of fair play and resource development. Those are some of the policy issues, and I think some legislation may well be necessary.

Another area (and I don't know how to address it fully from a legal standpoint) goes back to the issue of public facilities. If in the long-term, for example, we can't have a Highway 90 anymore because it will be under water, what will you do with the private access rights that the beachfront owners now have? Let's say, for example, we decided, because we couldn't afford it anymore, simply to abandon maintaining those roads, tear them up, and put them somewhere else. You would have probably 15,000 parcels of property with no public access (unless they left a little shell path like was there 150 years ago). I think that is an interesting issue because at some point the public has to make a decision. If we can't afford to maintain those anymore, and we literally need to abandon them as a public facility, we need to recognize that there will be some private access problems. I don't know how to address that, but I think that it will require some legislation.

Another regulatory issue would be what to do at the state agency level. How do we organize them? And what responsibilities do we assign to our various state agencies to handle any of the regulatory and resource management aspects of the sea level rise? Here, I think our laws are probably okay as they are. We have agencies set up to handle the various issues that are going to come up. We have marine fisheries resource management agencies, we have a wetland management agency, and we have environmental protection agencies. Now I'm not saying that the regulations and internal organizational structures of the agencies are adequate to handle all the problems. But I think that by and large, the agencies to whom we have delegated those responsibilities have the basic legislative power to do the job. It is just a question of using it to address these newer issues. I frankly don't see a big problem, from the legislative standpoint, in those areas.

The last area I want to talk about is that which the state delegates down to the local governments. I think we need a little bit of work here. When you stop to think that the sea level rise problem as it impinges on development is a geographic problem, you realize that (at least in our state) geographically-based regulation has largely been delegated to local governments through zoning, building codes, and flood plain management ordinances. We realize that much of how we respond is going to be a local issue, and we have to know that local governments who deal with the day-to-day issues of where you're locating buildings and that type of thing have the legislative authority to do the job. I realize, and I think we all need to realize, that sea level rise is a problem not in and of itself, but it is a problem only in those cases where man's development has approached the coast.

When we take a look at our state laws dealing with delegation and enabling legislation for local government control of land use such as zoning, building codes, and so on, our laws are rather weak. I didn't realize how weak they are until I started looking at it from this perspective. Our zoning enabling legislation is okay in a traditional sense. It sets up normal Euclidean zoning, and lets the cities and counties act on that. But it is rather narrowly written when you stop to look at it. It authorizes the cities and counties to adopt ordinances to "lessen congestion, insure safety from fire, public panic, and other similar dangers, to provide for adequate light and air, to prevent overcrowding, and to avoid undue concentration of population."

Those are all good things for sure, but it really doesn't say anything about how you zone to mitigate the long-term impacts of a natural phenomenon like sea level rise. While I don't think anybody would challenge it very seriously if you come down to the basics of our zoning enabling legislation, it really doesn't give the local governments the direct clear power to zone based on worries about where sea level will be in 100 or 150 years, and that is probably a little change we need to make.

Also, it appears that we don't have good firm enabling legislation for our flood hazard ordinances. Most of those ordinances are promulgated under the city and county health, safety, and welfare authorities, and sometimes it is handled under their zoning authority. I have researched the statutes for any specific authority on adopting flood hazard mitigation ordinances, and it turns out we don't have any, at least not that I have found.

We do have a few references to it that got put in the law after Hurricane Camille when we realized to be eligible for federal flood insurance we had to regulate at the local level. There was a real worry about regulating agricultural uses, so the only mention our state statutes made that I've been able to find about mitigating flood hazards is a specific provision that says you can't regulate agricultural uses at all, except for whatever the federal government requires that you absolutely do to be eligible for flood insurance.

I think we have a problem there. It has not been challenged yet, but I believe we do need to upgrade our state enabling legislation to make it clear that local governments can – through their zoning, building codes, and flood ordinances – take account of the long-term sea level changes to be sure that development respects this natural phenomenon.

That covers what we should do for spending, regulating and delegating authority. I would caution everyone to be careful of what I consider a knee-jerk reaction to regulate or to set up a new regulatory scheme. You may think that sea levels are rising, and since we don't regulate things like that directly, we need to have a whole new regulatory authority. I submit that we **do** have adequate agencies and regulations in place and I would resist the temptation to create new agencies to address the specific narrow issue because it is actually not such a narrow issue. It transcends all of the other regulatory issues we have in place right now. All of our resource management efforts are affected by this, and I don't see a need for an additional regulatory framework for handling the problem.

Let's talk a little bit about the timing of our legislative response to the problem, going back to the realization that it is largely a development versus natural sea level rise or man-induced sea level rise. Since it is a development problem, we have to ask the question, "Are we going to control development by mirroring the rate of sea level rise?" I don't think that is practical. We can't incrementally move all the buildings as sea level comes up. We certainly can't mandate the coast-wide "let's pick up and move inland type" effort, but we can do two things that, in the long-term, will constitute a very rational response to it.

First, we have to be very, very smart about how we regulate new development, and as painful as we think that may be politically, it is really not that bad. As a general rule, new development knows it has to deal with the whole panoply of regulatory requirements at the state and national level. To fine-tune them enough to take in concerns for where sea level is going to be in the next couple of generations is not that big a conceptional leap. I don't think it is that big a problem for new development designed around those constraints.

The other thing we should do is take advantage of natural disasters. I realize that sounds odd, but those of us who remember back often think that we lost a great opportunity to rebuild in a more rational way after the coast had been destroyed by Hurricane Camille In many ways, we had both a clean slate and a tremendous amount of resources coming from the federal government to have rebuilt in a more intelligent way. I firmly believe we lost a golden opportunity then, but we don't have to be so squandering of opportunities in the future. There's nothing that says we can't set up and plan as we have natural disasters in the future. And there is no question that we will have them.

After each one of those, we have some choice points about where to rebuild public facilities, where to rebuild our highways, and what to do with the development that's coming back. I submit those times are the times to make intelligent decisions, through legislation if necessary, but largely through local decisions. Those decisions should moderate the impacts of sea level rise.

We have to start planning for those today. Obviously, a natural disaster, of which we can take advantage, might happen tomorrow, or it might not happen for another 10 or 20 years. But to be smart about what we should do in response to those disasters, we need to make those decisions today while we have the leisure to do it. In the heat of just trying to restore normalcy after a disaster, you can't do that planning. It has to be done now through the zoning enabling legislation, flood plain and building code regulations, and smart planning at the local level. We can do things at the state level through legislation to encourage that.

I guess my presentation has been that the legislative perspective at the state level is a rather moderate one, and I want to stress that those are only **my** views. The other 173 legislators in Mississippi may think entirely differently, but it seems like it is rather moderate. After I prepared this presentation, I began to wonder if maybe we should be doing something more. But I realize that the real **big** legislative issues, the pressing ones from a public policy standpoint, are going to occur at the national level: flood insurance, disaster assistance, barrier island regulations, and so on.

Mississippi is sort of in a unique position. The really severe visible impacts of sea level rise seen in other states are not present here for a couple of unusual reasons. All of our barrier islands, with the exception of Cat Island, are owned by the federal government.

So we don't have a development issue out there. We don't have condominiums and hotels about to be undermined, so we don't have the problems that Florida has, that some Louisiana barrier islands have, and that some of the barrier islands on the Atlantic seaboard have.

Secondly, the historical development on the coast has occurred on the high ground. Until relatively recently, when all of these dredge and fill operations in the marshy areas of the coast happened, our forefathers, who didn't have the money and the equipment to harden up the coast quite so easily, were smart enough to develop on the higher ground. Under modern-day flood hazard ordinances, most lowland development is now up on stilts and within their lifetime – before they either blow over or rot away just from normal wear and tear – the sea level rise is not going to have a big impact on those places.

Getting back to my point about natural disasters, a lot of those places after the next cataclysmic hurricane probably should not be redeveloped. It may be ultimately cheaper for the federal government and the local governments to come in, simply buy up what's left, and put it in the conservation reserve because it will be more expensive to provide roads, sewer, water, and other facilities to those areas than it would be to just to buy some of the property and walk away from it. I don't see the critical problems in this state that exist in Louisiana where modest changes in sea level end up making New Orleans a Gulf waterfront town rather than a riverfront town. I think the problems in Alabama are rather similar to ours, with the exception of the more extensive development that they have on barrier islands.

In summary, I would have to conclude that the legislative perspective says that we don't need a major change in our legal structure in Mississippi to handle the problems. We have the policy issue about what we should do about property ownership. We have the issue of the deprivation of public right-of-way in cases where people need that to get access to their property. We have some minor changes in the various enabling acts for local zoning, flood plain management, and building codes. And we have to be smart about our public investment decisions.

The legal framework and the institutions that we have in place are quite capable of handling many of the problems that will come up. I'm very resistant to creating new institutions to try to address a problem that our existing institutions need to handle because this would do two things: it might create another ineffective bureaucracy (which we certainly don't need anymore of in Mississippi), and it also lets existing agencies off the hook. It is important for them, as time goes by, to evolve and to develop the ability to handle new problems as they arise.

Again, by my moderation I don't want to suggest that we don't have a big problem. I think the bigger problem that we have to concern ourselves with is reversing the ecological effects that we have created for ourselves by pollution. I don't want for one minute to try to downplay the importance of addressing that issue. That gets back to what I said at first, though. That's one of the **causes** of the problem of sea level rise and I was dealing with the **effects**. I would be very, very cautious about ever getting so complacent about our ability to deal with the effects of sea level rise that we moderate our incentives to do something about the causes. I think our legal framework and institutional framework for handling the effects (if we're smart enough about trying to address the causes) are largely adequate to handle the problem.

Emergency Preparedness – Consequences of Sea Level Rise

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Harrison County, Mississippi

My job today is to tie emergency preparedness and our Civil Defense posture into the possible rise of sea level. The people of the Mississippi Gulf Coast, and Harrison County in particular, are no strangers to the effects of hurricanes. We've had our experience with them over many, many years. The interesting thing and this is probably true of most of the coastal areas is that there is a great deal of real estate that is under 10 feet in elevation. These are very vulnerable areas, not only on the front beach but along the rivers, streams, and the estuary.

During the 1915 hurricane, in the brand new harbor of Gulfport, there were several seagoing vessels washed ashore. This was one of our record storms and it did a great deal of damage. When you devastate a shipping port of that nature it's really quite harmful to the economy of the Gulf Coast. Highway 90 was covered with sand after the 1915 storm and washed out in many areas.

Local government began a study regarding building a protective seawall along the 28-mile beach to attenuate wave action and the future damage to that road. This was a tremendous undertaking. World War I intervened and the project was reinstated after the war. It was the longest single concrete structure ever attempted and consisted of a steel reinforced seawall with a basic elevation of 11 feet. This was considered an engineering wonder of the world and it was finally completed in 1927, all with local funds. Then came the great storm of 1947. This was our record storm up to that time, the most destructive ever experienced on this coast, and referred to by the Corps of Engineers and the Weather Service as a 100-year storm. The storm resulted in a tide of 12.2 feet and winds of 140 miles an hour. The seawall held with few exceptions. With the help of the federal government and through the Corps of Engineers, the county pumped in the longest man-made beach in the world to protect the seawall that protects the highway. The beach was intended to further attenuate wave action and received its ultimate test in the 500-year storm of 1969.

Wave action combined with the storm tide is the big destroyer in hurricanes. It is not the wind but the water that does most of the damage. The principle components of a wave are the crest, which is the high point of the wave, and the trough, which is its low point. Wave height is the vertical distance from the trough to the crest and the length is the horizontal distance between the crests. Of particular interest is the fact that the maximum wave height to length ratio is equal to 1.3; beyond that steepness ratio, the wave begins to break. Only half the wave's height is above the static water line. For an example, an 8-foot wave would add 4 feet of additional height above the static water line and this is one of the big destroyers in a hurricane or a storm.

You can forecast the height a wave will reach at certain wind speeds and over certain depths at various distance of travel called the fetch. The maximum fetch between the barrier islands and across the Mississippi Sound to the shoreline is 12 miles. For example, over 20 feet of constant depth at 100 miles an hour, the wave height would be just over 8 feet. But the depth in the Mississippi Sound is not constant. The bottom slopes gradually up to the beach as is the case with most of the Gulf coast. The Mississippi coast is blessed by having a natural barrier of islands ranging from 8 miles to 12 miles offshore. These islands serve to break up wave action including those generated by storms. The Mississippi Sound is relatively shallow, ranging from 18 feet at its deepest to the gradually sloping shoreline. The shoreline is further protected by the sand beach and the seawall.

Based on this information and additional facts, an example has been prepared of what happens to a wave as it comes from the Gulf of Mexico across the barrier islands and over the gradually sloping depths of the sound onto the shoreline. A 12-foot storm tide is used for this example. As the wave approaches the shore of the barrier islands the drag of the bottom slows it down. This shortens the wave length and increases the steepness. When it reaches a water depth of about twice the wave height, the crest peaks up. As it reaches a depth of water equal to 1.3 times the wave height, the wave becomes unstable, collapses, and spills most of its energy in the turmoil and surf.

As it crosses over the island where the minimum depth would now be about 9 feet, it reforms into a new wave while moving out into the deeper waters of the Mississippi Sound, but this new wave is smaller than the original wave because of its lost energy. As it reaches shallow water it again peaks and when it reaches a depth equal to 1.3 times its height it again breaks.

Let's take a look at some of the historical experience that we've had here on the Mississippi Gulf Coast from hurricanes. Our community suffered the most catastrophic active destruction in the history of the modern world (as seen through the eyes of the local government) in 1969. The little city of Pass Christian received the heaviest damage in 1969 with Hurricane Camille. The eye was rather small, only 5 miles across, and the winds extended out about 100 miles in the northeast quadrant of the hurricane and about 40 miles in the northwest quadrant. Winds of 239 miles an hour were logged on a vessel that was washed ashore. The rule of thumb formula the old-timers used was "for every 10 miles an hour of wind in a hurricane you can expect a rise in tide of one foot," so a 100-mile-an-hour wind will give you (under the right conditions) a 10-foot tidal surge and that correlates with the rise we experienced during Camille. The infrastructure of the community, of course, was devastated. There were 6,480 homes totally destroyed.

The population is increasing on the water. People want to move to the coast. I have no problem with building **on** the sea, I can sit on my gallery and look out at the boats going by and it is really a grand way of life. But I do have a problem building **in** the sea, and that is what a lot of our folks are literally doing. If we have a sea rise there are going to be more hurricanes because the atmosphere is going to be warmer and that is one of the main ingredients for the creation of a hurricane. When that huge tidal surge comes ripping ashore with what we call the "velocity zone" of that storm, there is just nothing constructed that is going to be able to withstand damage or destruction by the water.

I honestly believe that we've become our own worst enemy in respect to flood insurance. We didn't have flood insurance in 1969. You had to "eat" your loss and a lot of us did. Thank God for flood insurance today, but what it's doing, I'm afraid, is encouraging people to build in vulnerable areas. I would hope that someday we would just draw the line and say, "look fellow, if you want to build from here to the water's edge that is fine, go ahead, but you are self-insured." We've got to do something about this, folks, and it would seem to me that the only reasonable thing to do is to build strong, build back, and build high. Principles of good management urge the adoption of this course of action.

Sea Level Rise in Coastal Alabama and Mississippi

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The information presented in this paper was developed for the Alabama Department of Economic and Community Affairs, under Section 22, Public Law 93-251. They asked that the U.S. Army Corps of Engineers (USACE), Mobile District, document any increase in the level of the Gulf of Mexico associated with the rise in global sea level and assess its effect on Coastal Alabama. This paper discusses the data developed.

Sea Level Rise

"Since the beginning of recorded history, sea level has changed so slowly that for practical purposes it has been constant. This has been a fluke of history: sea level was rising about 3 feet per century from 15000 until 5000 B.C." (Titus, James G., 1986). Authorities disagree whether, during the last 5000 years, sea level rose to about its present level, where it has remained without significant change, or whether there have been small ups and downs (Tanner, William F., 1989).

There are two recognized and fairly obvious components of the rise in water level at any location. Those are

(a) Eustatic, or world-wide, rise in water level, and
(b) Subsidence (or uplift).

Gornitz et al. (1982), studied 193 tide gauge records worldwide to determine sea level trends for the past century. They concluded that mean global sea level rose 12 centimeters (cm), about 4.75 inches (in), during the century 1880 to 1980. In the Gulf of Mexico, Gornitz calculated a mean rise of 23 cm, about 9 inches. Since the rise in the Gulf of Mexico is about twice that for the eustatic rise, it may be that the Gulf of Mexico basin is subsiding (Germiat and Sharp, 1990). For the purposes of this work, however, there was no effort to separate these components, since relative rise in sea level and its possible effects was the major concern.

There are three long-term tide gauges in this general vicinity. They are at Biloxi, Mobile, and Pensacola, Florida. The map in Figure 1 shows the general location of these gauges and Figure 2 shows their specific sites. The data from these gauges, which were used in this work are tabulated in the appendix. In addition, data from the gauge at Cedar Keys, Florida, location map in Figure 3, were used as representative of open Gulf conditions. There are two somewhat shorter-term gauges at Dauphin Island, Alabama. The data from these gauges were not used in this analysis for reasons discussed below.

Biloxi, Mississippi

The oldest tide gauge in the Mobile District is the USACE gauge at Biloxi. It was established by the New Orleans District for the Mississippi River Commission in 1881 and remained in place until June 1885. The gauge was originally located on or near the L&N Railroad bridge across the mouth of Biloxi Bay between Ocean Springs and Biloxi. It was reestablished on the L&N bridge in October 1895, probably at the original location (Miller, John, Chief, Water Collection Unit Hydraulics Branch, New Orleans District, U.S. Army Corps of Engineers, personal communication).

The gauge remained on the L&N bridge until October 1938, when it was moved about 4,000 feet south to the Highway 90 bridge, also between Ocean Springs and Biloxi. The old gauge remained in service until the new recorder was correctly adjusted. Although the original highway bridge has been replaced by a newer one, the gauge is still in place on the old structure, which is now in use as a fishing pier. The Mobile District assumed responsibility for the gauge in September 1983 and has operated it since. The data from this gauge are essentially continuous from 1896 until the present. There have been periods, however, where a full year of data was not gathered. Those years with partial data are shown in the tabulation. The annual means computed for years with partial data were within the general variability range of the data set, so they were used in the analysis. It may be, however, that some seasonable effects were lost.

The annual means from the Biloxi data are plotted on Figure 4. A 5-year moving average was computed as a smoothing function and is shown. The annual mean for 1973 appears to be an anomaly since it lies far outside the normal range of the data and no other gauge in this area recorded a mean that high. Records show major floods on regional waterways during the period the high was recorded and it seemed probable that we were observing a record flood (or floods), rather than a record tide (or tides). To be comprehensive, that point was shown, however, that single datum was omitted from the regression analysis. The means for the 3 years before 1896 were also included in the regression analysis, but were omitted from the plotted line. That first analysis used 96 years of data and the least squares straight line shown is the result. It has an X coefficient of 0.005906, which was rounded to 0.006. That coefficient is the slope of the line and is equivalent to a rate of rise of 0.006 feet/year (ft/yr).

These data were further analyzed by a statistician presently attached to our staff. Her analysis indicated that the line showed a good time-correlated fit. She also found that nine data points were extremes. If these points are omitted and the remaining 87 points reanalyzed, a slightly better fit can be obtained. But it was not certain these points could be omitted, and a reasonable rounding resulted in the same rate of rise from either equation, therefore, the first equation was retained and is the one shown.

Mobile, Alabama

The USACE gauge for Mobile is located on Pier A South at the Alabama State Docks, about 2½ miles above the mouth of the Mobile River. This gauge was established in August 1940 and has been in continuous operation since that date.

The annual means for the gauge at Mobile are plotted on Figure 5, with the 5-year moving average add-

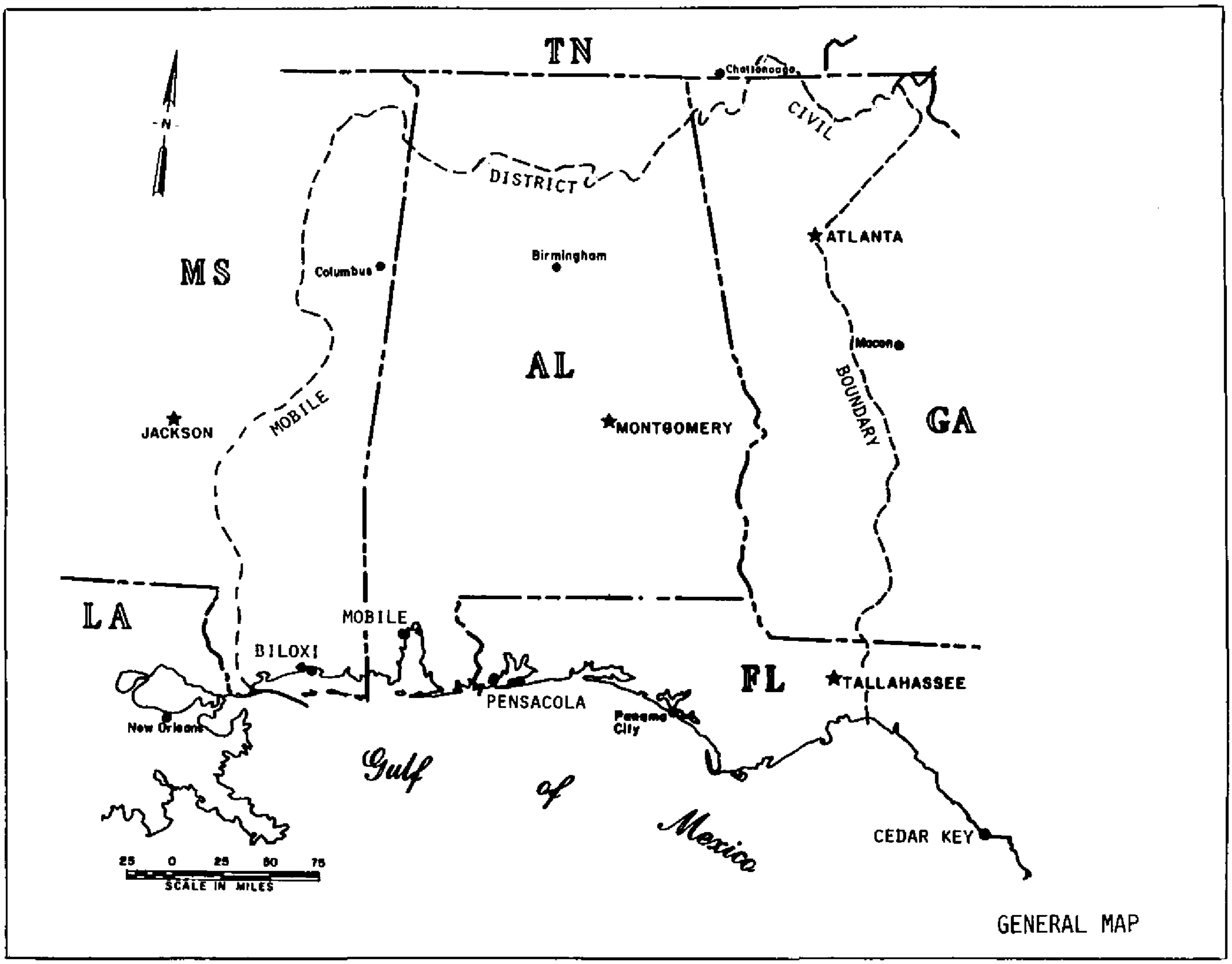

Figure 1. Map shows the general location of long term Gulf tide guages (see figure 2).

ed. The equation for the straight line is shown. The X coefficient (and rate of rise) for that line is 0.005077 which was rounded to 0.005 ft/yr.

Pensacola, Florida

The National Ocean Service (NOS), National Oceanographic and Atmospheric Administration (NOAA), gauge is located on the northwest side near the end of the municipal pier in Pensacola. It has been in operation since 1924.

The annual means for the Pensacola gauge are plotted on Figure 6 along with the 5-year moving average. The straight line has an X coefficient of 0.007464, rounded to 0.0075 ft/yr for rate of rise.

Cedar Keys, Florida

According to NOS, the NOAA gauge at Cedar Keys is one of two in the northern Gulf on open water. (The other, at Freeport, Texas, about 42 miles southwest of Galveston, showed a higher rate of rise than the other gauges, and was judged by the writer to be influenced by local subsidence.) The gauge at Cedar Keys was first established in 1915 and was in service until 1924. It was reestablished in 1939 and has been in service since.

The data for Cedar Keys are plotted on Figure 7. The 5-year moving average was plotted for each of the two data segments but the gap was omitted for the regression analysis. The coefficient obtained was 0.005810 which was rounded to 0.006 ft/yr for rate of rise.

Dauphin Island, Alabama (NOAA)

This gauge was established in 1966 and is still in service. It is on the end of the fishing pier near Fort Gaines on the eastern end of the island. This places it in the mouth of Mobile Bay. Probably because of the increased exposure here, it has often been out of service for periods long enough to make the data dif-

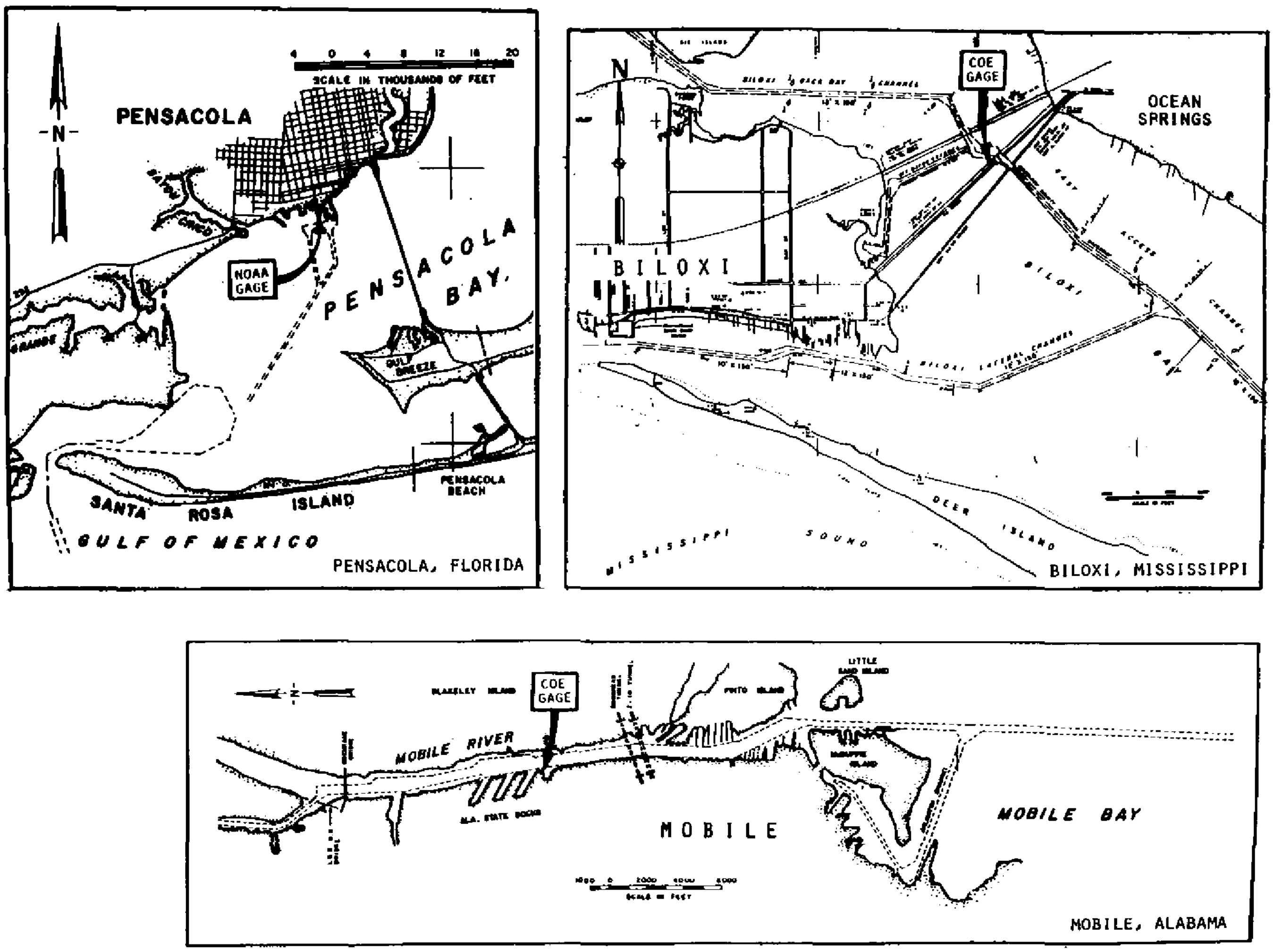

Figure 2. Specific locations of the three long-term recording guages.

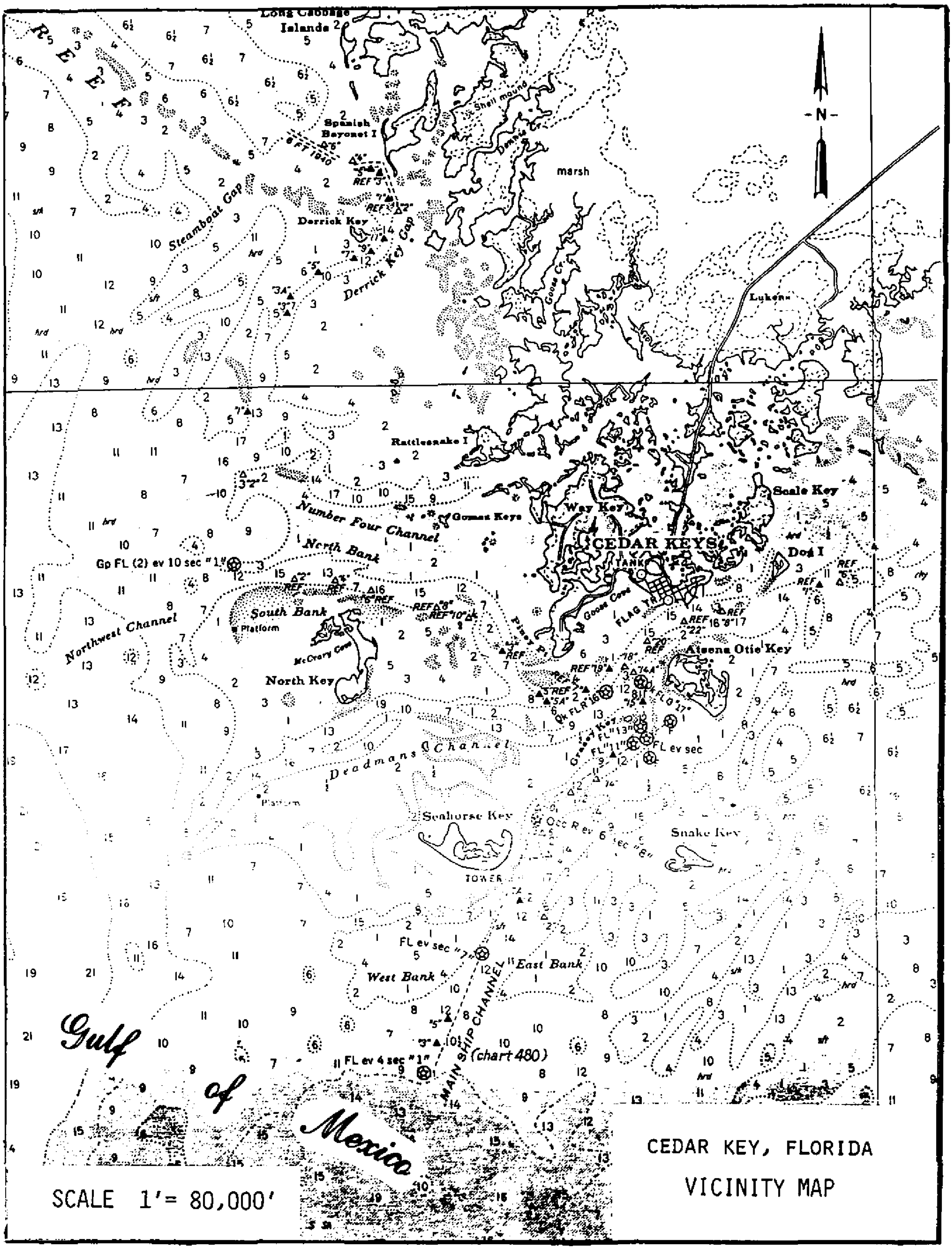

Figure 3. Data from the Cedar Keys, Florida guage were used as representative of open Gulf of Mexico conditions.

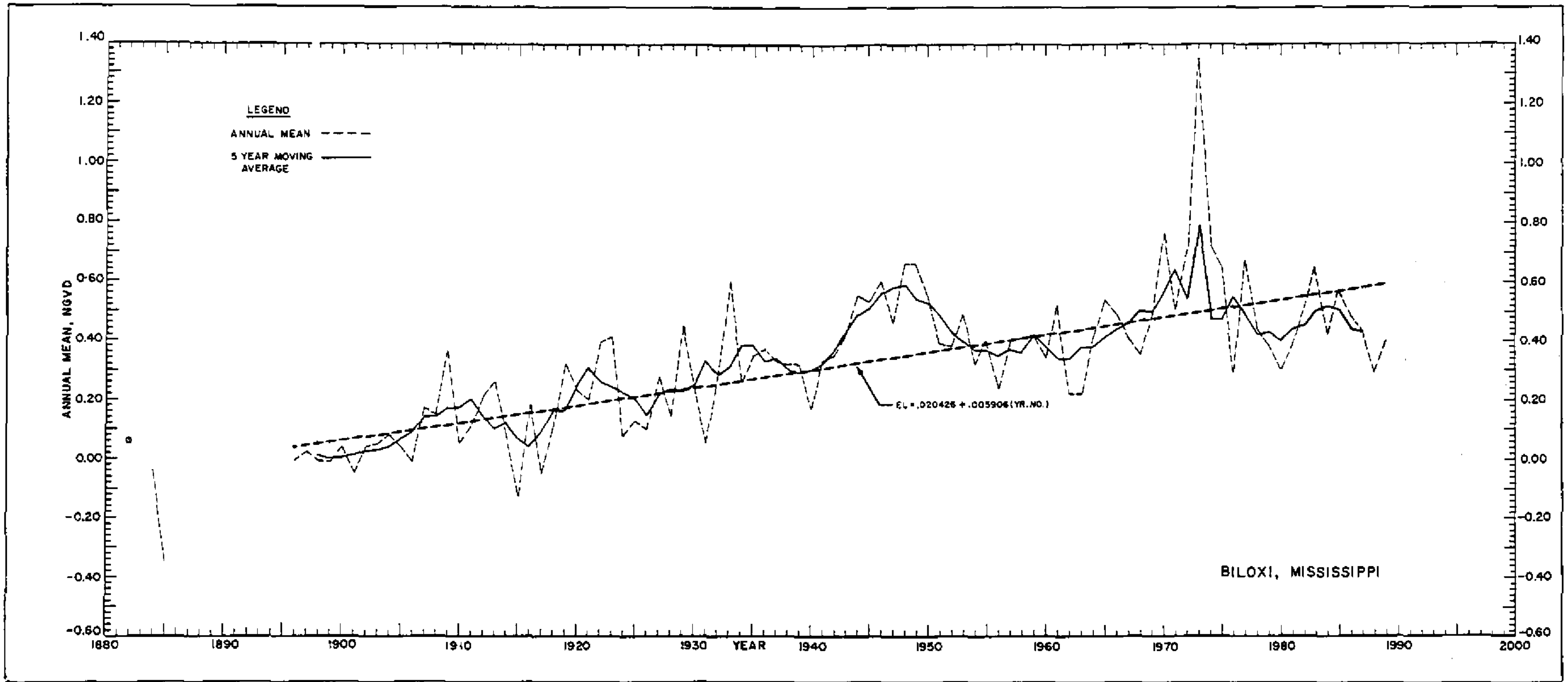

Figure 4. Annual means and 5-year moving average for the guage at Biloxi, Mississippi.

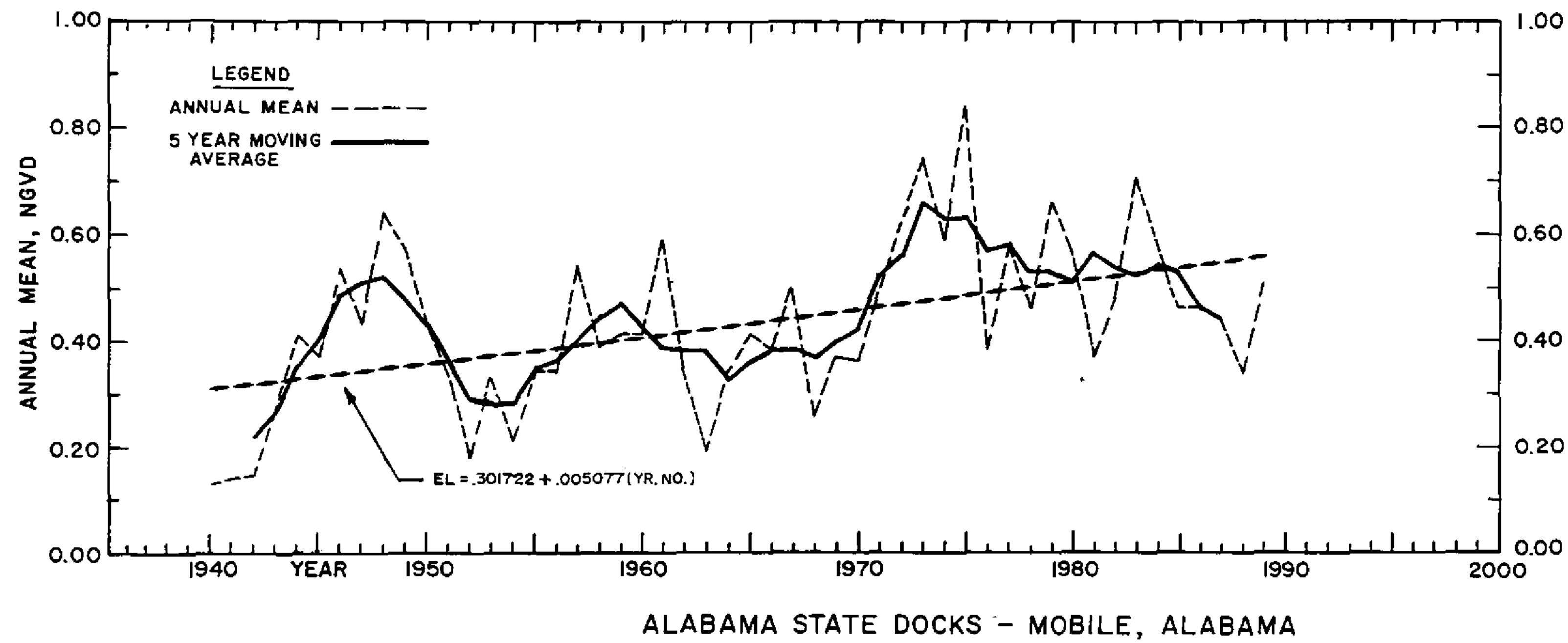

Figure 5. Annual means and 5-year moving average for the guage at Mobile, Alabama.

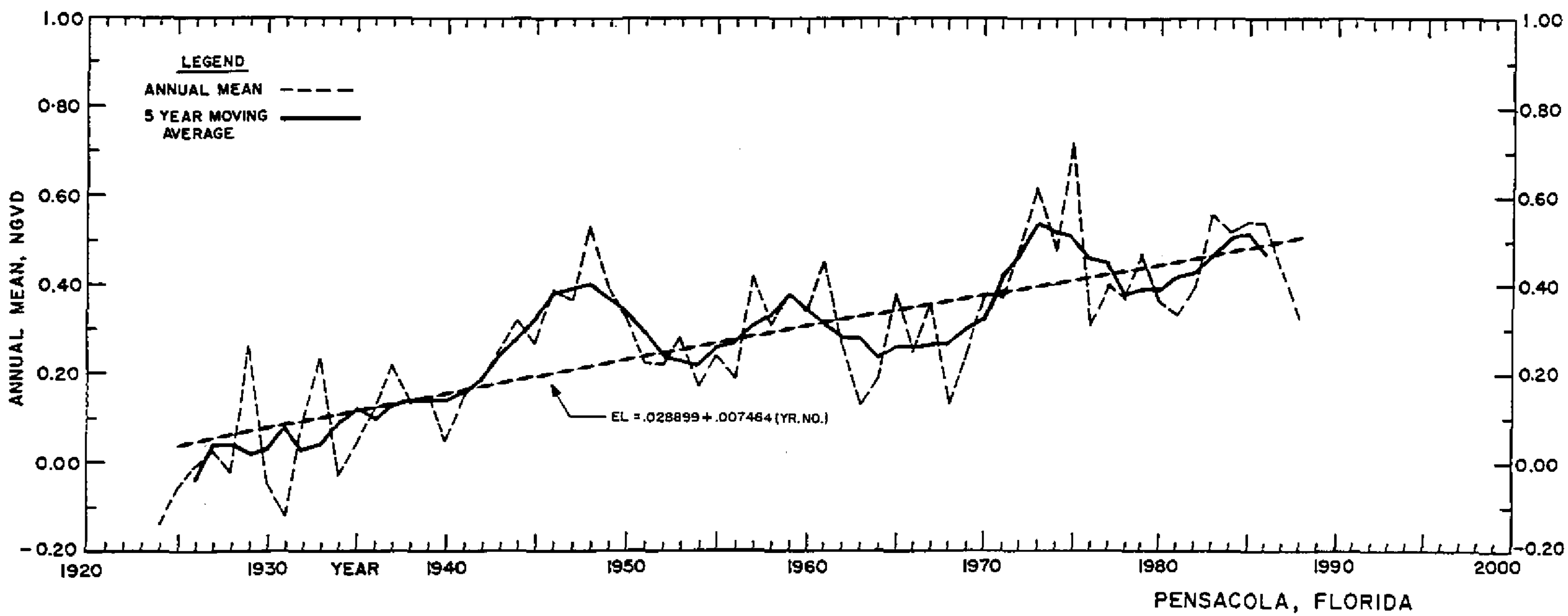

Figure 6. Annual means and 5-year moving average for the guage at Pensacola, Florida.

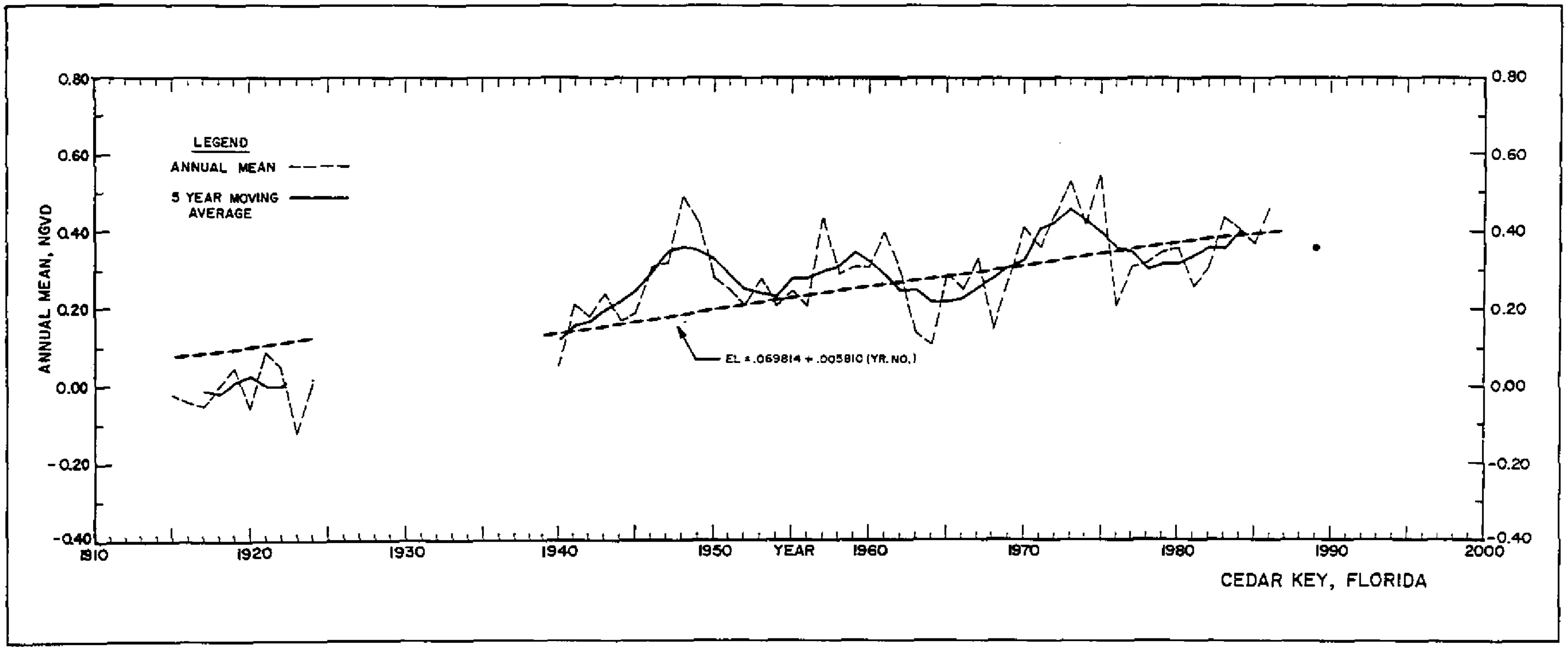

Figure 7. Annual means and 5-year moving average for the guage at Cedar Keys, Florida.

ficult to work with for an analysis such as this one and, therefore, those data were not used.

Dauphin Island, Alabama (USACE)

This gauge was established in 1963 and has been in continuous service since. It is on the end of the Alabama Marine Lab pier inside Dauphin Island Bay. Experience has shown that the gauge is heavily influenced by local conditions and, therefore, these data were not used.

An NOS representative suggested that it might be interesting to compare the data variances for the long-term gauges. Based on that analysis, we can say that, for the Mobile and Biloxi gauges for the period 1940 through 1989, the samples were drawn from populations with equal means. Put another way, for 95 percent of the time, samples drawn from either population will show no significant difference. We can also infer that, were the Mobile gauge as old as the Biloxi gauge, it would show essentially the same rate of rise. We can make a similar statement for the Pensacola and Cedar Keys gauges. Based on the sample evidence, i.e., data from the 1940-1989 period, the Mobile and Cedar Keys gauge readings show very significant differences. These differences are probably caused by some other influence that just mere chance. It is interesting to note that the data from Gornitz (1982) yield a rise in the Gulf of Mexico that coincides with that found at the Pensacola gauge.

Discussion of Rounding

Tide elevations are accurately recorded to the nearest 0.01 foot (about 0.12 inch or 3.05 mm). The gauge data does not, at least to this writer, justify the number of decimal places resulting from the mathematics of the regression analyses, and the X coefficients were, therefore, rounded to three decimal places, still one more that justified by the significant figures of the gauge data. We can conclude that, on the average, the relative rate of rise in the Gulf of Mexico and the coastal waters of Alabama and Mississippi is between 0.005 and 0.007 foot per year. Over the long-term, and probably more accurately, water levels in this area have risen between 0.5 to 0.75 foot in the last century.

Since a variety of units have been used in other works, for convenient comparison, Table 1 shows the information developed for this work converted to units used in other papers and reports.

As a result of the recent interest in sea level rise and its relation to the "greenhouse effect," there has been much activity in this field. Several works (Ramsey et al., 1989, NRC Committee Report, 1987) have discussed the problems with tide gauge data, concluded that these records include a lot of "noise," and that "noise" includes considerable local effects. It has been shown that these local effects increase for gauge locations further inside bays, or, put another way, as the distance from the gauge to the open gulf increases. Unfortunately, the long-term data for this vicinity comes from gages that are well within bays. As a result, the data and their interpretation are subject to argument. Satellite altimetry may resolve these problems (Workshop on Sea Level Rise, Palm Coast, FL, 1988).

Table 1. Tabulated rates of rise.

Station	ft/yr	in/yr	cm/yr	mm/yr
Biloxi, MS	0.006	0.07	0.18	1.80
Mobile, AL	0.005	0.06	0.15	1.55
Pensacola, FL	0.0075	0.09	0.23	2.28
Cedar Keys, FL	0.006	0.07	0.18	1.77

Future Sea Level Rise

The available records are very "noisy" and probably do not cover an adequate period for accurate predictions. There is a clear need for additional study with more accurate observations. However, there have been several scenarios on sea level rise developed (USEPA 1987, NRC Committee 1987). The lowest of these projects a eustatic rise of 0.5 meter (about 1.6 feet or almost 20 inches) by the year 2100. The highest estimate is for 368 cm, 3.7 meters (about 12 feet) for the same period. Of course, any effects of local subsidence must be added to the eustatic rise.

Future projections of sea level rise have been based on the well-documented rise in mean global temperature since about 1885, shown on Figure 8 (Hansen and Lebedeff 1988). Whether this effect is due to greenhouse warming is still open to debate. In addition, global temperature seems to have stabilized, possibly temporarily, around 1980. Complicating the picture still further, the mean temperature for the continental United States for the same period is essentially unchanged, and that for the southeastern U.S. has declined (Virginia State Climatology Office, 1990). If, however, global temperature resumes its increase, which seems likely, it would be reasonable to assume that sea level would continue to rise also.

Recommendation

Clearly there presently is not enough information to predict accurately any future rise in sea level generally or in the Gulf of Mexico specifically. There has been, however, a definite increase in Gulf level during recent time. It seems probable that this is

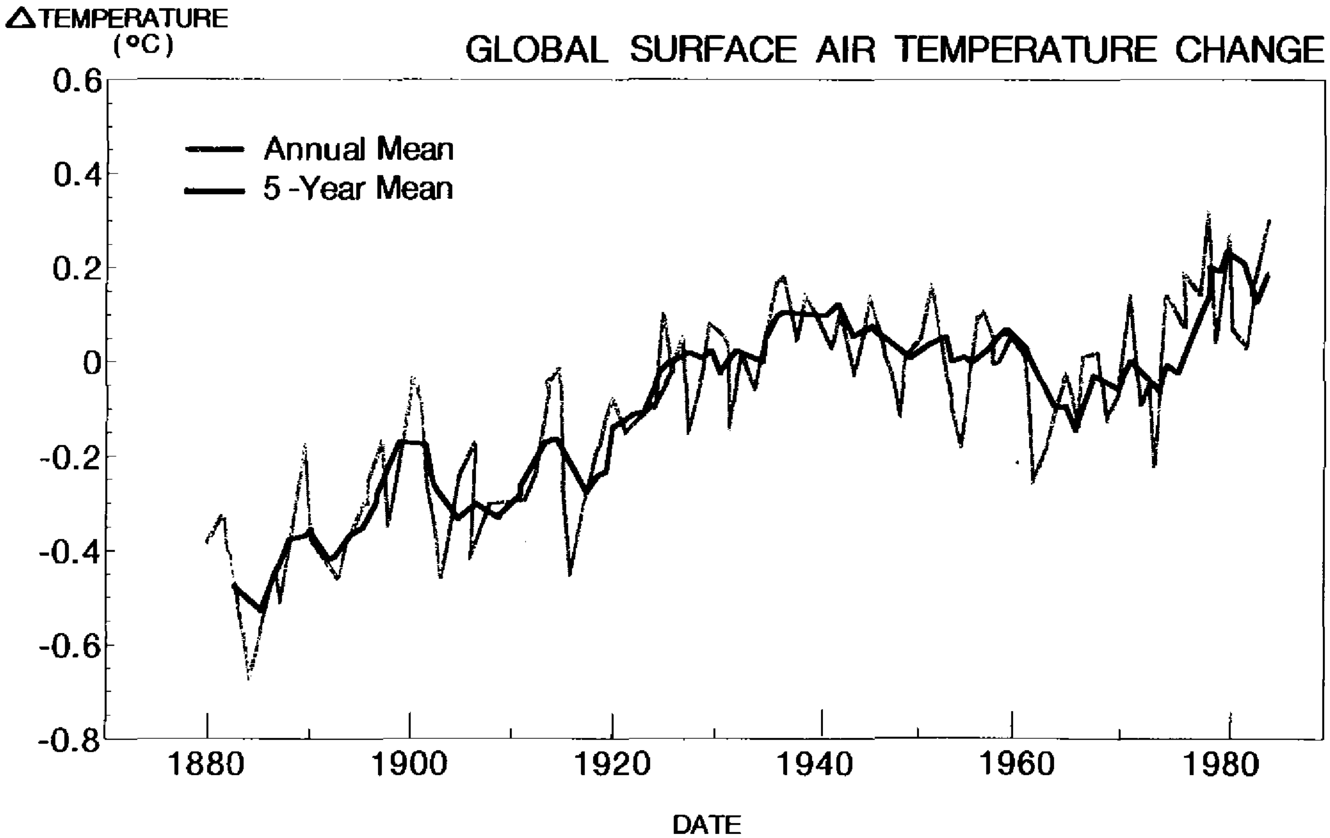

Figure 8. Mean global surface air temperature change over the last century.

evidence of a long-term trend that will continue. Therefore, it would be prudent for the states of Alabama and Mississippi to begin planning for the effects of a possible rise in Gulf level of several feet within the next century. The writer strongly recommends that these states, as an absolute minimum, plan for the consequences of a rise in Gulf level of at least one foot in the next century.

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This bibliography lists a total of 200 references pertaining to sea level rise.

APPENDIX

Data from Gulf of Mexico tide guages

Biloxi, Mississippi

Year	Recorded Months	Ann. Mean NGVD
1882		0.06
1884		-0.04
1885		-0.35
1896		-0.01
1897		0.02
1898		-0.01
1899		-0.01
1900		0.04
1901		-0.05
1902		0.04
1903		0.05
1904		0.08
1905		0.04
1906		-0.01
1907		0.17
1908		0.15
1909		0.36
1910		0.05
1911		0.11
1912		0.21
1913		0.26
1914		0.08
1915		-0.13
1916		0.18
1917		-0.05
1918		0.11
1919		0.32
1920		0.23
1921		0.20
1922		0.39
1923		0.41
1924		0.08
1925		0.13
1926		0.10
1927		0.28
1928	12	0.14
1929	12	0.45
1930	12	0.24
1931	12	0.05
1932	12	0.30
1933	12	0.60
1934	12	0.26
1935	11	0.35
1936	12	0.37
1937	12	0.33
1938	12	0.32
1939	12	0.32
1940	12	0.17
1941	12	0.33
1942	12	0.35
1943	12	0.41
1944	12	0.55
1945	12	0.53
1946	12	0.60
1947	9	0.46
1948	12	0.66
1949	12	0.66
1950	12	0.55
1951	12	0.39
1952	12	0.38
1953	12	0.49
1954	12	0.32
1955	12	0.40
1056	12	0.24
1957	12	0.40
1958	12	0.41
1959	11	0.42
1960	12	0.34
1961	12	0.52
1962	12	0.22
1963	12	0.22
1964	12	0.41
1965	12	0.54
1966	12	0.49
1967	12	0.41
1968	12	0.35
1969	7	0.49
1970	10	0.76
1971	12	0.51
1972	12	0.71
1973	11	1.35
1974	11	0.72
1975	8	0.65
1976	10	0.29
1977	7	0.67
1978	8	0.44
1979	10	0.38
1980	12	0.30
1981	12	0.38
1982	11	0.50
1983	7	0.65
1984	11	0.55
1985	12	0.92
1986	12	0.85
1987	12	0.78
1988	12	0.64
1989	12	0.75

Alabama State Docks Mobile, Alabama

Year	Recorded Months	Ann. Mean NGVD
1940	4	0.13
1941	12	0.14
1942	12	0.15
1943	12	0.27
1944	12	0.41
1945	12	0.37
1946	12	0.53
1947	12	0.43
1948	12	0.64
1949	12	0.57
1950	12	0.42
1951	12	0.33
1952	12	0.18
1953	12	0.33
1954	12	0.21
1955	12	0.34
1956	12	0.34
1957	12	0.54
1958	12	0.39
1959	12	0.41

1960	12	0.41
1961	12	0.59
1962	12	0.35
1963	12	0.19
1964	12	0.34
1965	12	0.41
1966	12	0.38
1967	12	0.50
1968	12	0.26
1969	12	0.37
1970	12	0.36
1971	9	0.49
1972	12	0.62
1973	12	0.74
1974	12	0.59
1975	12	0.84
1976	10	0.38
1977	12	0.58
1978	12	0.46
1979	12	0.66
1980	12	0.56
1981	12	0.37
1982	12	0.48
1983	12	0.71
1984	12	0.58
1985	12	0.46
1986	12	0.46
1987	12	0.44
1988	12	0.34
1989	12	0.51

Pensacola, Florida

Year	Recorded Months	Ann. Mean NGVD
1923	8	0.26
1924	12	-0.14
1925	12	-0.06
1926	12	-0.01
1927	12	0.03
1928	12	-0.02
1929	12	0.26
1930	12	-0.05
1931	12	-0.12
1932	12	0.10
1933	12	0.23
1934	12	-0.03
1935	11	0.04
1936	12	0.12
1937	12	0.22
1938	12	0.14
1939	12	0.15
1940	12	0.05
1941	12	0.15
1942	12	0.19
1943	12	0.25
1944	12	0.32
1945	12	0.27
1946	12	0.39
1947	12	0.37
1948	12	0.53
1949	12	0.39
1950	12	0.33
1951	12	0.22
1952	12	0.22
1953	12	0.28
1954	12	0.17
1955	12	0.24
1056	12	0.19
1957	12	0.42
1958	12	0.31
1959	12	0.38
1960	12	0.34
1961	12	0.45
1962	12	0.27
1963	12	0.13
1964	12	0.19
1965	12	0.38
1966	12	0.25
1967	12	0.36
1968	12	0.13
1969	12	0.25
1970	12	0.38
1971	12	0.37
1972	12	0.49
1973	12	0.62
1974	12	0.48
1975	12	0.72
1976	12	0.31
1977	12	0.40
1978	12	0.37
1979	12	0.47
1980	12	0.36
1981	12	0.33
1982	12	0.40
1983	12	0.56
1984	12	0.52
1985	12	0.54
1986	12	0.54
1987	12	0.43
1988	12	0.32

Note: The above information was computed using data from "Sea Level Variations for the United States 1855-1986," published by NOS, NOAA. A gauge zero of -8.54 feet and data for years after 1986 was obtained from NOS by telephone.

Cedar Keys, Florida

Year	Recorded Months	Ann. Mean NGVD
1914	9	0.09
1915	12	-0.92
1916	12	-0.04
1917	12	-0.05
1918	12	0.00
1919	12	0.05
1920	12	-0.05
1921	12	0.09
1922	12	0.05
1923	12	-0.12
1924	12	0.01
1939	12	0.13
1940	12	0.05
1941	12	0.21
1942	12	0.18
1943	12	0.24
1944	12	0.17
1945	12	0.19
1946	12	0.31
1947	12	0.32
1948	12	0.49
1949	12	0.42
1950	12	0.28
1951	12	0.25
1952	12	0.21
1953	12	0.28
1954	12	0.21
1955	12	0.25
1056	12	0.21
1957	12	0.44
1958	12	0.29
1959	12	0.31
1960	12	0.31
1961	12	0.40
1962	12	0.29
1963	12	0.14
1964	12	0.11
1965	12	0.29
1966	12	0.25
1967	12	0.33
1968	12	0.15
1969	12	0.28
1970	12	0.41
1971	12	0.36
1972	12	0.45
1973	12	1.53
1974	12	0.42
1975	12	0.55
1976	12	0.21
1977	12	0.31
1978	12	0.32
1979	12	0.35
1980	12	0.36
1981	12	0.26
1982	12	0.31
1983	12	0.44
1984	6	0.41
1985	10	0.37
1986	11	0.46
1989	12	0.38

Note: The above information was computed using data from "Sea Level Variations for the United States 1855-1986," published by NOS, NOAA. A gauge zero of -3.38 feet and data for years after 1986 were obtained from NOS by telephone.

Effects of Sea Level Change on the Barrier Islands and Inlets

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Abstract

The Mississippi-Alabama barrier islands are low elongated bodies of sand that separate the Mississippi Sound from the Gulf of Mexico. Four shallow tidal passes between the five islands allow communication between the marine waters of the Gulf of Mexico and the brackish waters of the Mississippi Sound. The passes are relatively wide (5.6 to 9.3 km.) low areas in the barrier island platform that extends from Dauphin Island on the east to Cat Island on the west. The water depth in the passes is generally less than 4.5 meters, except in the pass channels, which are cut up to 14 meters into the barrier platform.

The barrier islands are migrating westward due to the east to west littoral drift. The down-drift islands are relatively sediment-starved due to sediment losses in the island passes, weakening of the littoral drift system to the west, and reduction of available sediment. These processes are presently causing sediment starvation along the barrier islands and will be aggravated by an increase in the rate of sea level rise.

Relative sea level changes based on tide gauge records along the Mississippi-Alabama segment of the U.S. continental coastline is about 0.16 meter/century. However, the warming effects of increased atmospheric carbon dioxide and other trace greenhouse gases may substantially increase the rate of sea level rise. Scenarios by several investigators estimate eustatic increases of sea levels in the range of 0.5 to 1.5 meters by the year 2100. If these prove correct, the Mississippi-Alabama barrier island chain could be reduced to a sandy shoal within the next century.

Introduction

Recent scientific evidence indicates that the atmospheric concentrations of various gases, known collectively as greenhouse gases, have been increasing worldwide. These gases include carbon dioxide, chlorofluorocarbons, methane, and nitrous oxide. Experts believe that an increase in these gases has caused a decline in the stratospheric ozone and a rise in global temperatures. Continued warming of the atmosphere will have significant global effects, including a general rise in the level of the oceans.

Presently, one cannot know with precision the future rate of sea level rise. Agencies such as the Environmental Protection Agency, the National Oceanic and Atmospheric Administration, and the Marine Board of the National Research Council have conducted studies and reviews to assess the potential consequences of the anticipated increased rate of rise in worldwide sea level. Estimates of the eustatic sea level rise scenarios differ greatly. Several estimates are compared in Figure 1, which is taken from the 1987 study of the Marine Board of the National Research Council. Because the rate of future sea level rise is uncertain, the Marine Board examined three possible eustatic sea level rise scenarios with sea level rises of 0.5, 1.0, and 1.5 meters (m) by the year 2100.

It is interesting to speculate on the potential implications of sea level rise and its effects on the coastal areas of Mississippi and Alabama at the end of the next century. The effects would be profound along the low segments of the Mississippi-Alabama coast. A one meter rise in sea level would flood low-lying environments along the coastal bays and estuaries, increasing the area of the Mississippi Sound and its estuaries by as much as 10 to 15 percent. Additionally, it is likely that the protective barrier island chain that separates the Mississippi Sound from the Gulf of Mexico would be substantially reduced or destroyed due to the combined effects of increased erosion and sediment starvation.

Holocene Sea Level Changes

During early Holocene time, that portion of the coastal plain now submerged by Mississippi Sound was crossed by rivers and streams as they flowed toward the Gulf shoreline, which was well seaward of the present Mississippi-Alabama barrier island system. As sea level rose in response to the melting of the Pleistocene ice sheets during the most recent transgression of the sea (20,000 to 5,000 years B.P.) the courses of the rivers and streams filled and were buried beneath Holocene sediments of Mississippi Sound (Frazier, 1974). About 5,000 years ago, the rapid rate of sea level rise slowed and the modern shorelines and estuaries began to take their present shape (Fairbridge, 1980).

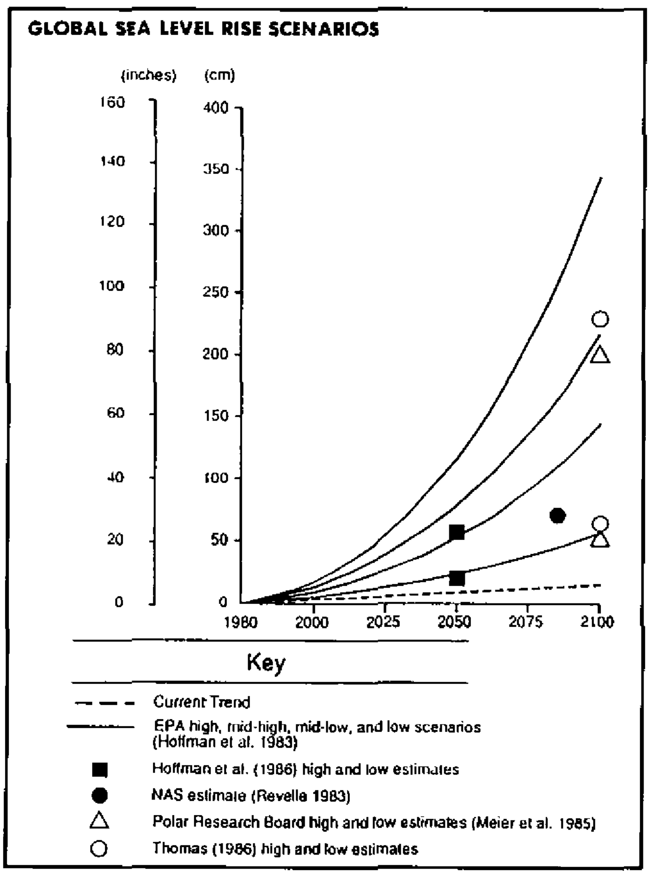

Figure 1. Estimates of local relative sea level changes along the U.S. coastline. Figures are in mm/year and are based on tide gauge data over various time interval during the 1940 to 1980 period. Adapted from Stevenson et al. (1986).

Alluvial sediments, which were deposited across the continental shelf during the period of lowered sea level, were winnowed and reworked into the Mississippi-Alabama barrier island complex during the Holocene post-glacial rise of sea level. Although the fluctuation during the past several thousand years remains in debate, it is believed that sea level began to slow its rate of rise between 5,000 and 3,000 years ago, and stabilized near its present level. Work by Stapor and Tanner (1977) and Tanner et al. (1989) at St. Vincent Island, Florida, suggests that, along this relatively stable shoreline, sea level has fluctuated within only one meter or so during the past 5,000 years.

Based on an analysis of tide gauge records by Hicks et al. (1983) and subsequent refinements by Stevenson et al. (1986) it appears that the relative sea level rise along the Mississippi-Alabama coast is about 1.6 millimeters per year or 0.16 meter per century (Figure 2). However, historical trend analysis for estimating future sea level rise is uncertain, due to the predicted acceleration in the rate of sea level rise as a consequence of man's activities.

Mississippi-Alabama Barrier Islands and Passes

Five barrier islands located 10 to 14 miles (16 to 23 kilometers) offshore along the Mississippi-Alabama coast separate Mississippi Sound from the Gulf of Mexico. The islands are low sand bodies situated on a relatively broad Holocene sand platform that extends 70 miles (113 kilometers) from Dauphin Island on the east to Cat Island on the west. The platform varies in thickness from 25 to 75 feet (7.6 to 23 meters) and rests on Holocene marine clays or on Pleistocene sediments. The barrier islands are nourished chiefly by littoral drift from shelf sands seaward of the islands' sand sources to the east. The barrier island chain predates the St. Bernard lobe of the Mississippi Delta complex, which began to prograde about 3,000 years ago and continued until it was abandoned approximately 1,500 years ago.

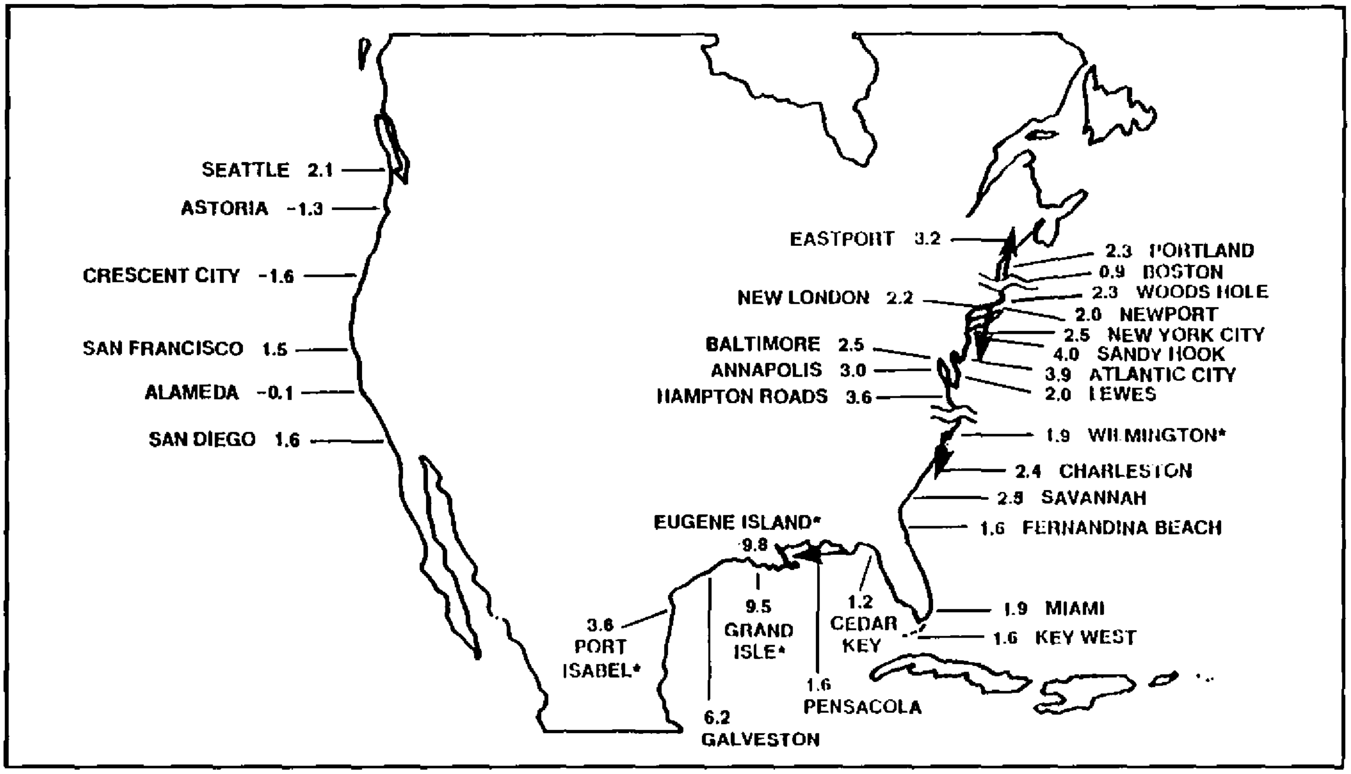

Figure 2. Range of eustatic sea level rise scenarios by various investigators reflect the present imprecision and uncertainties in estimating the rate of future sea level rise. Taken from the National Research Council Committee on Engineering Implications of Changes in Relative Mean Sea Level report (1987).

Four shallow tidal passes between the islands allow communication between the marine waters of the Gulf of Mexico and the brackish waters of the Mississippi Sound. The four tidal passes from east to west are: Petit Bois Pass, Horn Island Pass, Dog Keys Pass, and Ship Island Pass. The tidal passes are 3.5- to 5.8-mile (5.6- to 9.3-km) wide low areas in the Holocene barrier island platform (Figure 3).

The water depth in the passes is generally less than 15 feet (4.6 meters), except in the pass channels where stronger tidal currents have cut into the sand barrier platform. Each pass has one or two tidal channels. Presently the maximum depths in the channels range from 46 feet (14 meters) in Horn Island Pass to 23 feet (7 meters) in Petit Bois Island Pass. Due to the water depths in the tidal channels, the nearly full thickness of the Holocene island platform east of Cat Island has likely been reworked during the migration of the islands and tidal passes.

In contrast to the other islands, Cat Island at the western down-drift end of the Mississippi-Alabama barrier island chain, is interpreted to be a relict of an earlier stage in the life cycle of the barrier platform when there was a more robust littoral drift system and an abundant sediment supply. During the pre-St. Bernard Delta period of vigorous sedimentation, all of the islands in the barrier chain probably exhibited progradational ridges similar to those now found only on Cat Island.

Unlike Cat Island, which has been protected and preserved by the St. Bernard Delta, the other barrier islands have been modified and reworked during the past 1,500 years by processes of island and tidal inlet migration, accompanied by a general weakening of the littoral drift and a reduction of the available sediment supply.

Littoral Drift

The direction of net littoral drift along the islands is from the east to the west in response to prevailing wind and wave patterns out of the southeast (Eleuterius and Beaugez, 1979). The sediments that nourish the barrier island chain are attributed to longshore sand transport from updrift beaches east of Mobile Point along the eastern Alabama-Florida shores. Onshore movement of sediment from the continental shelf may contribute to the littoral sand transport budget of the barrier islands (Foxworth, et al., 1962; Otvos, 1970). Contributions to the barrier islands sediment budget from the Mobile River system are believed to be relatively modest since much of the sand-size material being delivered to Mobile Bay is being deposited and incorporated into the prograding Mobile River delta complex in the upper reaches of the Bay (Ryan and Goodell, 1972).

The amount of sediment entrained in the littoral system along these Gulf Coast barrier islands is not known with confidence. However, estimates by Garcia (1977) place the total net littoral transport at Dauphin Island, the eastern most island in the chain, to be about 150,000 m^3/yr (196,000 yd^3/yr). This estimate is in good agreement with earlier estimates by Gorsline (1966) for the beaches of the West Florida Gulf coast, and Johnson (1956) for the net littoral drift at Perdido Pass at the Florida-Alabama border.

The net littoral drift along the other islands of the Mississippi-Alabama chain has not been determined. Neither the amount of sediment lost from the littoral system in the inlets, nor the sediment gained from offshore sources are known. However, in all likelihood, the western islands are presently sediment-starved and any westward island growth is in part at the expense of cannibalization of sediment from the eastern end of the islands. Field observations at Ship Island tend to confirm the observation that the western portion of the island chain is receiving very little sediment and is eroding at a rapid rate. Shoreline position and change along Gulf barrier islands, based on data from charts and aerial imagery, have been carefully compared by Shabica et al. (1984). They have found that over the past several decades westward progradation is at a meager rate of 1.4 meters per year at West Ship Island, compared to westward growth rates of 4.6 meters per year for Horn and Petit Bois Islands. Dauphin Island, at the eastern end of the barrier chain, has a westward growth rate of 7.4 meters per year.

Island and Inlet Migration

The original passes and tidal channels likely formed by storm action cutting through low portions along

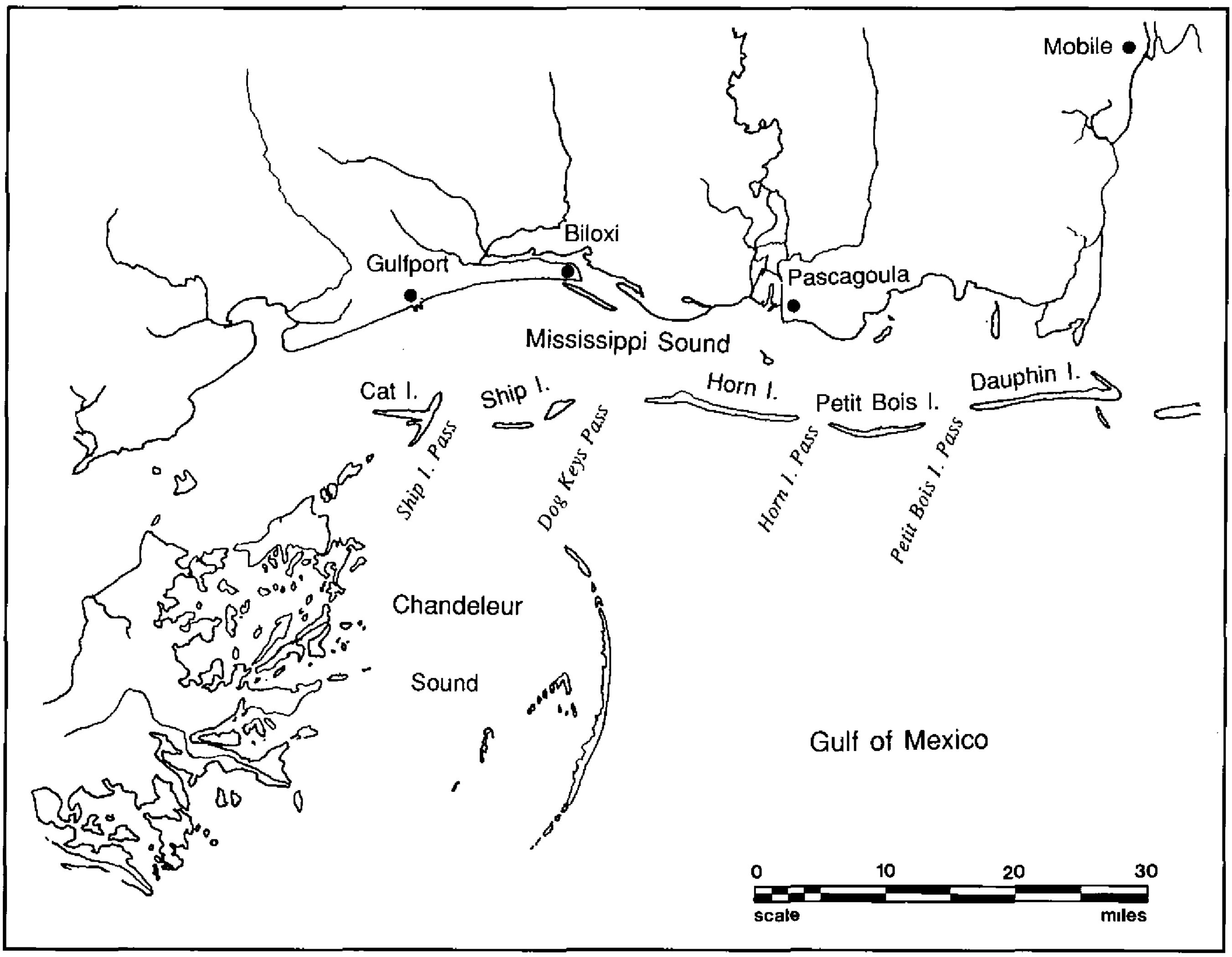

Figure 3. General location chart showing the island passes or inlet and the barrier islands of the Mississippi-Alabama barrier island chain.

the barrier island platform. Once established the channels were deepened by tidal currents until equilibrium was reached. At the same time passes and the tidal channels migrated down-drift in response to up-drift island accretion and sediment filling of the inlet channels. As the barrier island passes migrate, large volumes of sand are commonly left behind, stored within tidal ebb and flood structures.

The Dog Keys Pass has two channels which give rise to an episodic westward migration of Horn Island. The western end of Horn Island pauses as it fills one channel and a secondary channel develops. Once the channel is filled the island then migrates rapidly across the interchannel shoal to position of the more western channel, and the process is repeated. The channels and shoals in the Dog Keys Pass, as well as island migration, are clearly illustrated when the bathymetric and shoreline charts of the pass are compared. The first detailed survey in 1854, shows several small keys on the shoal extending eastward from East Point of Ship Island and a single tidal channel between Ship and Horn Islands. The 1917 survey shows the westward migration of Horn Island and the development of a secondary channel. The 1970 survey shows continued westward migration of Horn Island and erosion of the east end of Ship Island (Figure 4).

Along the length of Horn Island, is a series of three sets of distinctive lineations recurved toward the Mississippi Sound side of the island. At the locations of the recurved lineations, the shoreline on the Sound side of the island exhibits a slight offset. The western set of recurved ridges coincides with the 1854 shoreline position. An examination of the patterns of the ridges on aerial photos reveals that these offsets correspond to positions where the island apparently paused for a period of time in the course of its general migration to the west. Shoals and lobes of sand, commonly found on the north Sound side of Horn Island are interpreted to be the remains of flood tidal structures that mark former tidal inlet positions (Figure 5).

Pre-St. Bernard Delta Period of Island Progradation

The bold progradational ridge system of Cat Island, located at the western down-drift end of the Mississippi-Alabama barrier island complex, is unique. This system predates the eastward prograda-

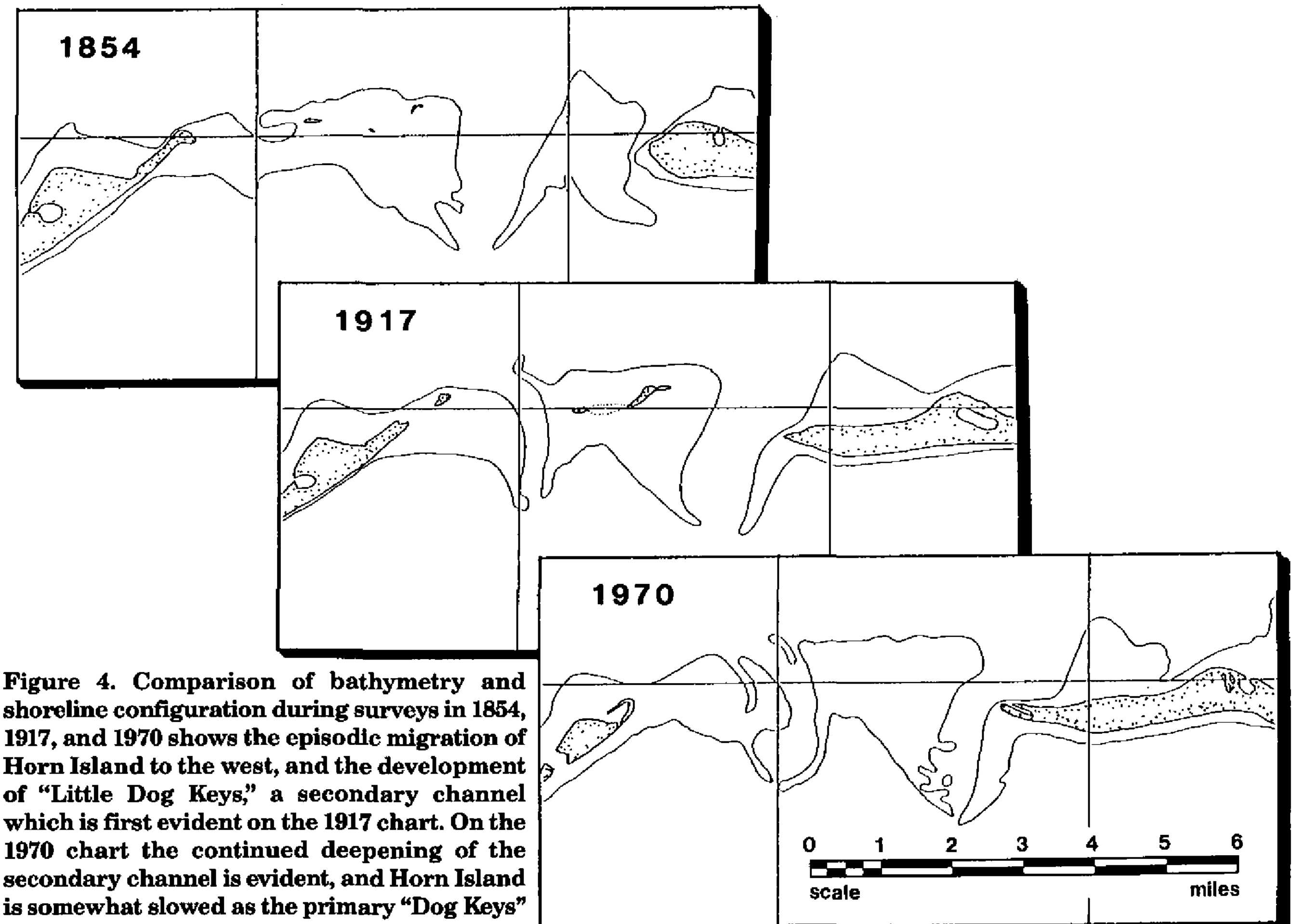

Figure 4. Comparison of bathymetry and shoreline configuration during surveys in 1854, 1917, and 1970 shows the episodic migration of Horn Island to the west, and the development of "Little Dog Keys," a secondary channel which is first evident on the 1917 chart. On the 1970 chart the continued deepening of the secondary channel is evident, and Horn Island is somewhat slowed as the primary "Dog Keys" channel is receiving much of the littoral sediment.

tion of the St Bernard Delta 3,000 to 1,500 years ago, amd appears to be a relict of a pre-St Bernard Delta period of robust sediment availability and transport (Rucker and Snowden, 1989). The nearest prominent progradational ridges similar to those of Cat Island are found 80 miles (130 kilometers) to the east of Mobile Bay on the Fort Morgan Peninsula near little Point Clear.

It is likely that sediments were abundantly available during the Pre-St. Bernard Delta period from alluvial sediments spread across the continental shelf during the Pleistocene period of lower sea levels. During this period the other barrier islands of the Mississippi-Alabama complex may have exhibited the robust ridges and swales now characteristic only of Cat Island and the Fort Morgan Peninsula.

The forested ridges of the Mississippi-Alabama barrier islands to the east of Cat Island are not characterized by the Cat Island type of bold parallel ridge system: they are not as sharply defined and generally not as continuous. Progradational ridge sets similar to those preserved on Cat Island, that may have once existed on the other Mississippi-Alabama barrier islands, have subsequently been reworked by episodic inlet and channel migration during the post-St. Bernard Delta period.

Effects of Sea Level Rise

The Mississippi-Alabama barrier islands are already in a sediment starved condition. The combined influence of effects induced by the sea level rise could reduce the island to a shoal during the coming century. Among the most important effects, are shoreline recession, due to erosion, to reach a new equilibrium profile at a higher sea level; island erosion and wash-over due to the influence of increased cyclonic storm activity; and the widening of tidal passes to the Mississippi Sound as a result of adjustment to an increased tidal prism.

Shoreline Recession

The shoreline on the Mississippi-Alabama barrier islands will be displaced vertically by an amount equal to the anticipated rise in sea level. Horizontal recession of the shoreline can be approximated by the "Bruun Rule." Bruun (1962) formulated the principles that describe the relationship between rise in sea level and shoreline erosion. Beaches are in equilibrium with the processes at work on them. They respond to a sea level rise by erosion on the emerged portion of the shoreline and retreat of the beach. The material

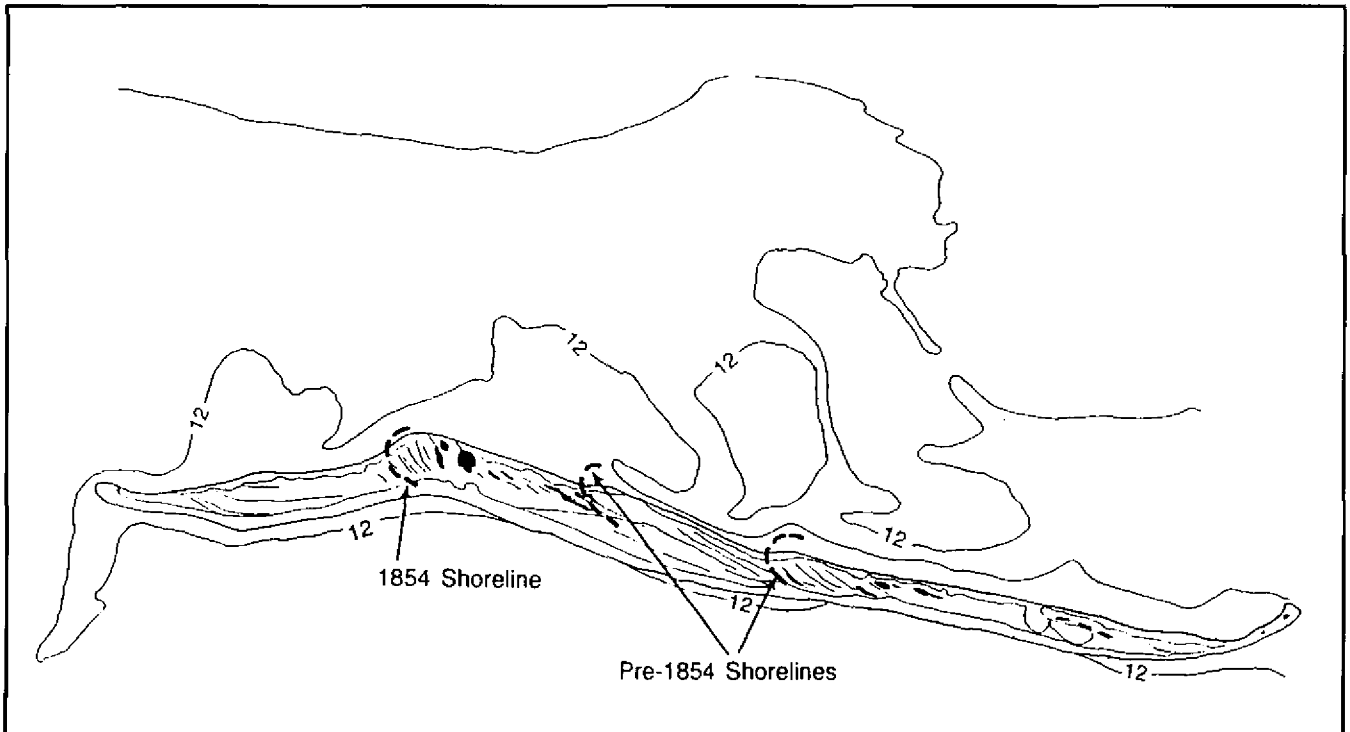

Figure 5. Outline of Horn Island showing sand shoals generally shallower than 12 feet. The sand shoals on the sound side of the island, and the recurved surface ridge lineations mark positions of the inlet and the west end of Horn Island during its episodic migration westward. Based on the distance the island has migrated since 1854, it is likely that the entire island has been reworked by inlet migration during the past 600-700 years. From Rucker and Snowden (1990).

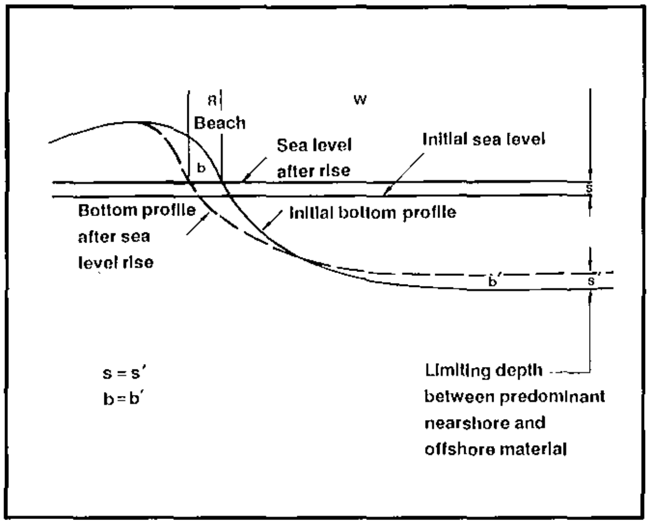

Figure 6. Diagram schematically showing the concept of the "Bruun Rule." A rise in sea level (s) will result in a equal rise in the offshore sea bottom (s'). The volume of material eroded from the beach (b) resulting in beach recession (R) is equal to the sediment deposited on the adjacent inner shelf (b').

removed during shoreline retreat will be redeposited on the adjacent inner shelf. This is a cross-shoreline two-dimensional model which balances quantities of sediment eroded from the shore and deposited on the sea floor (Figure 6).

Bruun (1962) found good agreement along the southeastern coast of Florida between the predicted and actual erosion, in which the distance of shoreline recession was about 100 times the vertical sea level rise. The "Bruun Rule" was verified by Schwartz (1965) in small scale wave tank tests, and was verified in the field by Hands (1976) in the Great Lakes.

Some of the limitations of a two-dimensional model and difficulties in defining boundary conditions is discussed by Brunn (1986). While in practice it may be difficult to confirm and quantify the model boundaries, especially in light of shorter-term profile adjustments by tides and coastal storms, it is nevertheless a useful concept with which to demonstrate the shoreline recession that will take place along the barrier island chain as a consequence of sea level rise. The narrowing of the islands will make them even more vulnerable to the destructive effects of storms and hurricanes.

Storm Effects

Tropical cyclonic storms and hurricanes have long affected the barrier islands of the Gulf Coast. For example it is believed that the separation of Petit Bois Island from Dauphin Island was probably storm-induced. The separation of the islands occurred after 1732, when the French mapped only a single island, but well before the area was first surveyed by the U.S. Coast Survey in 1848. Based on a comparative study of early charts in the area, Hardin et al. (1976) have documented the subsequent westward migration of Petit Bois Island and bathymetric changes in Petit Bois Pass.

Other Mississippi-Alabama barrier islands have been breached during storms in the historic past. However, these cuts have not generally developed into passes but have usually filled within a few years or decades after their formation. For example, a 1916 hurricane produced a shoal across the narrow neck of Dauphin Island, dividing it into two segments. The breach was completely filled with sediment by 1948 (Hardin et al., 1976). Ship Island was breached by a 1947 hurricane. This breach was filled by the late 1950's. The island was again breached by Hurricane Camille in August 1969. This cut has not yet been filled in the 21 years since the hurricane. Knowles and Rosati (1989) report that Camille Cut is now well-developed and East and West Ship Islands are functioning as separate and distinct barrier islands.

The western portion of Dauphin Island, which narrows to 650 to 980 feet, is commonly washed over during major storms and it is certain to be an early casualty to rising sea level. When the width of an island becomes sufficiently narrow, it is washed over by storms with regularity and tends to "roll over" and migrate landward. Eventually the island is either reduced to a shoal or may weld itself upon the mainland. This phenomena has been documented in detail by Leatherman (1984) on Assateague Island, Maryland.

During the 82-year period between 1899 through 1980, a total of 16 hurricanes have crossed the Mississippi-Alabama coast (Neumann et al., 1985). Nine of these have been major hurricanes (Category $\geq$ 3). It is expected that during the next century there will be increased storm and hurricane activity (de Sylva, 1986). Increasingly high air temperatures caused by the greenhouse gases will increase the temperature of the sea surface. A surface temperature of at least 26.8°C (77°F) is required to fuel the generation of a tropical cyclonic storm (Wendland, 1977).

Mississippi-Alabama coastal areas can expect an increase in frequency and intensity of tropical cyclones, as well an increase in the length of the hurricane season, due to the increase in sea surface temperatures anticipated during the coming century. Storm surges of rising water resulting accompanying the landward movement of a cyclonic storm will increase in frequency and severity, causing an acceleration of barrier island erosion and breaching

Tidal Response

Mississippi Sound is classified as a microtidal estuary since its diurnal tidal range is only about 1.7 feet (0.52 meter). The Mississippi Sound estuary has an area of approximately 1,850 square miles (4,790 square kilometers). Even though the tidal range is small, because of the large area of the estuary, it has a large tidal prism. A tidal prism of 4.32×10^{10} cubic feet has been calculated for Mississippi Sound (National Oceanic and Atmospheric Administration, 1985). Thus, a relatively large volume of water moves daily in and out of Mississippi Sound through the barrier island passes.

The tidal currents generated by the movement of this volume of water results in a comparatively strong current in the channels of the island passes. Winds across the Sound cause a setup or drawdown of the tides dependant on the wind direction and strength. Current speeds in the passes commonly range from 0 to 3.0 feet/second (0 to 91 centimeters per second). Meteorological effects, such as the passage of cold fronts or during storms, can double the strength of the tidal currents (Corps of Engineers, 1984).

By the end of the next century, a one-meter rise in sea level will flood low-lying areas in Mississippi Sound and its estuaries. The accompanying 10 to 15 percent increase in the tidal prism—the volume of water that must move through the barrier island passes each day—will increase substantially.

An equilibrium relationship has been demonstrated along a sandy coastline, between the tidal prism of a bay and the cross-sectional area of the entrance. Thus, as the tidal prism of the Mississippi Sound increases, the passes will deepen and widen, or new passes may be created. The net effect on the island chain is the reduction of the entrained sediment in the littoral drift that is able to bypass the island passes. This reduction will contribute to further sediment starvation on the down-drift islands.

Summary

The combined effects of shoreline erosional adjustment to higher sea levels, wash-over, inlet formation due to increased cyclonic storm intensity and activity, and sediment starvation due to pass enlargement as a result of the increased tidal prism of Mississippi Sound could result in the near destruction of the Mississippi-Alabama barrier island chain. Initially, the islands would grow narrower and shorter as the dimensions of the island passes increase. With the exception of Cat Island, the down-drift islands would grow increasingly sediment-starved since it would become more difficult for sediment to bypass the widened island passes. Cat Island, protected and isolated by the Chandeleur Island remnant of the St. Bernard Delta of the Mississippi River, is fundamentally not receiving sediments and is no longer in the littoral system of the Mississippi-Alabama barrier island chain.

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Northwest Florida and Southeast Alabama:

Historic Shoreline Stability During A Period of Relative Sea Level Rise

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Abstract

Evidence supporting a stable coastline during a period of relative sea level rise is presented for the northwestern Florida coast and southeastern Alabama coast. Historic records of sea level fluctuations, obtained from the National Ocean Service tide gauge at Pensacola, indicate a rate of relative sea level rise averaging 2.4 mm/year from 1924 to 1986.

When compared with the six remaining NOS tide gauges in Florida, Pensacola shows the highest rate of rise over the entire period of record available for each gauge. Historic shoreline trends since the mid-1800's demonstrate that the vast majority of the 225-km stretch of coast from Destin, Florida to Morgan Point, Alabama has maintained stability and is progradational in places.

Three localized sites of net erosion located along low profile areas of western Santa Rosa Island, eastern Perdido Key, and Morgan Peninsula, can be explained by repetitious foredune breaching and overwashing that occurred during historic hurricanes.

Historic stability has been maintained along this coast due to an abundant supply of sediment transported from two independent sources; a Pleistocene headland at Destin, and the inner shelf adjacent the Alabama coast. Sedimentological evidence, coupled with net longshore transport calculations obtained from Destin to Morgan Point, strongly suggest that Santa Rosa Island is being maintained by a mature longshore transport system supplied by sediment from an eroding Pleistocene source to the east. West of Santa Rosa Island, a distinct increase in the carbonate (shell) fraction in step samples suggests inputs of sediment from the adjacent, very low gradient, inner shelf. A detailed sediment budget constructed for Pensacola Pass, and further supported by wave refraction simulations, indicates negligible sediment transfer between Santa Rosa Island and the Florida/Alabama coast to the west.

These findings may have important implications for long-range planning along the northwestern Florida and the Alabama coastlines, particularly in prior planning for future sea level rise.

Sea Level Rise, Past and Future:

Mississippi and Adjacent Coastal Sectors; Geological and Environmental Perspectives

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Abstract

Concern about marine inundation of coastal areas that could soon endanger even stable northern Gulf coastal sectors arose from the likelihood of accelerated ice cap melting, the result of a worldwide warming trend. In recent decades, at certain north Gulf tidal gauges the Gulf rose slower than the assumed global eustatic rate. Shorter-term sea level trends could reliably be established by an expanded network of tidal gauges, not exposed to anomalous hydrologic effects in passes and semi-enclosed bays. Shore erosion, due to local sea level rise on the Mississippi coast and documented in the past 130 years, was most intensive near the subsiding Louisiana delta complex. Eustatic rise at Grand Batture-Point aux Pins and elsewhere may have played a minor contributing role in shore retreat. Accelerated marine inundation in the future would heavily impact vegetation distribution and would reduce total coastal wetland area. Beach erosion rates would increase. Harbors, roads, industrial facilities and residential subdivisions would have to be relocated or abandoned. The cost of future dislocation may be minimized with foresight in regional planning, soundly based on up-to-date hydrological and geological research.

Introduction

Global warming, in combination with local causes of land subsidence by the middle of the next century may result in significant sea level rise. This is a concern for long-range coastal planners and environmental experts worldwide.

Although most of the Mississippi coast is located in a stable sector, its southwestern corner, including Cat Island, has undergone significant subsidence during historic times and lost sizable areas of ecologically valuable wetlands to the sea. Continuing severe shore recession affects additional areas, including the Alabama border zone. Should global sea level rise accelerate in the next few generations, its costly effects would also impact the rest of the northeastern Gulf coast.

Factors in Past and Future Sea Level Rise

(1) Global eustatic sea level rise: causes and estimated future rates. Greenhouse effect and thermal expansion.

When ice and snow accumulation in polar and high mountain regions is outweighed by summer melting, the global sea level rises. Gornitz and Lebedeff (1987) held that global mean sea level rise, corrected for long-range trends amounted to 1.0-1.2 mm/yr during the past hundred years. Peltier and Tushingham (1989) indicated a rise of 2.4 mm/yr, instead. They attributed no more than 25% of this rise to the thermal expansion of water. According to Revelle (1983), this factor alone may raise sea level by one foot by the year 2100 A.D. A 7°C global temperature rise by that year, due to thermal expansion alone, may result in a maximum 83-cm (approximately 3 ft) sea level rise (Titus, 1986).

A steadily increasing impact by industrial and other human activities, superimposed on various natural causes, is widely held at least partly responsible for the 25% increase in atmospheric carbon dioxide concentrations in the past century (Matthews, 1990). During the last glacial substage, this value was only 190-200 ppm and at the start of the modern industrial age, about 280 ppm. Between 1958 and 1990, the carbon dioxide concentration over Hawaii rose from 315 ppm to 355 ppm. It may reach 550-600 ppm in the next generation (Matthews, 1990). Increase in the atmospheric content, primarily of carbon dioxide, methane, CFCs, nitrous oxide, and water vapor is regarded as leading to an enhanced greenhouse effect. This results in increased retention of solar heat by the atmosphere. Thomas (1986) and Ayers et al. (1989) suggested that doubling of the "greenhouse gas" concentration eventually will lead to a global warming of approximately 0.7 to 3°C (2 to 7°F) by 2040 A.D. and cause extensive ice cap melting.

Balancing factors (e.g., human activity-related increase in atmospheric dust particles that reflect the sun's radiation, and increased precipitation of snow in polar regions) may somewhat mitigate the greenhouse effect in the future. According to some calculations, the average worldwide temperature has already increased by about 0.5°C (1°F) since the late 1800's (Matthews, 1990). On the other hand, Maul and Henson (1990) report that the southeastern U.S. actually cooled since the 1940's and the 1959-1988 period was 0.6°C cooler than the 1929-58 time interval.

During the next several generations, intensive, ocean-influenced basal and surface melting of the potentially unstable Antarctic ice shelves, particularly in West Antarctica could lead to their precipitous disintegration. Significant global atmospheric and oceanic warming may cause rapid eustatic sea level rise. It is generally recognized, however, that thermal inertia of the sea considerably delays oceanic warming, causing a significant time lag between global warming and ice shelf disintegration.

Due to differences between assumptions and models, estimates of future sea level rise by different authors vary considerably. Mercer's "doomsday" projection (1968), involving catastrophic West Antarctic melting, was the first to trigger professional and public concern about coastal inundation in the near future. Nummedal (1983) predicted a 40-cm (1.3-ft) eustatic sea level rise by 2020, with an added 73-90 cm (2.4-3 ft) in south Louisiana due to local subsidence. On the basis of various scenarios, Hoffman and others (1983, 1986) estimated a 3.5- to 17.1-cm (0.1-0.6 ft) eustatic rise by the year 2000 A.D. and 23 to 117 cm (0.7 to 3.9 ft) by 2050. Thomas (1986) estimates that by 2050, global sea level is most likely to rise by 55 cm (2 ft) and 110 cm (3.6 ft) by the year 2100 A.D. Titus (1986) suggests a rise of 10-20 cm by 2025, and a 50-to 200-cm (1.6 to 6.6-ft) range by 2100.

(2) Compactional subsidence: natural and human-induced causes.

Consolidation of loose, muddy, and organic-rich Quaternary deposits leads to significant volume and thickness reduction through porosity loss. Ground water and hydrocarbon extraction have the same effects. Relative sea level rise in the southern part of the Mississippi Delta complex, exceeding global eustatic rate ten-fifteenfold, results primarily from compaction of a 120-180 m (400-600 ft) thick, unconsolidated Holocene sediment sequence and from tectonic causes (regional downwarp, faulting).

(3) Isostatic and neotectonic effects.

The weight of ice sheets and ocean water over land depresses continental areas, while release from such overburden results in isostatic rebound (uplift) and thus in a relative sea level drop. Similarly, the regional **uparching** of unglaciated coastal regions compensates for sediment loading and subsidence in an adjacent (geosynclinal?) **downwarp** zone (e.g.,in south Louisiana). This type of broad tectonic uplift has been and is presently taking place in Louisiana, Mississippi, and Alabama, just inland from subsiding coastal areas (Jurkowski and others, 1984; R. Bowen, this volume). Localized tectonic subsidence, involving apparent sea level rise, may also result from growth fault activity.

(4) Additional climatic influences on sea level and sediment supply.

Changes in the regional climate, affecting atmospheric pressure systems, wind and current regimes (e.g.,storm cycles) may periodically raise sea level for extended time periods (Komar and Enfield, 1987). Such fluctuations occur within a vertical range of 10-30 cm, occasionally of 1 m (3.3 ft).

Warming may also increase storm activity and thereby coastal erosion. It also would tend to diminish runoff, thereby reducing sediment volumes that reach the shoreline. Ayers et al. (1989) note that a 4-7° F temperature increase without corresponding 5-15% precipitation increase, would cause a 9% to 25% total annual runoff reduction in the Delaware Basin.

Global and regional warming, additionally, boosts water vapor content in the atmosphere, thus enhancing the greenhouse effect.

(5) Compensating vertical coastal wetland aggradation.

Sea level rise-related land loss may be mitigated if natural or human influence-related sediment supply from streams continues in delta wetland settings, especially in coastal salt marshes. Construction of dams and reservoirs, as in the Mobile-Alabama River system, blocks sediment transport to estuaries, lagoons, and open shores. Upstream sediment trapping thus indirectly enhances sea level rise effects and increases coastal erosion.

Mississippi and Adjacent Coastal Areas

Geological past; Late Pleistocene-Holocene sea level fluctuations.

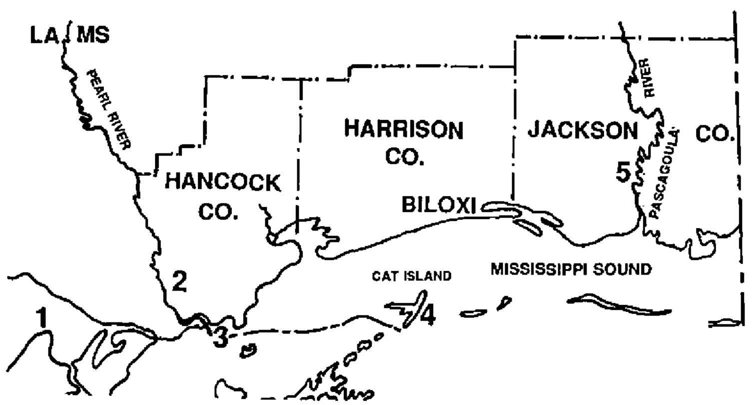
As indicated by Late Pleistocene marine and littoral deposits (Otvos, 1982, 1991), during the last interglacial period, between 136,000 to 115,000 (-82,000) years ago (Radtke and Gruen, 1990), the sea level was higher than presently. Following initial Sangamonian transgression, marked by deposition of the muddy-sandy nearshore-inshore Biloxi Formation, wide beach ridge plains, capped by eolian dunes (the Gulfport Formation), developed along the shore. The steady sea level stood approximately 6 m (20 ft) above the present.

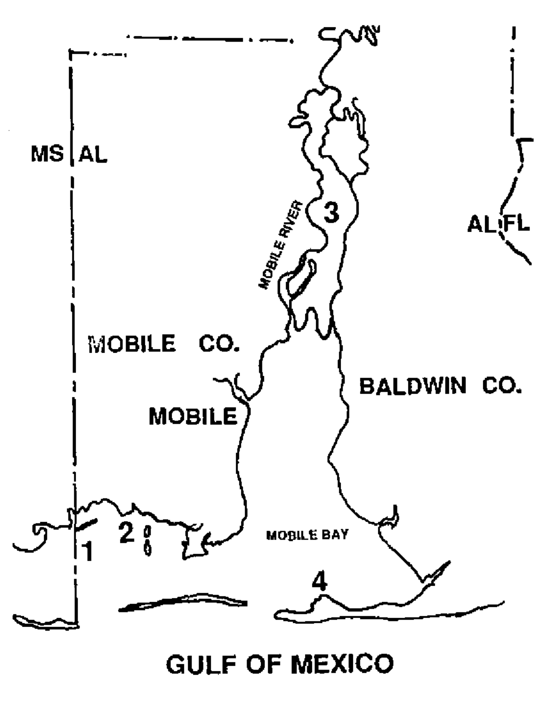
Sea level declined and then fluctuated during the earlier Wisconsinan glacial period. The shoreline retreated seaward and sea level dropped below 100 m about 20,000-18,000 years ago when streams became deeply incised into the widened coastal plain.

Postglacial global melting resulted in marine invasion of the lower stream valleys by Mid-to-Late Holocene times. The shoreline gradually shifted back to its present position. Two radiocarbon dates from the Pensacola-Biloxi area indicate that the sea level stood at approximately -22 m about 9200 yr B.P. and about -7.2 m by about 5700 yr B.P. (Otvos, 1991). Between 6,000 and 5,000 years ago, the Gulf rose at a record rate of 15.3 mm/yr (Nelson and Bray, 1970). No reliable data exist on sea level changes during the last few millennia. However, drill data from the Mississippi barrier islands and the record of two stranded islands in the south Hancock marshland suggest that sea levels during the last three to four millennia were very near to or coincided with the present one.

In the following, variations in the relative significance of factors that are involved in sea level variations and coastal erosion-accretion processes are briefly reviewed at a few key localitites.

Figure 1. Index maps. (1a-below) Louisiana and southwestern Mississippi locations–1, Point aux Herbes, LA; 2, Pearl River; 3, south Hancock marshland; 4, Cat Island. (1b-right) Southeastern Mississippi and Alabama locations–1, Grand Batture area, MS-AL; 2, Pt.aux Pins; 3, Mobile River Delta; 4, Fan-shaped Little Point Clear strandplain, northwestern Morgan Peninsula, AL.





Historical impact of marine incursion

(1) Relict Escatawpa delta plain, Mississippi-Alabama border.

In geologically very recent periods, the meandering Escatawpa River discharged its waters directly to the Sound. The stream constructed a small subaerial delta that straddled the present state line (Otvos, 1982). After an eastern tributary of the "pirating" Pascagoula River captured the Escatawpa flow, the abandoned delta became reshaped and was reduced by shore erosion. Combination of shore retreat and littoral sand transport from eroding delta shores, some time before 1848, created the 8-km long, 150-m to 400-m wide Grand Batture barrier spit along the marshy delta plain. A similar, 3-km long, 200-m wide double spit formed from eroding Point aux Pins, seaward extension of a tongue-shaped, slightly elevated Pleistocene ground (Figs. 2 and 3).

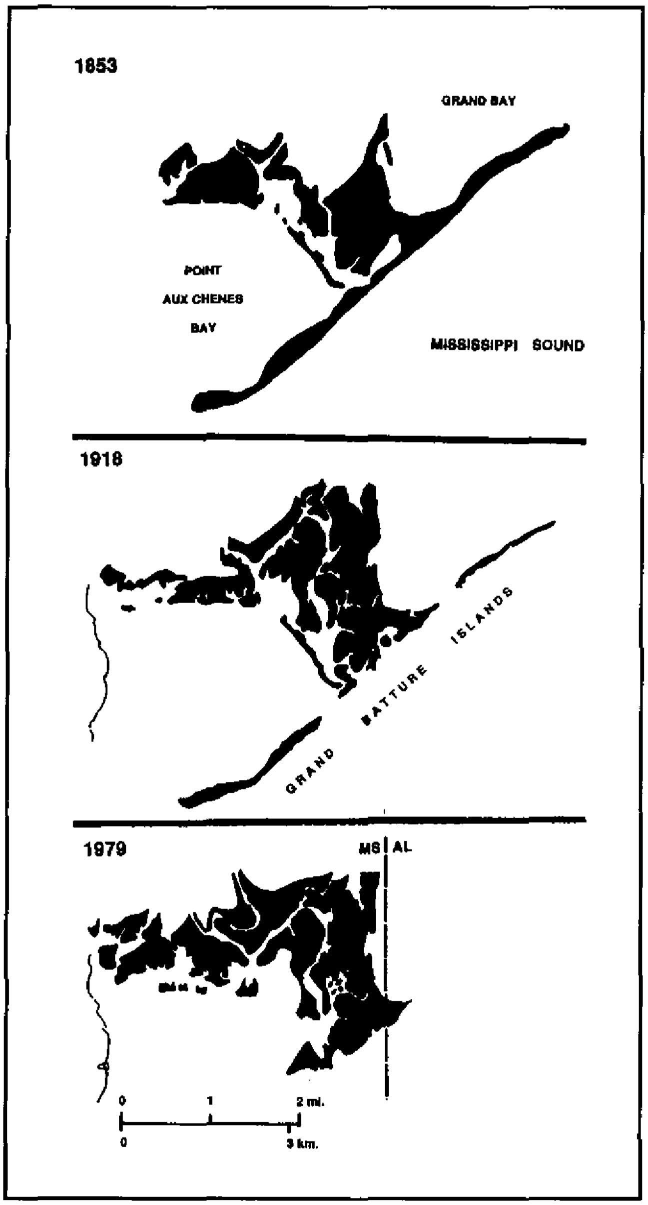


Figure 2. Coastal erosion stages in Grand Batture area. Based on 1853 U.S. Coast Survey Chart No.328 (1848 Suvey); 1917 U.S. Coast and Geodetic Survey Chart No.4020; Grand Bay SW USGS Quadrangle,1977, and NOAA aerial photography (Roll 2846; 1979). [Location: Fig.1b-1].

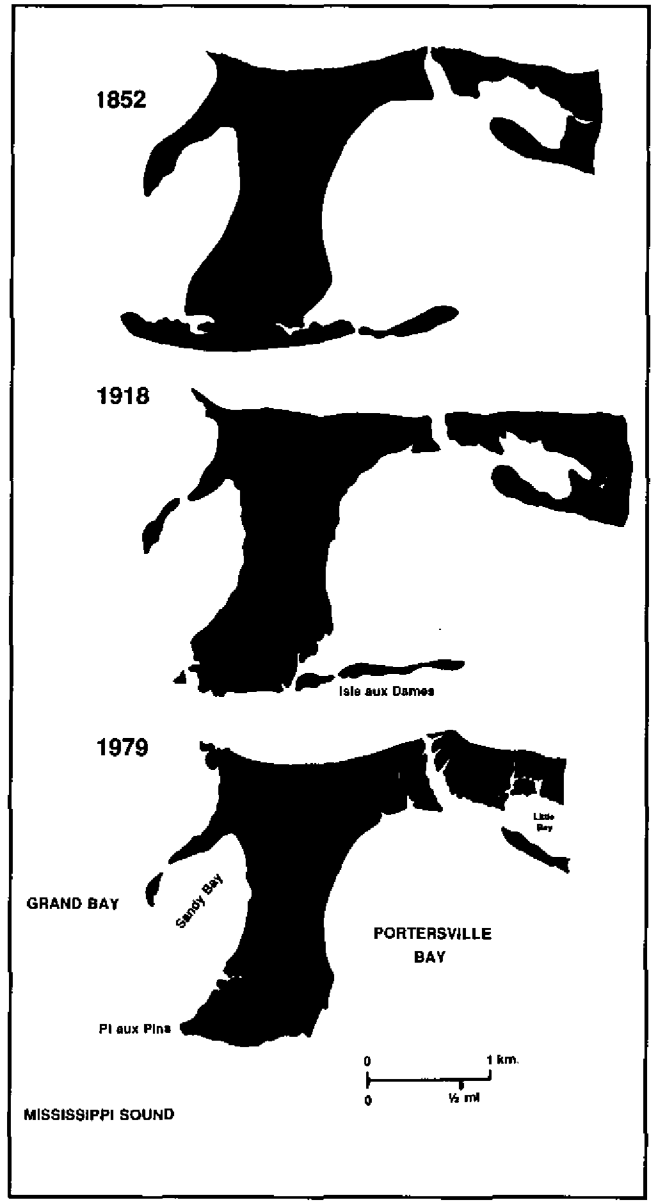


Figure 3. Erosion history at Point aux Pins. Based on 1852 Coast Survey Chart No. 329 (1848 Survey); U.S. Coast and Geodetic Survey Chart No. 4020, 1917; Isle aux Herbes Quadrangle, USGS, 1958, and NOAA aerial photography, Roll 2846, 1979. [Location:Fig.1b-2].

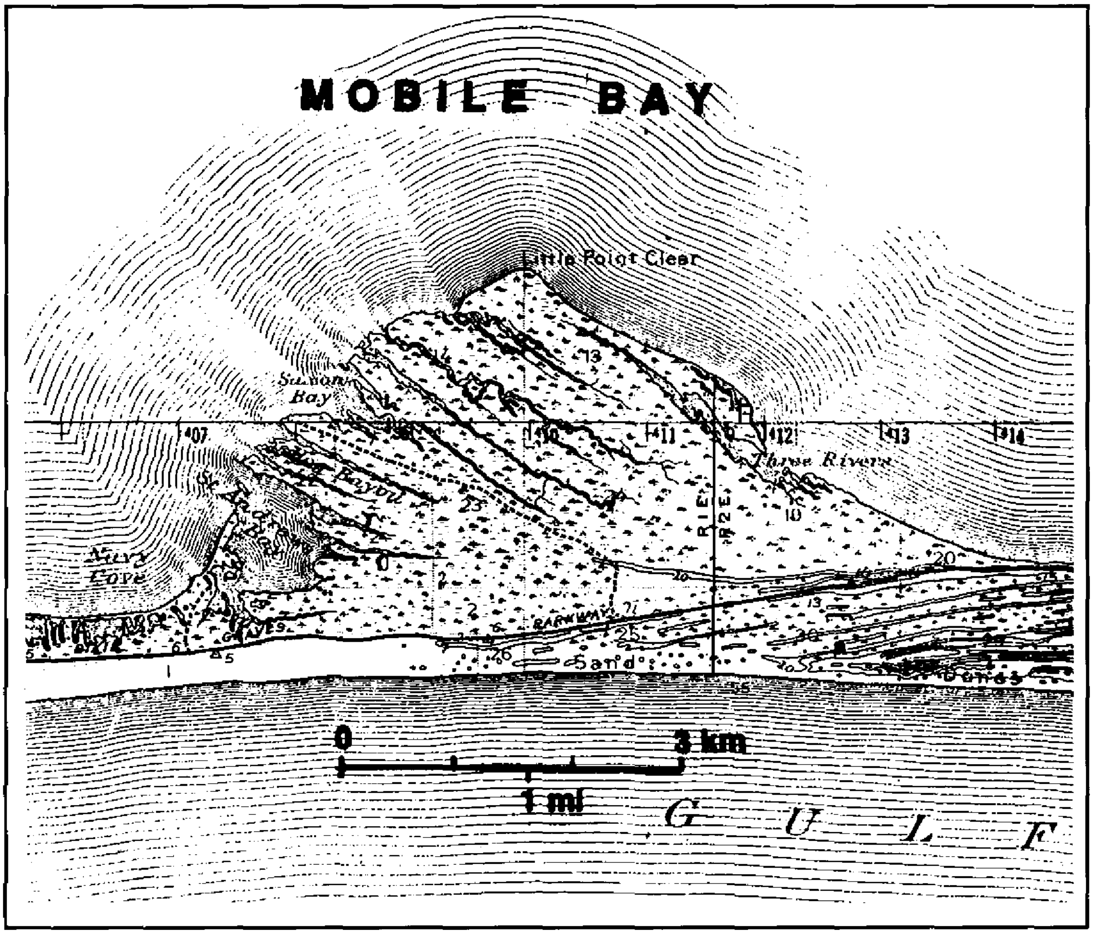


Figure 4. Little Point Clear strandplain set on Morgan Point Peninsula, AL. USGS Weeks Bay Quadrangle, 1941. [Location: Fig.1b-4].

Within a century of the first accurate surveys, the Grand Batture shore retreated by half a mile. Spits became fragmented to form Grand Batture and Isles aux Dames islets, then were gradually reduced to shoals. NASA aerial photos indicate that between 1979-1989 the most exposed, southernmost Grand Batture shore sector underwent further fragmentation and slight retreat (Fig. 8). Erosion on the Grand Bay-Portersville Bay shores diminished on occasions when Dauphin and Petit Bois Islands linked to form a continuous barrier that protected eastern Mississippi Sound. Erosion increased when gaps between individual island segments widened, allowing higher wave energies to reach the mainland.

Historic coastal charts, published since the early 18th century, display significant variations of Petit Bois Pass, between the two islands. The width of the Pass, presently about 8.25 km, was only 2.2 km in the early 1850s. Tropical and winter storms, followed by island recovery and growth, were instrumental in these changes. Considering the thinness of unconsolidated Holocene deposits under Grand Bay (approximately 1.8-3 m, or 6-10 ft; Ludwick, 1964), sediment compaction could not have caused subsidence. However, the slight sea level rise over the last 130 years may have played a marginal role in facilitating erosion.

(2) Submerged Morgan Peninsula Strandplain, Southeastern Alabama.

A fan-shaped strandplain that juts into Mobile Bay near the west end of the Peninsula at Little Point Clear marks the previous, curved terminus of the long barrier spit, formed in Late Holocene times (Fig.4). This sediment-starved ridge plain subsided and was overgrown by marsh, and occupied by open water embayments in the interridge swales. Coreholes, drilled along the length of the Peninsula indicate the presence of 27-30 m (90-100 ft) Holocene deposits that include a 20-25% interval of compactable mud and muddy sand. Land subsidence was probably related less to eustatic sea level rise and crustal downwarp than to sediment compaction.

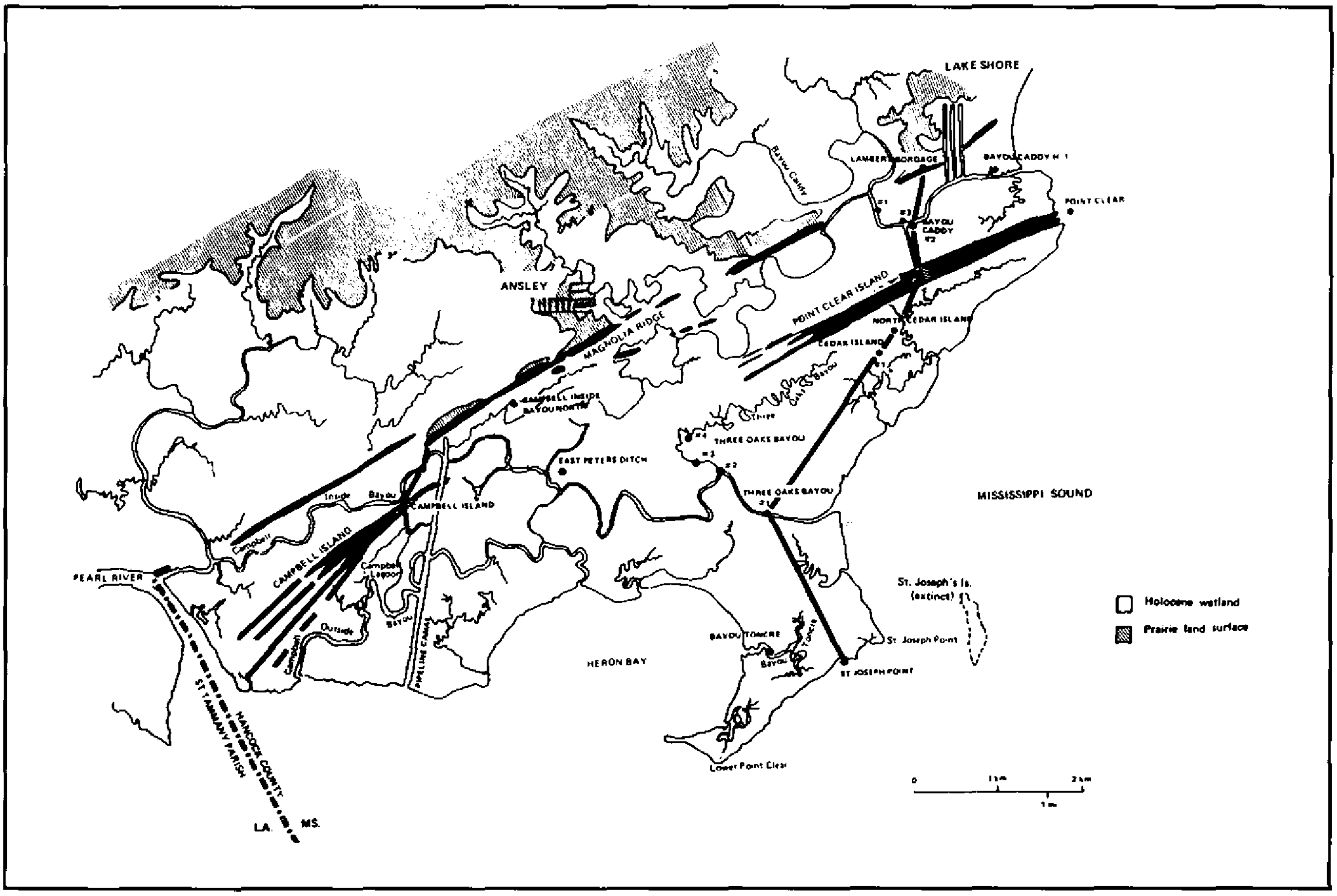


Figure 5. Subsiding-eroding wetland with marshbound relict barrier islands, south Hancock County, MS. Dashed lines southwest of Campbell and Point Clear Islands mark buried island segments, shown by marsh surface lineaments [Location: Fig.1a-3].

(3) Subsiding South Hancock-Cat Island Region, Southeastern Mississippi.

The south Hancock marshland, southeast of the Pearl River delta includes Point Clear and Campbell Islands; two Late Holocene barrier islands, stranded in the marshland. As lineaments in the marsh surface, especially southwest of each island suggest, the southwestern island ends subsided and were buried beneath the marsh (Fig. 5). Marshlands between about 3000 and 1500 years ago were located behind protective Mississippi St. Bernard subdelta lobes. The large subdeltas were actively creating new land areas. Subsequently, since the start of subdelta disintegration, the Hancock marshes steadily lost ground. The 1.1-km long St. Joseph's Island, at one time apparently part of the mainland, completely disappeared in the last century. Since 1852, various Hancock shore segments retreated by as much as 180-400 m (Fig. 6). The peninsula narrowed by about 28% between the mouth of Bayou Toncre and St. Joseph Point (Fig.4). Compaction of the 9-15 m (30-50 ft) Holocene sediment sequence under the marshes may partly be responsible for the subsidence and consequent coastal erosion (Otvos, 1988). To the south, the St. Bernard subdelta complex has experienced even higher rates of erosion and land loss.

Southeast of the Hancock area, T-shaped Cat Island, a strandplain-covered barrier island, at North Bayou (Fig.7) carries strong indications of subsidence. Island subsidence is accompanied by sea water intrusion into interridge lows. These swales are now filled by elongated ponds and marshes. A younger set of strandplain ridges became completely submerged under the Middle Spit marsh. Little Bay occupies a broad interridge zone between two beach ridge sets (Fig.7). Two coreholes revealed a thick [c.13.5 m (45 ft)] Holocene sandy sequence under the Island. Four meters of compactible muddy sand occurred in one drillhole.

The South Hancock area and Cat Island lie in the flank zone of the subsiding Mississippi St. Bernard subdelta zone. Combination of tectonic downwarping and sediment compaction resulted in relative sea level rise that appears to significantly exceed submergence

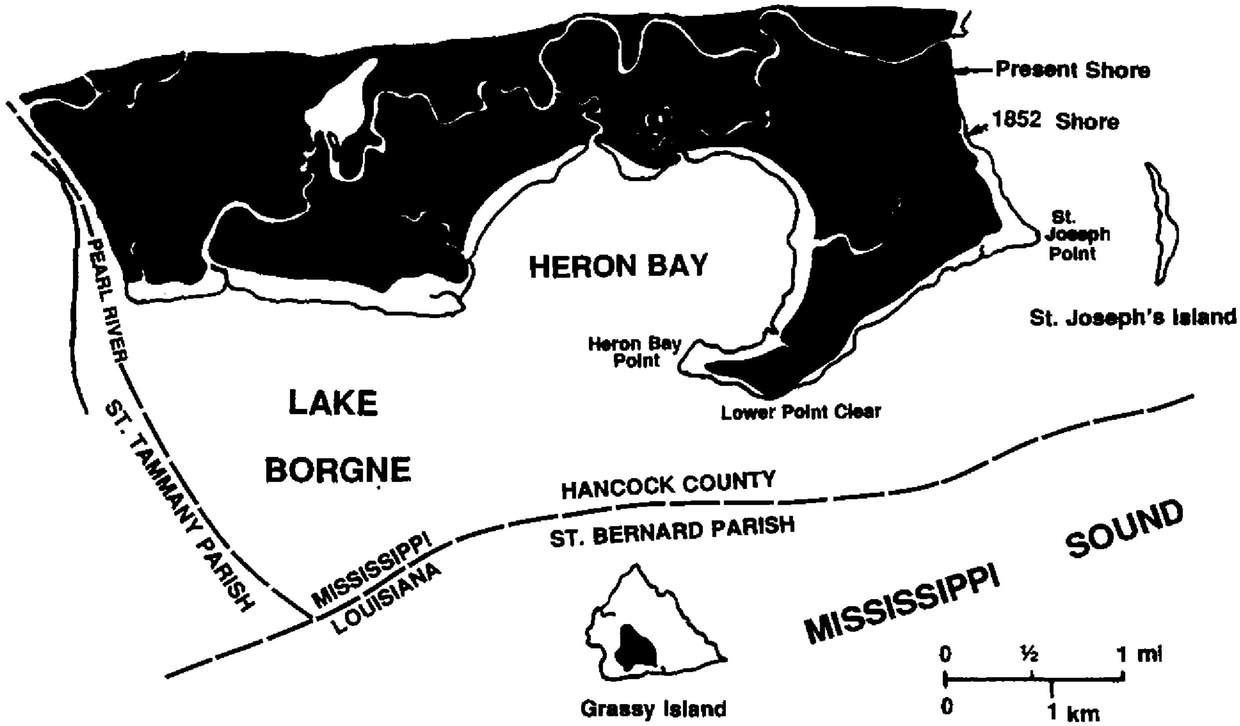


Figure 6. Erosional changes in south Hancock marshland between 1852 and 1977. Solid black: present marshland area. (Based on 1852 U.S. Coast Survey Chart No. 371, photorevised Grand Island Pass USGS topographic quadrangle, 1970, and NOAA aerial photography; Roll 2846, 1979).

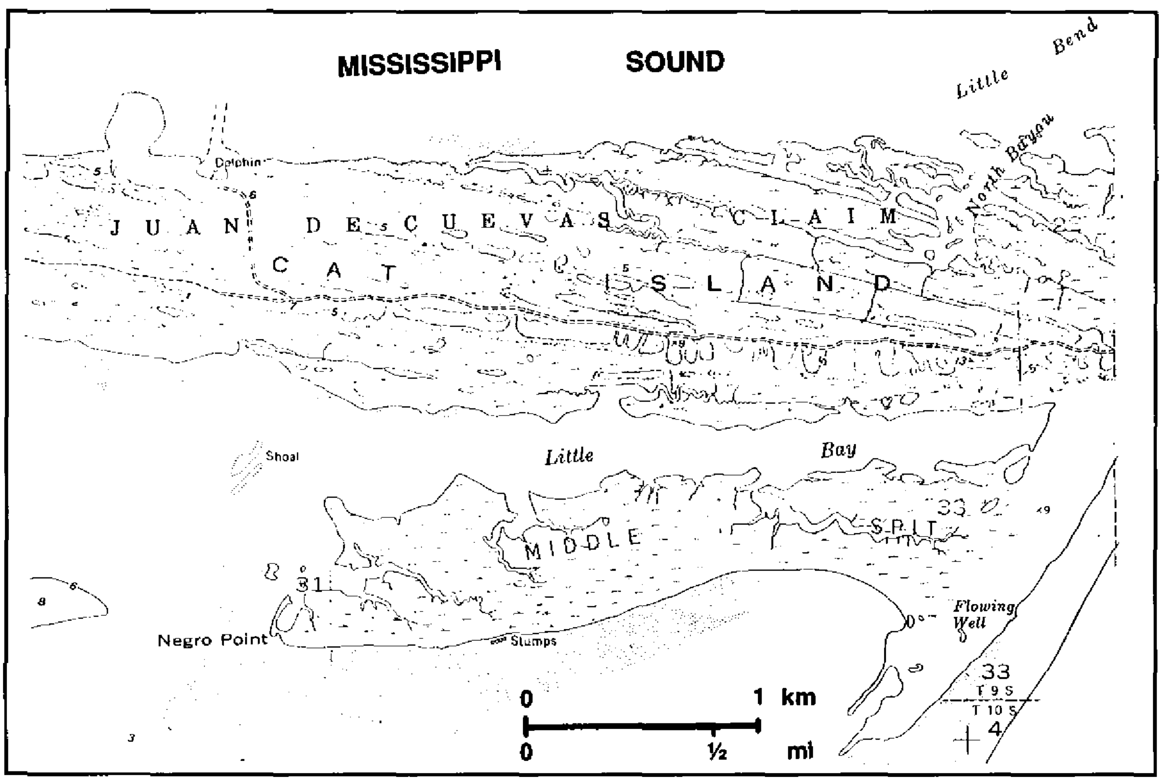


Figure 7. Narrow embayments in inundated swales. Subsiding island strandplain, northeastern Cat Island, MS. (USGS Cat Island Quadrangle, 1951). [Location: Fig. 1a-4].

rates on the central and east Mississippi Coast. Cat Island's partial submergence was greatly facilitated by the blocking effect of the north/south-oriented double barrier spit that starved the downdrift island shores. This gently arching large spit that intercepted westward-directed littoral drift, formed through erosional reworking and retreat of the original eastern island end. Wave energy-dampening previous growth of the St. Bernard subdeltas has already reduced sediment transport to the island prior to spit formation (Otvos, 1982).

Measuring Sea Level in Mississippi and Adjacent States

Sea level data, based on well-maintained gauges with stable foundations, may document short-term trends reliably if the periods covered are sufficiently long. Records, shorter than one to two lunar nodal cycles (18.6-27.2 yrs.) may be influenced by anomalous tidal, stream runoff, and other localized hydrological effects (e.g., gauges in Mobile Harbor, Alabama and the Atchafalaya Delta area, Louisiana). Several long records from the southeast United States suggest a sea level decline before 1931, followed by a rapid rise into the 1950's. Subsequently, the rise lessened again (Maul and Hanson, 1990). Long-term (50 yr+) data sets in this general area are available from two locations only: Biloxi Bay (operated by the U.S. Army Corps of Engineers), and Pensacola Bay (NOS).

Due to differences between geological and hydrological conditions at different gauge locations, different time length, and calculation methods used in computing and interpreting sea level rise it is questionable whether a "Gulf eustatic sea level" is a valid concept. This term has been mentioned in the literature to contrast with global eustatic sea levels.

Problems that arise from unstable gauge foundations and/or inadequate records are illustrated by data sets from two Grand Isle, Louisiana, gauges (National Ocean Survey and U.S. Army Corps of Engineers records listed in: Penland et al., 1988). The difference between values of the stations for the 1942-62 subperiod (3.0 mm/yr vs. 11.4 mm/yr) was greater than between values of the entire 1942-82 period (10.3 vs. 13.0 mm/yr). Reliable long-term gauge records, unaffected by localized subsidence variations and influences of hydrological anomalies are nonexistent or scarce along the northeastern Gulf shore and even in certain Mississippi Delta areas.

Regional Tide Gauge Information

Pensacola-Florida Panhandle

According to geodetic leveling data by Holdahl and Morrison (1974), the land area at Pensacola is undergoing 1 mm/yr subsidence. Linear regression analysis data, cited by Ramsey and Penland (1988) imply that between 1923-80 the sea rose by 2.3 mm/yr. NOAA-NOS Tidal Datum Application Unit figures (Milt Rutstein, pers. comm., 1990) suggest that sea level at Pensacola rose 1.9 mm/yr during the 1924-59 time interval. My comparison between averaged 1941-59 and 1960-78 data sets suggest only a 0.5 mm/yr rise. As this value is half of that of the land subsidence, it implies a rate of 0.5 mm/yr apparent sea level drop.

Biloxi-Mississippi Coast

Holdahl and Morrison reported zero vertical land movement along the Mississippi-southwestern Alabama mainland shore and a rise of up to 4 mm/yr in the adjacent inland zone. Preliminary 1955-1988 (1955-1978) data sets, analyzed by D. B. Zilkoski of the National Geodetic Survey (written comm.,1990), provided greater subsidence values. Land subsidence, in relation to a Mobile-area bench mark, amounted to 1.6-3.3 mm/yr on the Mississippi mainland coast but was less in southwestern Alabama. The benchmark, according to Holdahl and Morrison's survey data (1974), is located in a zone of 1 mm/yr uplift. Therefore, if confirmed, these figures may translate into a 0.6-2.3 mm/yr land subsidence and corresponding relative sea level rise on the Mississippi coast. The values are independent of the other sea level rise components, such as global eustatic sea level variations and local hydrological effects.

Prior to 1938, the U. S. Army Corps of Engineers-managed Biloxi gauge was on the Biloxi Bay railroad bridge. It was transferred to the old Ocean Springs highway bridge in 1938 (W. W. Burdin, this volume). Based on averaged 5-year data sets of 1882-1941 and 1928-1989 data series, I have calculated a sea level rise of 2.3 mm/yr at the gauge. Additional figures, processed by linear regression and cited by Penland et al. (1988), came not from NOS tidal gauge data in Biloxi, but from a 40-year record interval of the Corps of Engineers gauge. The authors calculated a 1.5 mm/yr overall sea level rise for the 1942-82 period, including an apparent 2 mm/yr sea level **drop** during the 1942-62 interval. The NOS Tidal Data Section (Douglas Martin, pers. comm.,1990) reports that the Biloxi NOS gauge, located on the GCRL Marine Education Center pier, operated only between 1979-89.

In order to accurately monitor sea level rise and land subsidence along other Mississippi Sound shore sectors as well, additional tidal gauge locations and geodetic land surveys are needed. The South Hancock shore outside Pearl River's direct influence, is among the recommended locations. Until more detailed and refined geodetic and tidal records become available, no firm conclusions can be reached about the relative impact of eustatic and other effects on sea level changes. Vertical coastal marsh accretion that may counter sea level rise, should be widely monitored. Marsh accretion rates are yet to be measured on the northeast Gulf coast.

Louisiana Tidal Gauge Data

Tidal gauge values on Lake Pontchartrain's south shore come from an area where only 6-12 m (20-40 ft) loose Late Holocene deposits cover the Pleistocene surface. Therefore, compactional subsidence here was much less important than further south. The 3.6-4.5 mm/yr subsidence vales of the northern and southern (West End) shore sectors (Ramsey and Penland, 1989) are only slightly higher than the Biloxi value. They contrast strongly with the Little Woods and Point aux Herbes figures from the southeast lake shore (10.1-10.9 mm/yr). The last two gauge locations are the nearest to the Mississippi coast. The Little Woods gauge is located only 16 km (10 miles) east of the New Orleans West End tidal gauge. Gauge data are unavailable from the extensive and heavily eroding St. Bernard Parish area.

The presence of an east-west striking fault under the Lake, just north of Point aux Herbes (Fig.1a; Kolb and others, 1975, Plate 2) tentatively suggests that ongoing fault movements locally may influence sea level along southeast lake shore. Gauge data here probably reflects ongoing localized downfault subsidence. Compactional subsidence, due to the thinness of the underlying Holocene sequence, is minor.

Land Areas Endangered by Future Marine Inundation

Mainland Marshlands and Stream Valleys

Intertidal marshes, vital components of the coastal ecosystems would be first affected by transgression. If sediment deposition does not keep up with rising sea level, they become displaced landward along with the shifting shoreline. In contrast with several Atlantic coastal areas, data on marsh accretion by sediment aggradation are unavailable in the subject area. Inland reservoir lakes, part of the Mobile River drainage system, contribute to coastal erosion by trapping sediments before they reach estuaries and coastal marshes. Future damming of the Pascagoula and Pearl Rivers would have the same effect. Most of Mississippi's tidal marshes (approximately 290 sq km; Eleuterius, 1987) are located in the south Hancock and the lower Pascagoula areas. Significant erosion of the most exposed south Hancock and Grand Batture marshlands will continue even at the present rate of sea level rise.

As sea level rises, fresh water marshes and swamps of the present stream floodplains (e.g., Honey Island Swamp in the Pearl River Delta) are replaced by brackish marshes. Because the streams presently occupy valleys that are deeply cut into the high upland surface, continuing transgression would result in gradually narrowing, long estuarine embayments. The sizable south Hancock and Grand Bay marshlands along the north shore of the Mississippi Sound, would be the first to be eliminated by wave erosion. Unless vertical marsh accretion keeps pace with sea rise, because of the northward narrowing valleys, the salt marsh acreage lost in the lower estuary reaches during marine inundation would be replaced only by increasingly smaller salt marsh acreage upstream.

A 3-m (10-ft) sea level rise, barring a catastrophic Antarctic ice sheet "meltdown" not expected for many centuries, would eventually shift the heads of the estuarine embayments about 28 km inland in the Pearl River Valley, approximately 22.5 km in the Pascagoula Valley, and about 56 km from the present bayhead in the Mobile River Valley.

Beach Maintenance

Artificially nourished Harrison and Hancock County beaches on the Mississippi mainland, vital for the local tourist industry and protection of coastal highways, have been experiencing a steady erosion. On three occasions between 1951 and 1988, a total of approximately 6.8 million cubic meters of sand was placed on the Harrison County beach. First, a new beach was constructed; later, subsequently eroded sand volumes were partially replaced. In addition to routine nourishment, 840,000 cubic meters of sand would be required to maintain the intertidal and supratidal portion of the Harrison County beach at a width of 70 m to compensate for each foot of future sea level rise.

A good portion of the recent explosive condominium and private home development on the southeastern Alabama-northwestern Florida coast occurred perilously close to the intertidal zone. A worst-case scenario places many buildings near or within the zone of marine inundation by the mid-21st century and exposed to increasingly damaging storm tides well before that time.

High Mainland Shores

Most of the Mississippi-Alabama mainland open shoreline is flanked by elevated ground, generally 2.4-3.0 m (8-10 ft) above mean sea level, and higher.

These sectors are underlain mostly by Late Pleistocene barrier and alluvial deposits (Gulfport and Prairie Formations) and Neogene units (eastern Mobile Bay shore). Between Morgan Point and central Perdido Key, Late Holocene strandplain dune ridges back the Gulf shore in southeastern Alabama. Scarp recession already is pronounced at several locations. East Belle Fontaine bluff, west of Pascagoula (Fig. 1b), for instance, receded 25 m (8.25 ft) between 1969-1990. It destroyed several summer homes in the process.

Storm waves that ride on a gradually rising sea level would pose a mounting danger to land, in particular if continued global warming increases the frequency and ferocity of tropical storms. The 26-mile (41.6-km) Harrison County coastal highway in Mississippi eventually would have to be rerouted. Commercial and yacht harbors would equally be affected; so would sub-

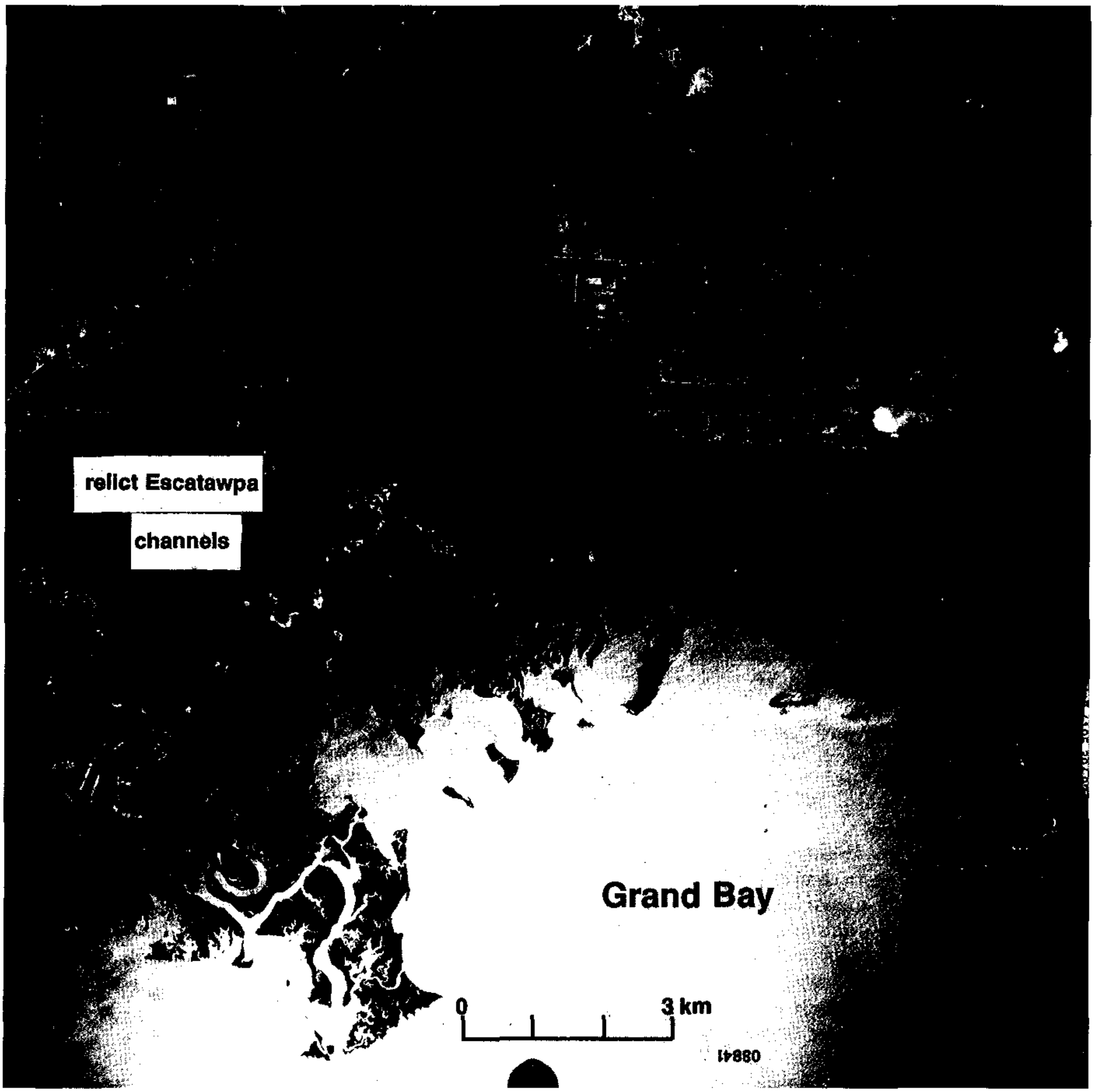


Figure 8. Grand Batture and Pt. aux Pins shore, 1989. NASA aerial photography, Roll #3841 (compare with Figures 2 and 3).

divisions on the Mississippi Sound and Mobile Bay shores (e.g., West Belle Fontaine, MS; the Daphne-Point Clear sector, AL).

At a later stage, low-lying industrial-commercial sites along the northwestern Mobile Bay shore, including the industrial-harbor waterfronts at Mobile and Theodore, may also have to undergo gradual relocation.

Barrier Island and Pass Changes

Rising sea level would seriously impact and soon overwhelm the already narrowing, low Chandeleur island chain and intertidal shoals south of the Mississippi coast. The sturdier Mississippi-Alabama barrier islands (Figs. 1a,b) would be much less affected by an initial 1 to 2-foot rise. However, narrow, low island sectors (central and western Dauphin Island, eastern West Ship Island) will be even more vulnerable to storm overwash and recurring island segmentation than presently. The littoral sand supply that reaches the island chain from the Morgan Peninsula-Mobile Bay ebb tidal delta would continue.

The southeast Alabama mainland and east Dauphin Island sectors are expected to remain relatively stable in the early stages of sea level rise and continue to provide a route for westward-directed littoral drift. Ample littoral sediment supply, transmitted along the Mobile Bay ebb-tidal delta, allows the island chain to delay serious shore recession. The islands could compensate for the rising sea by vertical aggradation and lateral progradation. On the other hand, even a minor sea level rise would increase the frequency and, thus, the severity of periodic storm impact on the more vulnerable island sectors. Subdivisions on densely-built, low and narrow east-central Dauphin Island are likely to suffer the most damage. As long as the Mississippi-Alabama islands and Morgan Peninsula remain in their present positions, rising sea level, widening lagoons and bays would result in increased estuarine water volumes. To maintain a dynamic equilibrium between tidal exchange volumes and pass channel dimensions, the channels would become deeper and wider.

Only when the westward-moving sand supply is eventually diminished would the rising sea reduce barrier island dimensions. At the same time, elevated saline ground water levels and the more frequent overwash would result in wider brackish lagoons and ponds in island interiors. Depending on the island dune field elevations and their continuity and width, at a certain stage of the marine transgression, the barrier islands will become more susceptible to storm overwash and increased segmentation than at present. Eventually they may start on a path of landward migration.

Surface and Ground Water Salinity

As the rising sea deepens and widens tidal passes, increased influx of high salinity Gulf waters to Mississippi Sound would be noticed even in the early stages of transgression. Subsequently, due to diminishing littoral drift, barrier island segmentation and reduction and salinities in the Sound and contiguous mainland bays would increase. Marked ecological changes would follow in the entire nearshore zone. Increasing intrusion of the estuarine salt wedge into streams from which fresh water had been taken for various purposes, could have a profound impact on local economies.

Shallow ground water horizons, utilized in densely inhabited areas (as on the central Mississippi coast and the eastern shore of Mobile Bay) could be similarly affected. If in direct physical contact with adjacent, increasingly salty estuarine bodies, such aquifers could be ruined by the salt water intrusion.

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A Review of Coastal Erosion and Wetland Loss in Louisiana

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Abstract

The Mississippi River delta and chenier plains in Louisiana are experiencing catastrophic coastal land loss rates exceeding 100 km²/yr. Louisiana's coastal zone contains 40 percent of the U.S. wetlands and 80 percent of the nation's loss occurs here. The origin and stability of these coastal environments is tied to the sediments discharged by the Mississippi River through the delta cycle process. Sediments accumulate in well-defined delta complexes at approximately 800-1,000 year intervals followed by abandonment and barrier island formation. The delta-cycle process, that builds new delta complexes, barrier islands, and cheniers is currently stopped by flood and navigation control structures. These structures harness the flow of the Mississippi River within a massive levee system, channeling most of the sediments off the continental shelf.

Deprived of sediments and subsiding rapidly, Louisiana's wetlands are vanishing. Researchers have long recognized the catastrophic coastal land loss conditions occurring and speculated on the causes. The chronic problem of wetland loss is well documented, but poorly understood. Over the last decade, two schools of thought have developed in the coastal research community concerning the relative roles of the causal factors driving the extreme rates of land loss and change. One school of thought emphasizes the natural processes of the delta cycle process and human activities are ranked as secondary in importance. In contrast, the other school of thought placed primary importance on human activities and of secondary importance are the natural processes. A review of previous coastal land loss research indicates the only way to accurately determine the relative roles of different types and processes of land loss is to develop a classification suitable for quantitatively mapping the spatial distribution and contribution of each geomorphic loss type to the total amount of land loss in a given interval of time.

Introduction

Coastal erosion and wetland loss are serious and widespread problems of national importance with long-term economic and social consequences. Louisiana is experiencing the highest rates of coastal erosion and wetland loss in the United States and possibly the world. Rates of coastal loss have increased from 10 km²/yr to more than 100 km²/yr over the last century (Morgan and Larimore, 1957; Craig et al., 1980; Gosselink et al., 1979; Wicker, 1980; Gagliano et al., 1981; Sasser et al., 1986; Adams et al., 1978; Walker et al., 1987; Coleman and Roberts, 1989; Britsch and Kemp, 1990; Penland et al., 1990). Louisiana's barrier islands, whose presence creates and maintains an extensive barrier-built estuarine system, protect the marshes and bays from offshore wave conditions and saltwater intrusion from the Gulf of Mexico. These islands are vanishing, decreasing in area and eroding at very rapid rates (Peyronnin, 1967; Penland and Boyd, 1981,1982; Morgan and Morgan, 1983; McBride et al., 1989).

The disappearance of Louisiana's barrier islands will result in the destruction of the large estuarine bay systems and the acceleration of wetland loss. Coastal land loss severely impacts the fur, fish, and waterfowl industries, valued at an estimated $1 billion per year, as well as the environmental quality and public safety of south Louisiana's sea level citizens (Gagliano and van Beek, 1970; Gosselink, 1984; Turner and Cahoon, 1987; Chabreck, 1988; Davis, 1983, 1989). The region's renewable resource base depends on the habitat provided by these fragile estuarine ecosystems. Understanding the coastal geomorphological processes, both natural and human-induced that control barrier island erosion, estuarine deterioration, and wetland loss in Louisiana is essential in evaluating the performance of the various restoration, protection, and management methods currently envisioned or employed.

Coastal erosion and wetland loss are posing a growing challenge to Louisiana and other Gulf Coast states as our population becomes increasingly concentrated in and dependent upon coastal areas. The Environmental Protection Agency (EPA) and National Research Council (NRC) forecast the rates of sea level rise will increase over the next century. This increase will dramatically accelerate coastal land loss in the future (Barth and Titus, 1984; National Research Council, 1987).

Because of its geologic setting, the severe coastal land loss conditions found in Louisiana today provides a worse-case scenario for the future coastal conditions forecast by the EPA and NRC. More importantly, Louisiana's coastal problems document the importance of understanding the processes driving coastal land loss. The U.S. Geological Survey (USGS) and Louisiana Geological Survey (LGS) cooperative coastal research program strives to improve our knowledge and understanding of the processes and patterns of coastal land loss and of the forecast of adverse impacts on people and resources in the coastal zone (Sallenger and Williams, 1989).

Many solutions to most coastal land loss problems caused by geologic processes overly emphasize stopping the result of the process and do not give adequate consideration to the process itself. This approach results in many engineering solutions that rely on costly brute force rather than more sophisticated, less expensive approaches that are in concert with natural processes defined by scientific study (Penland and Suter, 1988; Penland et al., 1990). The lack of understanding the processes also leads to oversimplified concepts producing false hope that simple solutions exist.

The key objectives of the USGS and LGS cooperative coastal research program are to provide good scientific information on coastal erosion and wetland loss suitable for developing a strategy to conserve and restore coastal Louisiana and to improve communication among scientists, engineers, and decision makers. This paper summarizes the geologic framework in which coastal erosion and wetland loss occurs in Louisiana. In addition, this paper discusses the controversy surrounding the causes of coastal land loss and the relative roles of natural processes and human activities.

Regional Geology

Delta Plain

The coastline of the northern Gulf of Mexico is dominated by the Mississippi River. Since about 7,000 yr B.P., the Mississippi River has built a deltaic platform comprising numerous individual delta lobes and groups of unrelated lobes known as delta complexes (Russell, 1936; Fisk, 1944; Kolb and Van Lopik, 1958; Scruton, 1960; Frazier, 1967; Coleman, 1988). The delta-building process consists of prodelta platform establishment, followed by distributary progradation and bifurcation, that results in delta plain consolidation (Figure 1). This process continues until the distributary course is no longer hydraulically efficient. Abandonment occurs, initiating the transgressive phase of the delta cycle. The abandoned delta subsides, and coastal processes rework the seaward margin, generating a sandy barrier shoreline backed by bays and lagoons (Kwon, 1969; Penland et al., 1981). Coastal land loss occurs naturally during this stage. Transgressions occur repeatedly, both for delta complexes and delta lobes.

The contemporary delta plain can be subdivided into two distinct categories, active deltas and abandoned deltas. Delta building occurs in 20 percent of the delta plain and is restricted to the Modern complex and the newly active Atchafalaya complex. The Plaquemines delta of the Modern complex is abandoned. The four remaining complexes, the Maringouin, Teche, St. Bernard, and Lafourche are all abandoned and have some type of transgressive shoreline or shoal sand body developing. The Balize lobe of the Modern delta complex is represented by the familiar "bird-foot delta" model. The delta has prograded into deep water near the shelf margin and the greater accommodation space results in the accumulation of hundreds of meters of sediments in one deltaic cycle. Mass movement of sediments is extremely important in building the deltaic sequence.

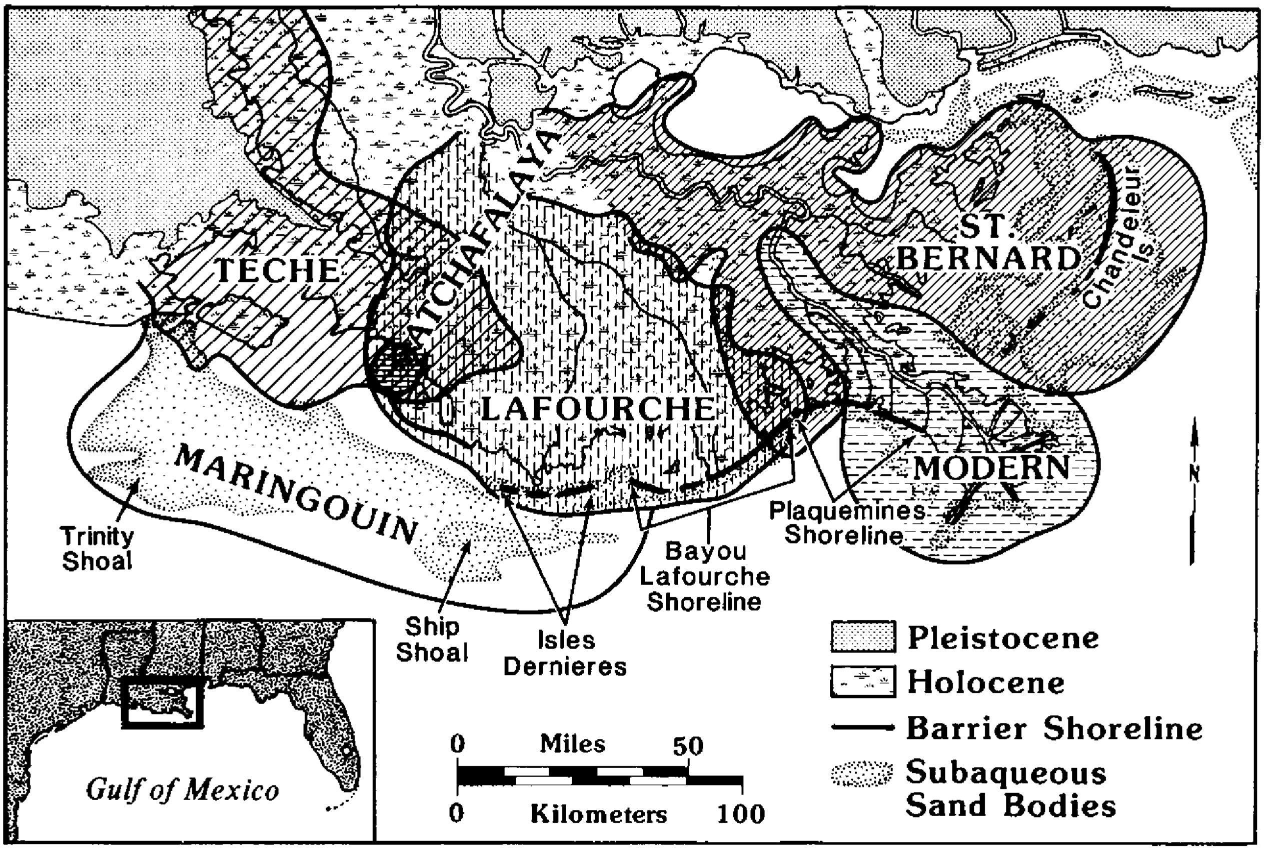

Figure 1. Frazier's (1967) model of the Mississippi River delta plain depicting the location of the transgressive barrier shorelines and shoals.

The Atchafalaya delta complex emerged as a subaerial feature after the 1973 flood (van Heerden and Roberts, 1988). According to Fisk (1952), the Atchafalaya has been a distributary of the Mississippi River since the mid-1500's and by the 1950's had captured about 30 percent of the flow of the Mississippi River. Because the route of the Atchafalaya River to the Gulf is some 300 km shorter than the current course of the Mississippi River, Fisk (1952) predicted a relocation of the main distributary to the Atchafalaya course. As a result, a series of large control structures have been built north of Baton Rouge to hold the Mississippi River in its present position. Were it not for these structures, the Balize delta would probably have been abandoned by now and have entered the transgressive phase.

As a delta is abandoned, marine processes begin to dominate the system. Coastal land loss occurs and deltaic sand bodies supply coarse sediment to the nearshore current field. An erosional headland with flanking barrier spits develops, and an evolutionary process of barrier island formation begins (Penland et al., 1988). The abandoned Bayou Lafourche delta headland is the most recent example of this landform. Erosion rates on the central headland average as much as 20 m annually, reaching over 50 m in hurricane years (Ritchie and Penland, 1988). The Timbalier Islands to the west of the Bayou Lafourche headland and Grand Isle to the east, represent a Stage 1 barrier system (Figure 2).

The Plaquemines barrier shoreline associated with the Modern delta complex also represent a Stage 1 barrier system (Ritchie et al., 1990). With continued subsidence, marine waters intrude into the backbarrier marshes, resulting in the formation of a saline lagoon, separating the barrier from the mainland marshes and forming Stage 2, the barrier island arc. The best examples of this are the Isles Dernieres derived from the Lafourche delta complex and the Chandeleur Islands derived from the St. Bernard delta complex (Penland et al., 1985; Ritchie et al., 1989). Further subsidence removes the coarser-grained distributary mouth bar and channel deposits from the nearshore wave field, resulting in a cessation of sediment supply to the barrier islands. At this point, continued reworking by waves and storms begins the degradation of the barrier islands. The subaerial island area decreases greatly as sands are lost seaward to an inner shelf sand sheet, landward by overwash, and captured in tidal-inlet sinks. This process is well-illustrated by the evolution of the Isles Dernieres. Ultimately the barrier system loses its subaerial integrity and forms Stage 3, and inner-shelf shoal (Penland et al., 1989a).

Chenier Plain

The chenier plain is a series of alternating ridges and mud flats, first described by Russell and Howe (1935) and Howe et al.(1936). The term chenier is derived from the French word "Chene" for oak, the tree that grows on the crests of the higher ridges. The chenier plain stretches 200 km from west of Sabine Pass, Texas, to Southwest Point, Louisiana (Penland and Suter, 1989). The width of the deposit ranges from 20 km to 30 km, with elevations of the ridges varying from 2 m to 6 m (Figure 3). Gould and McFarland (1959) used shallow borings and radiocarbon dates to interpret the sedimentary facies and stratigraphic history of the chenier plain. Transgressive and regressive wedges overlie a soil zone that is also the Pleistocene-Holocene unconformity. The wedge thickens from 3 m to 6 m and is progressively younger seaward. Vertical sequences consist of basal and up-

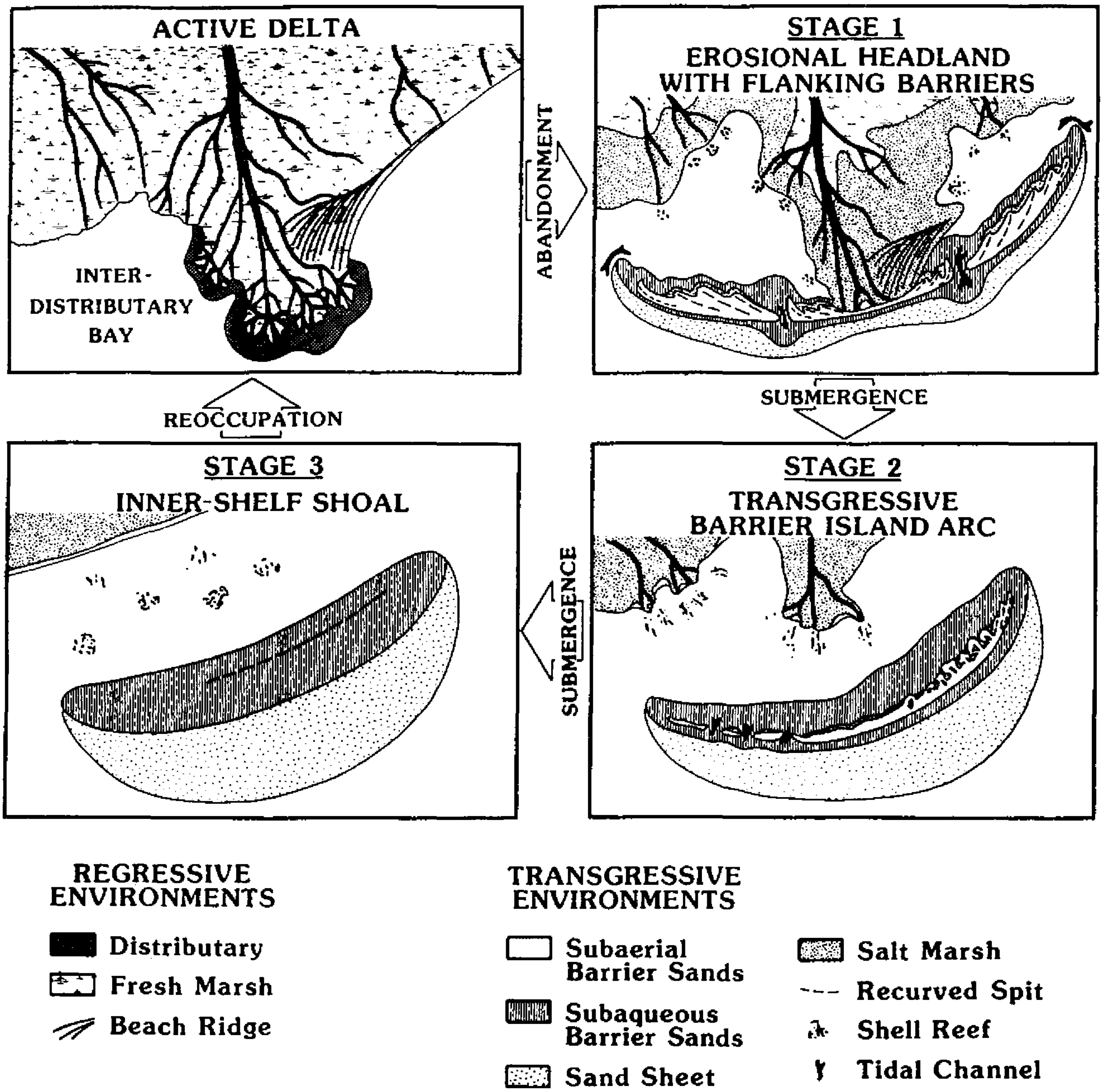

Figure 2. The genesis and evolution of the transgressive depositional systems in the Mississippi River delta plain are best summarized within the framework of a three-stage geomorphic model (Penland et al. 1988).

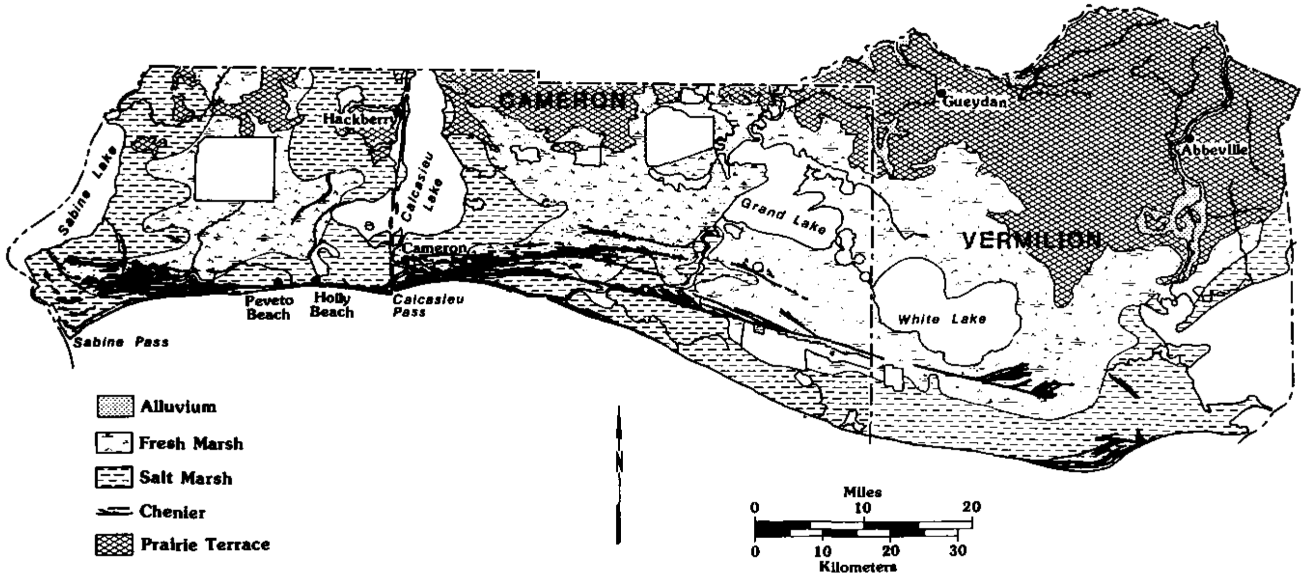

Figure 3. The regional geomorphology of the Mississippi River chenier plain.

per layers of marsh or bay mud separated by intermediate layers of shoreface sand and mud. Shoreface deposits either grade upward into chenier sand shell or are overlain by bay and tidal-flat sand and mud. A thin but extensive layer of organic-rich marsh sediments caps the sequence.

Shoreline composition and rate of seaward progradation of the chenier plan were determined by proximity of the Mississippi River outlet. Shallow-water mudflats were rapidly deposited when the main distributaries of the river lay in the southwest portion of the delta plan. When those deltas were abandoned, marine processes reworked the mudflats concentrating the coarsest material into chenier ridges. Periodic repetition of these processes produced the alternating chenier ridge and mudflat topography. Recent work on mud-flat progradation associated with the development of the Atchafalaya delta (Wells and Roberts, 1981) has shed some new light on the processes of chenier formation (Wells and Kemp, 1981; Wells, 1986; Kemp, 1986). With the position of the Atchafalaya River delta complex at the western margin of the deltaic plain, significant mudflat progradation is occurring in the area west of Freshwater Bayou and in the Cameron-Calcasieu area. Major mud-flat progradation appears to be linked to the passage of cold fronts and hurricanes.

Coastal Land Loss

Behind the protective barrier islands are extensive estuaries that are rapidly disintegrating by pond development, bay expansion, coastal erosion, and human impacts (Morgan 1967). The chronic problem of wetland loss in Louisiana is well documented, but poorly understood (Wicker, 1980; Gagliano et al., 1981; Britsch and Kemp, 1990). Previous studies show coastal land loss has persisted and accelerated since the 1900s. Much speculation and debate in the research, government, and environmental communities surrounds the issue of coastal land loss, the processes driving coastal change, and the strategy of coastal protection and restoration.

Coastal land loss refers to the set of processes that convert land to water. Coastal change is a more complex concept. It describes the set of processes driving the conversion of one geomorphic habitat type into another geomorphic habitat type. The process of coastal land loss and change typically follows the conversion of vegetation wetlands to an estuarine water body, followed by barrier island destruction and the conversion of estuarine water bodies to less productive open Gulf of Mexico conditions.

The coastal land loss process can be subdivided into two major types: coastal erosion and wetland loss. Coastal erosion describes the retreat of the shoreline along the exposed coasts of large lakes, bays, and the Gulf of Mexico. In contrast, wetland loss is used to describe the development of ponds and lakes within the interior wetlands and the expansion of large coastal bays behind the barrier islands and mainland shoreline.

Coastal Erosion

Louisiana is experiencing the highest costal erosion rates in the United States (Morgan and Larimore, 1957; Adams et al., 1978; Penland and Boyd, 1981; van

Beek and Meyer-Arendt, 1981; Morgan and Morgan, 1983; McBride et al., 1989). In the U.S. Geological Survey's National Atlas of the United States of America (1988), Louisiana appears on the coastal erosion and accretion plate as the nation's erosion hot spot (Figure 4). Coastal erosion rates in Louisiana average – 4.2 m/yr with a standard deviation of 0.3. The coastal erosion rates ranges between 3.4 m/yr and –15.3 m/yr. The average Gulf of Mexico shoreline change rate is –1.8 m/yr, the highest in the U.S. By comparison, the Atlantic erodes at an average rate of –0.8 m/yr, while the Pacific coast is relatively stable at an average rate of $\pm$ 0.00 m/yr. In Louisiana, the majority of the coastal erosion is concentrated in the barrier shorelines that front the Mississippi River delta plain.

The average coastal erosion rate of –4.2 m/yr represents the long-term conditions exceeding 50 years averaged together by per unit length of shoreline for 600 km of coast. This number is not representative of the individual storm events that drive the long-term average as well as the coastal erosion hot spots. Coastal erosion is not a constant 365-days-a-year process; bursts of erosion are associated with the passage of major cold fronts, tropical storms, and hurricanes (Harper, 1977; Penland and Ritchie, 1979; Boyd and Penland, 1981; Dingler and Reiss, 1988; Ritchie and Penland, 1988; Dingler and Reiss, 1990). Field measurements have documented 20 to 30 m of coastal erosion during a single storm event lasting 3 to 4 days. these major storm events produce energetic overwash conditions that erode the beach and reduce the barrier landscape into lower relief landforms (Penland et al., 1989b).

In addition to beach erosion, the total area of Louisiana's barrier shoreline is decreasing rapidly. In 1880, the total barrier island area in Louisiana was measured by 98.6 km^2 and by 1980 the total area had decreased to 57.8 km^2. This represents a 41% decrease in area at a rate of 0.41 km^2/yr (Penland and Boyd, 1982).

The barrier shoreline system, with the highest rate of coastal erosion in Louisiana is the Isles Dernieres located in Terrebonne Parish (Penland and Boyd, 1981; McBride et al., 1989). From 1890 to 1988, the Isles Dernieres shoreline experienced an average of 1,644 m of beach erosion at a rate of – 12.2 m/yr (Figure 5). The greatest amount of beach erosion was measured in the central barrier island arc at Whiskey Island, where a total of 2,573 m of beach retreat took place at an average rate of –19.1 m/yr. In 1890, the total area of the Isles Dernieres measured 3,360 ha, and

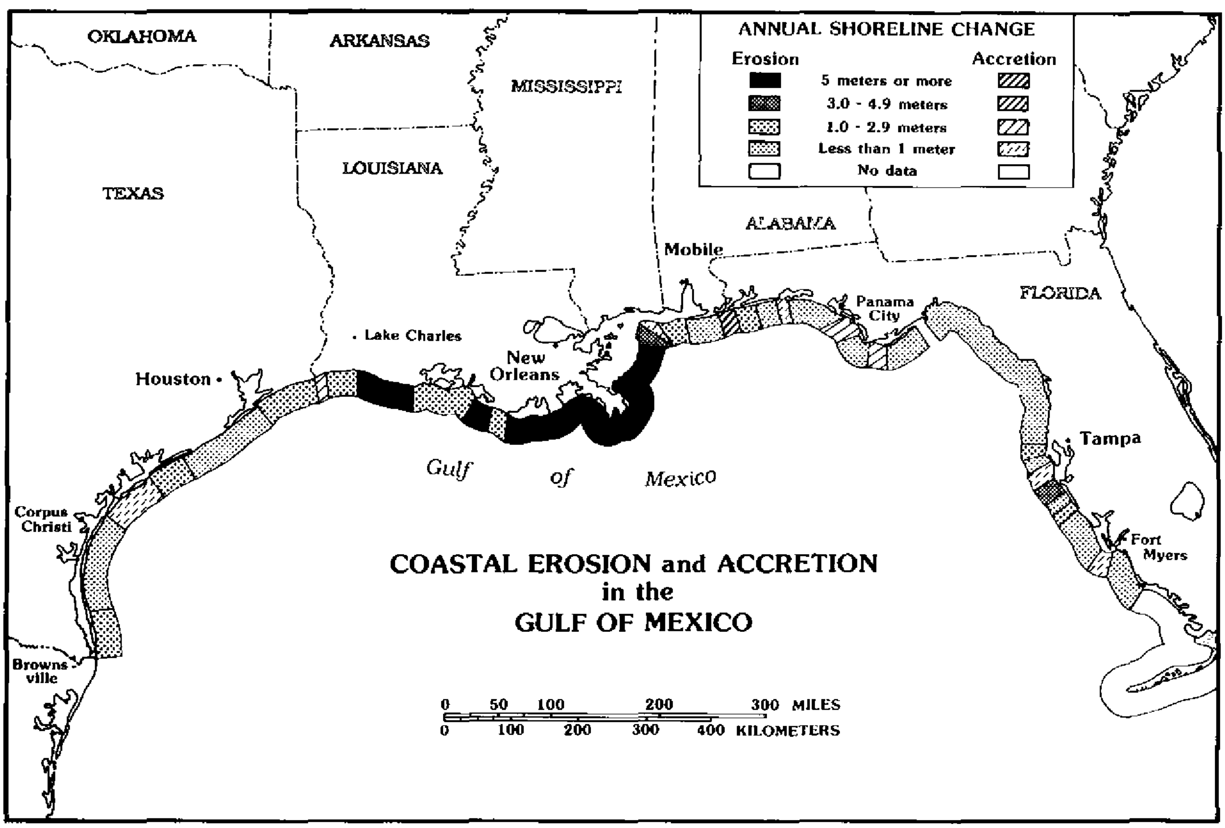

Figure 4. The distribution of coastal erosion in the Gulf of Mexico (U.S. Geological Survey 1988).

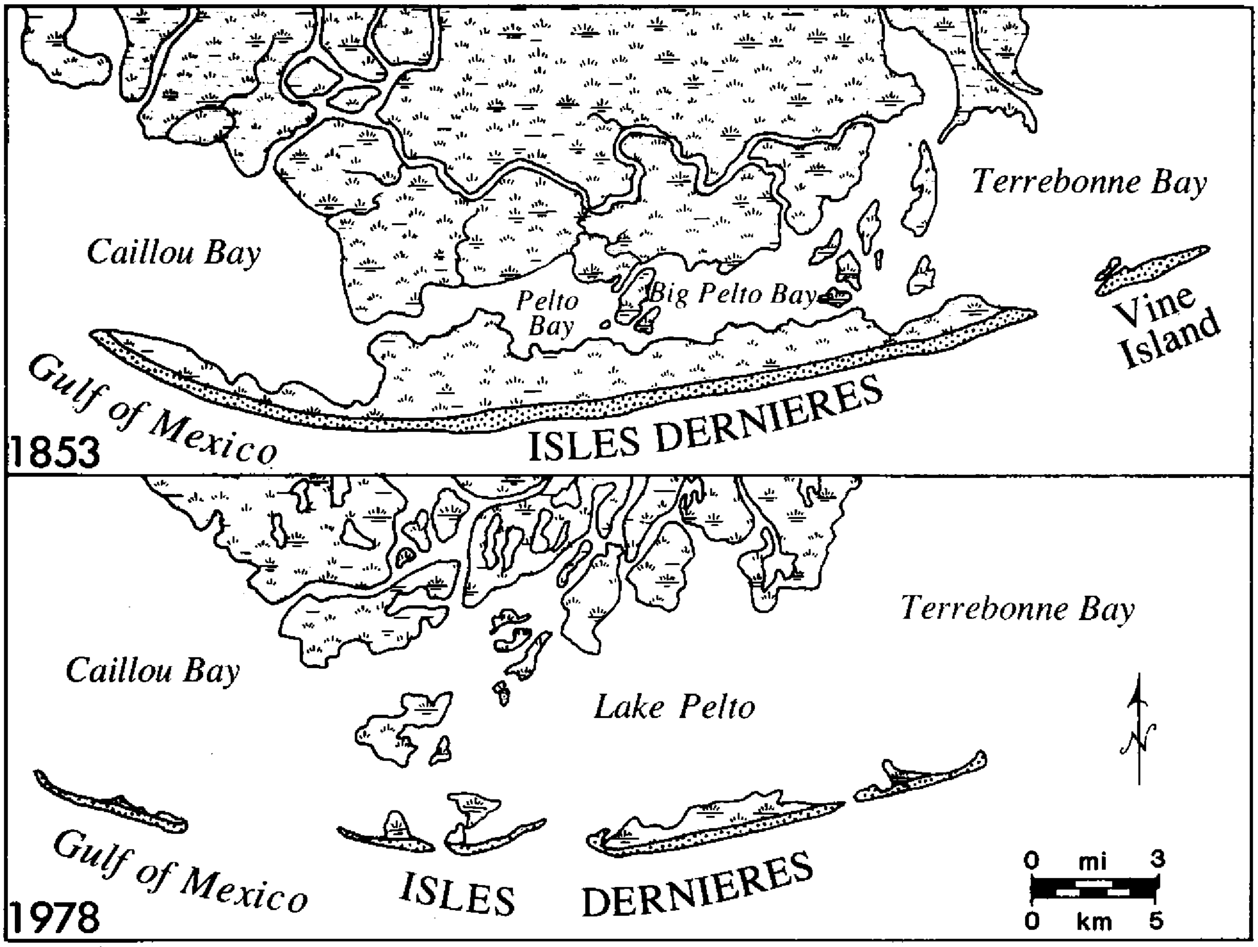

Figure 5. Coastal erosion in the Isles Dernieres between 1853 and 1978 (Penland et al. 1981).

by 1988 the island area was measured at 771 ha, a total decrease of 2,589 ha or 77% in area over 135 years, at a rate of 26.4 ha/yr.

The first island in the Isle Dernieres barrier island arc forecasted to be destroyed by coastal erosion is East Island in 1998 and the last is Trinity Island by 2007. Of immediate threat to Louisiana, particularly Terrebonne and Lafourche Parishes, is the predicted loss of the Isles Dernieres by the early 21st century. The destruction of the Isles Dernieres will dramatically impact the stability and quality of the Terrebonne Bay barrier-built estuary and the associated coastal wetlands.

Wetlands Loss

Louisiana contains at least 40% of the United States coastal wetlands and is suffering 80% of the wetland loss (Figure 6). Nationwide, outside of Alaska, Hawaii, and the Great Lakes regions, coastal marshes occupy an area of 46,971,000 ha, most occur in the Gulf of Mexico and south Atlantic region of the United States. The northern Gulf of Mexico contains 21,510,000 ha of coastal wetlands or 45.8% of our nation's total (Alexander et al., 1986; Reyer et al., 1988). The Atlantic coast accounts for 24,773,000 ha or 52.7%, and while only 1.5% or 688,000 ha are located along the Pacific coast, Louisiana's 11,928,000 ha of coastal wetlands is equivalent to 48% of all the coastal wetlands found in the 14 U.S. Atlantic states.

Within the northern Gulf of Mexico, Louisiana contains 55.5% of the costal wetlands occurring there, or 11,928,000 ha out of a total of 21,510,000 ha. Within Louisiana, the Mississippi River delta plain contains 995,694 ha of salt marsh, fresh marsh, and swamp representing 74% of the state's coastal wetlands. To the west, the chenier plain contains 347,593 ha of coastal wetlands, accounting for the remaining 26%. Cameron Parish on the chenier plain, encompasses the largest expanse of salt and fresh marsh by a single parish, a total of 302,033 ha. On the delta plain, the 233,711 ha within Terrebonne Parish is the region's largest expanse of coastal wetlands, followed by Plaquemines Parish at 167,980 ha, Lafourche Parish at 118,224 ha, and St. Bernard at 104,906 ha. Louisiana's wetland parishes constitute the largest concentration of coastal marshes in the contiguous United States.

The current coastal land loss rate estimated is in excess of 12,000 ha/yr for the Mississippi River delta and chenier plains in south Louisiana (Figure 6). Of this total, 80% of the loss occurs in the delta plain and 20% in the chenier plain (Gosselink et al., 1979; Gagliano et al., 1981). Previous studies indicate the rate of coastal land loss has accelerated over the last 75 years. Rates of loss within the delta plain alone have accelerated from 1,735 ha/yr in 1913, 4,092 ha/yr in 1946, to 7,278 ha/yr in 1967 followed by 10,205 ha/yr in 1980 (Figure 7).

Forecasts were made that Lafourche Parish would be destroyed in 205 years, St. Bernard Parish in 152 years, Terrebonne Parish in 102 years, and Plaquemines Parish in 52 years from 1978 due to accelerating coastal land loss conditions (Gagliano et al., 1981).

New research results indicate coastal land loss persists at levels below those measured in the 1970's and below the rates predicted to accelerate into the future. Britsch and Kemp (1990) conducted a mapping study of coastal land loss using 50 15' USGS topographic quadrangle maps from the Mississippi River delta plain. Coastal land loss rate curves were developed

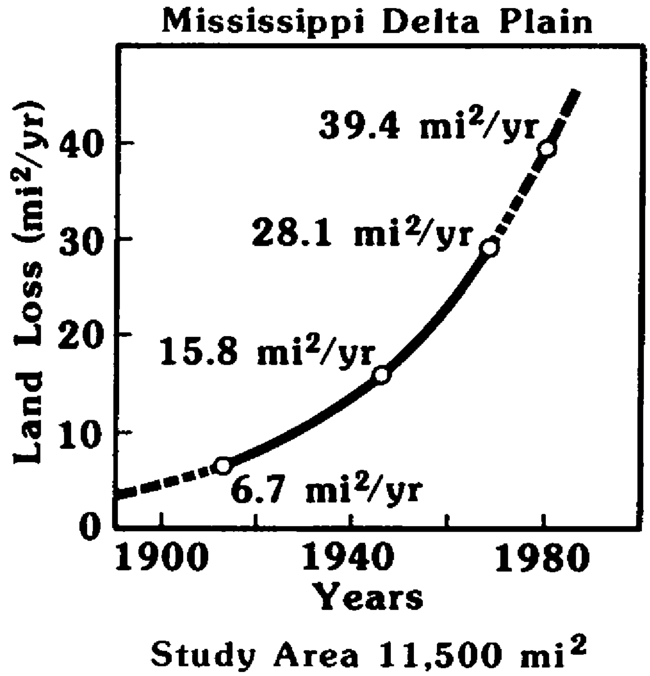

Figure 7. Coastal land loss curve for the Mississippi River plain by Gagliano et al. (1981).

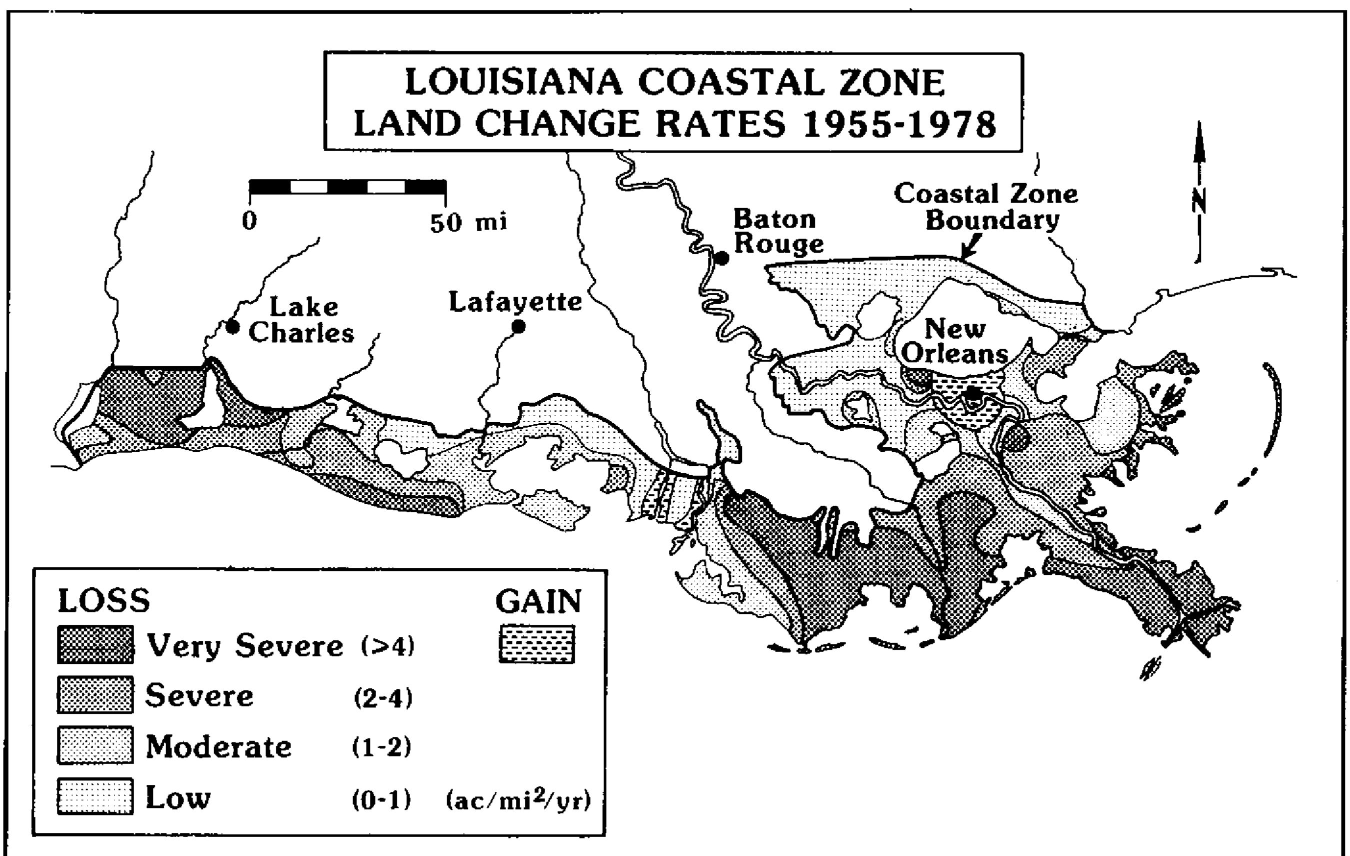

Figure 6. The distribution of coastal land loss in Louisiana (van Beeck and Meyer-Arendt, 1982).

for each quadrangle and the delta plain. The 1932-33 U.S. Coast and Geodetic Survey T-Sheets served as the base for aerial photography interpreted for the years 1956-58, 1974, and 1983. The results showed coastal land loss rates increased after 1930's from 3,339 ha/yr (12.89 mi^2/yr) in 1956-58 to 7,257 ha/yr (28.01 mi^2/yr) in 1974. After 1974, the coastal land loss rates decreased to 5,949 ha/yr (22.97 mi^2/yr) in 1983 (Figure 8). The numbers compared well with those measured by Gagliano et al. (1981) through 1967; however, the maximum rate of land loss mapped in 1978 exceeded the maximum rate mapped by Britsch and Kemp, (1990) for 1974. The Britsch and Kemp (1990) study again substantiated the catastrophic nature of the coastal land loss problem in Louisiana.

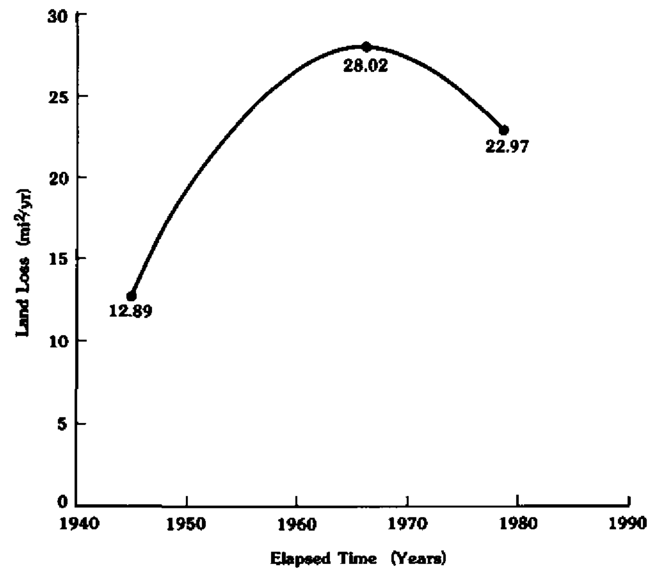

Figure 8. Coastal land loss curve for the Mississippi River delta plain by Britsch and Kemp, (1990).

Summary

Louisiana is experiencing catastrophic coastal land loss conditions due to the complex interaction of natural and human-induced causes. Controversy surrounds the issues of coastal land loss and coastal restoration. State and federal supported research on coastal land loss, as well as our experience in Louisiana, has documented that the most cost-effective methods for restoring Louisiana's coastal environments are ones that work with or enhance coastal geomorphological processes. Sediment and vegetation are the only tools that will be effective in restoring Louisiana's coastal zone. The protection and restoration of barrier islands, estuaries, and wetlands must be placed on the same priority as navigation and flood control in order to ensure the future of these important National coastal resources, the delta and chenier plains of the Mississippi River.

Acknowledgments

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Prediction of Effects Induced by Sea Level Change in the Northeast Gulf Must also Consider Neotectonics

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Abstract

Global (i.e., eustatic) sealevel change, as has frequently occurred (with relative levels perhaps as high as +40m and as low as –130m) during the last 2 million years, drives a landward migration of the coastline during times of rising sealevel and the reverse when sealevel falls. To this simple scenario, in the northeastern Gulf of Mexico (Mississippi-Alabama-West Florida), the complicating factor of irregular uplifting, subsidence, and possible faulting by ongoing processes driven from Earth's interior (that is, neotectonics) occurring along with the sea level change must also be considered. Studies recently completed by the author, when added to investigations reported by others, indicate that:

1. A hinge-line separating an inland zone of irregular uplift from an off-shore region of continuing subsidence has a location close to and paralleling the coast in Jackson County, while it swings inland in Hancock County and the adjacent portion of Louisiana;

2. The interior uplift has been irregular, producing "rises" and "swales" of large (60 x 20 km) scale;

3. The Mobile Bay region may be considered as a breached anticline of broad dimensions; and

4. Effects of neotectonics determined from investigations in geomorphology are in accord with geodetically-indicated deformation measured during this century.

Land Use Implications of Sea Level Rise

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Introduction

I work as planning director for the Southern Mississippi Planning and Development District, a 15-county regional development organization. In our planning efforts for Mississippi's sand beaches, Biloxi's urban waterfront, and other coastal communities, our planners are often asked, "Why do we need a waterfront (or beach) plan?" We typically respond, somewhat facetiously, "Because they're not making anymore waterfronts . . . so we must provide for the best possible use of what shoreline areas we do have."

Those of you familiar with coastal processes know that this oversimplified response is not entirely correct. Natural processes like erosion, subsidence, flooding, and tidal action, constantly reshape our coastline. So, we must be concerned about the long-term changes in our shoreline, if planning for our coastal communities and regions is to be effective. In a sense, new waterfronts are being created, little by little, with each passing day.

The effects of global warming may add significantly to the factors considered in planning for coastal areas. In addition to the typical demographic, economic, environmental, and related developmental trends, coastal planners may soon need to pay much greater attention to shoreline erosion and flooding problems generated by a predicted rise in overall sea level.

Sea Rise Cause and Effects

I know that many of my learned colleagues at this conference have addressed (or will address) the causes and impacts of the projected increase in sea level. At the risk of being redundant, I would like to briefly summarize these global implications so that we may better understand the potential impact on local, coastal, community development.

A consensus of the international scientific community predicts that we will see an increase in sea level as a result of global warming trends. The warming of the earth's atmosphere has been accelerated by recent environmental degradation, in particular, by the destruction of the earth's ozone layer. This warming trend has caused expansion of the volume of ocean water, and more rapid melting of alpine glaciers and the polar icecaps.

Global warming adds to an existing natural trend in sea level increases that has persisted for the last century. Based on extrapolation of this trend, global sea level is expected to increase by as much as 50 inches by the 22nd century, even without global warming.

When local trends and processes such as subsidence and emergence are factored into the global equation, the overall increase in sea level is projected by federal (EPA) scientists to be as high as 3 meters (about 10 feet), by the year 2100.

What global effects will this projected sea level rise have on both the natural and man-made environments? A recent EPA report indicates the following impacts:

- Increased volumes of ocean water will permanently flood wetlands and lowlands, accelerating coastal erosion and aggravating the conditions for serious coastal flooding.
- Projected rises in sea level will greatly increase salinity levels in coastal estuaries and aquifers, endangering fishing industries and threatening supplies of drinking water.
- Sea level rise will have a significant impact on urban development, reducing the availability and accessibility of existing recreational beaches and waterfront facilities, increasing the cost of flood protection, and restricting residential, commercial, and industrial development – as we now know them – in coastal areas.
- Increases in ocean elevation, in combination with other impacts of global warming, may foster increases in the incidence of droughts, hurricanes, rainfall, and higher temperatures, which in turn impact both the perceptions and the reality of the overall quality of life in a locality.

These global implications raise a whole host of issues about how coastal communities can be affected by impending sea level rise. These localized concerns can be grouped into four broad areas:

1. Submergence of Coastal Wetlands – Will all of our wetlands and lowlands become open water? Will the public still have access to the waterfront? Where will the new wetlands be? Who will control them? We need only look at what is happening to the Louisiana marshes right now to get an idea of what could happen in areas with unstable geology.

2. Inundation/Coastal Flooding – "Water seeks its own level." Will coastal communities respond to increased ocean volumes with what are now classic man-made solutions such as the canals of Venice, the dikes of Holland, or the levees and pumps of New Orleans? Can we afford these costly engineering solutions that cities that are below sea level have learned to live with?

3. Increased Salinity – Larger volumes of sea water will find their way upland, destroying estuarine areas, (possibly creating more estuaries), but in effect polluting aquifers. What will be the impact on fisheries? (Could this possibly be a boon to aquaculture, but a death knell to traditional industries?) Where will we get our drinking water? What about the water needed for industrial processes?

4. Coastal Erosion – This may be the primary concern of coastal land use planning: How do we keep from losing the ground we've got? In Mississippi, will our seawalls and beaches provide enough protection to withstand the oncoming tide? What about the impact on existing and on-going development of our barrier islands, particularly in coastal Alabama and Northwest Florida?

These sea rise issues raise a multitude of questions. We, at the community level, do not yet have many of the answers.

The good news, based on analysis of past sea rise trends in the northern Gulf of Mexico region by the Louisiana Geological Survey, is that Mississippi, Alabama, and Florida have experienced minimal sea level increases in comparison to the larger global trend. The Biloxi area has experienced an average increase of about 0.04 inch per year between 1939 and 1983. Mississippi, Alabama, and Florida can probably expect future sea level increases on a relatively low basis due to the fairly stable physical geography and geology of their coasts.

Louisiana, on the other hand, has not and will not fare as well. Its soft, spongy, coastal geology has contributed significantly to a relatively high trend in sea level rise and has accounted for the conversion of hundreds of thousands of wetland acres into open water. The Louisiana coast has experienced relative sea level increases as high as 0.5 inch in a single year. As much as 90 percent of Louisiana's higher rate of sea rise is attributable to subsidence.

An extrapolation of Louisiana's recent sea rise trends by the state's geological survey predicts an increase of about 5 to 7 feet for the Louisiana coast over the next century. For now, this forecast represents the worst case scenario for sea rise in our region.

Overall, for local planners in the Gulf region, the bad news is that we really don't know yet how bad the bad news is. Much more localized data and coastal monitoring are needed for us to make the best informed decisions. But planners are certainly not strangers to uncertainty. Given what we do know, we can still make some basic assumptions about how sea level increases will affect land use planning for coastal areas.

We will let the natural scientists attempt to solve the more difficult "coastal process-type" problems associated with submergence, emergence, and increased salinity. The balance of this report will deal with considerations that should be incorporated into local planning processes in order to address the coastal erosion and flooding concerns that may result locally from predicted sea level rise.

Local Responses to Projected Sea Rise

It's human nature to procrastinate. But it also makes good sense and usually costs less to plan. With the forecasted rise in sea level, how long can we afford to put off addressing the problems that may result? Do we start now to program expensive capital improvements for flood protection and erosion control? Or can we wait and see what happens? Can we implement less costly educational and regulatory programs to prevent or minimize sea rise impacts? How bad will it be? When will it happen?

First, to answer these questions we need current and accurate data at the local level. We need to improve our forecasting ability. And we need to constantly monitor ocean level changes and trends. Fortunately, a number of environmental and marine-related agencies at the state and federal levels are making innovative strides in information gathering and analysis that will greatly aid our coastal planning efforts.

Secondly, we as individual citizens, and we, collectively as communities, need to fully understand the potential impacts of sea rise. Education is the key. Conferences such as this and publications like the ones that have been prepared by several of our expert speakers are essential to aid our own understanding and to convert us lay persons into coastal educators in our own localities. A basic understanding of what can happen with sea level rise is critical to reaching local consensus as to what measures must be taken for coastal protection.

A third prerequisite involves local organization and capability. Many local governments do not act, they react. Without the public information, education, and consensus noted above, they may underestimate or even ignore potential sea rise impacts until its too late. Given no impending mandate, governmental leaders may not allocate the resources required to adequately provide for coastal protection. For those local governments that do make a commitment which addresses the sea rise problem, the protection measures employed will depend largely on their financial, legal, and technical capacities.

But the solutions to sea rise protection do not rest solely on the shoulders of local government. A fourth essential element relies on coordination and cooperation at all levels. A considerable amount of information, discussion, and planning will have to be shared, digested, and implemented among federal, state, and local agencies and organizations. And to implement and underwrite the required capital projects and regulatory measures, government will need extensive cooperation and assistance from the private sector.

With this foundation of community prerequisites established, we can now, finally, talk about some specific coastal protection measures that should be included in local land use planning. For the purposes of this discussion, I will group these measures into two broad categories: (1) structural solutions, and (2) regulatory policies.

Structural Protection

Construction solutions are generally part of a local capital improvement program, a major element of the local planning process. These are permanent, public improvements typically financed by long-term debt, repaid by local tax resources collected over the expected lives of these facilities. They take a relatively long time to plan and develop, and are usually expensive to design, construct, and maintain. These capital projects require a substantial public commitment, but they are usually expected to last from 20 to 50 years. Only larger communities have the capacity to program these facilities on a regular basis. Smaller locales have to be more strategic and resourceful – they must make more hard choices.

The following coastal protection measures fall into the structural projects category:

- Levees, dams, dikes, seawalls, bulkheads, breakwaters, jetties, groins, and similar containment or retainment facilities;
- Engineered drainage systems like storm sewers, channelized water courses, spillways, and pumping systems; and
- Beach replenishment and erosion control projects and maintenance programs.

The first two types of structural facilities, containment/retainment projects and drainage systems, are obviously the most expensive and require the most advance planning. The larger-scale versions sometimes create more environmental problems than they solve. In communities that will find themselves at or below sea level as a result of sea rise, these measures may be the only practical solutions. Smaller versions of these projects may also be necessary for flood prevention purposes in those areas above sea level that suffer from continual erosion of protective wetlands and beaches – especially during periods of storm surge or periodic flooding. Because of the sophistication and cost of these high-tech construction projects, they will require the most timely and accurate forecasting and monitoring of sea level rise.

Beach replenishment and erosion control measures, in areas that have beaches, tend to be the most cost effective coastal protection solution. The process involves periodically pumping in new sand onto the beach, often from ongoing dredging activities (that is, if the dredge material is suitable), and then maintaining the newly restored beach with erosion protection measures. Erosion control is typically accomplished by letting natural dunes form, planting natural vegetation, cleaning and shaping the beach on a regular basis, and sometimes constructing small groins or jetties to minimize lateral tidal erosion.

In the northern Gulf region (except in Louisiana), beach replenishment and maintenance may well be the primary construction solution for combating sea level rise and coastal erosion in many of our shoreline areas. In Harrison County, we are fortunate. We've just spent $4 million to replenish our 26-mile man-made sand beach. A regular beach maintenance program has been implemented. This restoration project was undertaken to protect our 10-foot (MSL, average) high seawall and U.S. Highway 90. The beach, as a tourism and recreational amenity, is an excellent fringe benefit.

If our luck holds, and the current searise forecasts do not get any worse, periodic sand beach replenishment and the seawall may be all the structural protection we need in Harrison County – at least for the next 50 years. Those areas that are not able or not willing to protect their beaches may not as be as fortunate.

Public Policy and Regulation

Many people mistakingly consider regulatory policies like zoning and land development controls to be the end-all and be-all of land use planning. The regulations tend to be the most controversial and thus, get the most publicity. I've tried to be a bit more comprehensive with our discussion of coastal issues, in order to show that good local planning involves a great deal more than regulation. In fact, land use regulation should be merely a tool in implementing a sound development plan. And to be meaningful, land use controls must be based on a thorough and understandable analysis of relevant development trends, forecasts, opportunities, and objectives. Plans and controls must be grounded in responsible public sentiment, and reflect true community values.

Land use controls are part of a myriad of policy devices that are used to implement community plans. Some policies can be educational or encouraging in nature. Rather than saying what you can't do, they provide incentives or advice on what you can do. Even doing nothing can be a policy, if that's the will of the local citizenry and its governing body.

Enough preaching. What policy and regulatory tools are available for coastal protection? The following provides a sample of some of the emerging concepts:

- Policies that encourage sea rise-cognizant design and construction of future waterfront facilities;
- Dis-investment development strategies in areas prone to coastal hazard;
- Expansion of flood protection and insurance programs to include erosion control programs; and
- Land use standards to ensure coastal protection, including zoning.

These planning techniques are listed in order from the least to the most restrictive. All are designed to build coastal protection measures into ongoing, local planning processes.

Local design and construction policies can be implemented that take sea rise forecasts into consideration. Design guidelines can be incorporated into local code enforcement programs to encourage waterfront construction which minimizes and prevents coastal erosion and reduces coastal flooding. As sea rise forecasting and monitoring becomes a more exact science, we will have a better idea of what the consequences will be. Then the guidelines can be upgraded, possibly into minimum standards, if so warranted.

In areas where we may lose existing wetlands, lowlands, and expanses of shoreline, we will need to implement "dis-investment" policies. Such policies might be as simple as **not** providing or expanding the community facilities and services required to support any further growth in the hazard areas. Or these policies may be more comprehensive and include the withholding of all financial, technical, and political support for development. In areas of relatively rapid sea rise, we may see more drastic measures like amortization and removal of existing structures, or even a moratorium on development.

The Federal Emergency Management Agency and a number of state environmental and marine agencies have investigated variations on the above themes. In fact, FEMA has congressional authority to incorporate coastal erosion protection into its oversight of the National Flood Insurance Program. The current thinking is to put the burden of coastal erosion protection on those that create it, and thus, need it the most. This is very similar to what has been done with the flood insurance program. And like flood insurance, communities will only be able to participate in a coastal erosion insurance program if they adopt more stringent erosion control regulations.

This brings us to the "E" Zones (Figure 1). On-going state and federal research is leading toward a standard method of coastal hazard regulation known as erosion or "E" zones. Like the "V" or velocity zones used by FEMA for flood hazard protection, the "E" zones would carve coastlines into measurable areas of varying degrees of erosion hazard. Zone measurements would be based on detailed area mapping, some of which I understand is now taking place, that would be combined with statistical data into a computerized geographic information system (GIS) for monitoring and forecasting coastal erosion.

The proximity to the shoreline of each "E" zone would prescribe what level of development, if any, could take place. The upland edge of the shoreline, measured at some physical reference point, would serve as the outboard boundary of the first "E" zone. This zone, which is the area in most immediate danger from erosion, would allow no new habitable structures and would encourage removal of existing buildings. Successive upland zones would limit construction to potentially moveable residences and then to readily moveable buildings, depending on hazard levels. 'E" zones would probably be administered as overlay districts in existing local zoning or flood protection ordinances, much like they are now as a requirement for participation in the national flood insurance program.

Other coastal land use controls being investigated at the various levels of government include the following propositions.

1) One proposal centers on strengthening state coastal management programs to increase wetland creation requirements when mitigating coastal permits requests. In other words, developers may be required to create a greater ratio of new wetlands as a trade-off for the environmental damage that may caused by their projects. Wetland creation standards could be designed to compensate for the expected loss in wetlands due to sea rise.

2) Another approach would establish a future date for a construction moratorium on certain types of marine construction that contribute to coastal erosion and flooding. For instance, local or state regulators could establish the year 2020 as a "sunset" date for new construction of bulkheads or residential boat slips. Beginning in that year, no one would be able to construct these types of marine projects. Everyone then has plenty of notice and everyone has to live by the same rules. The

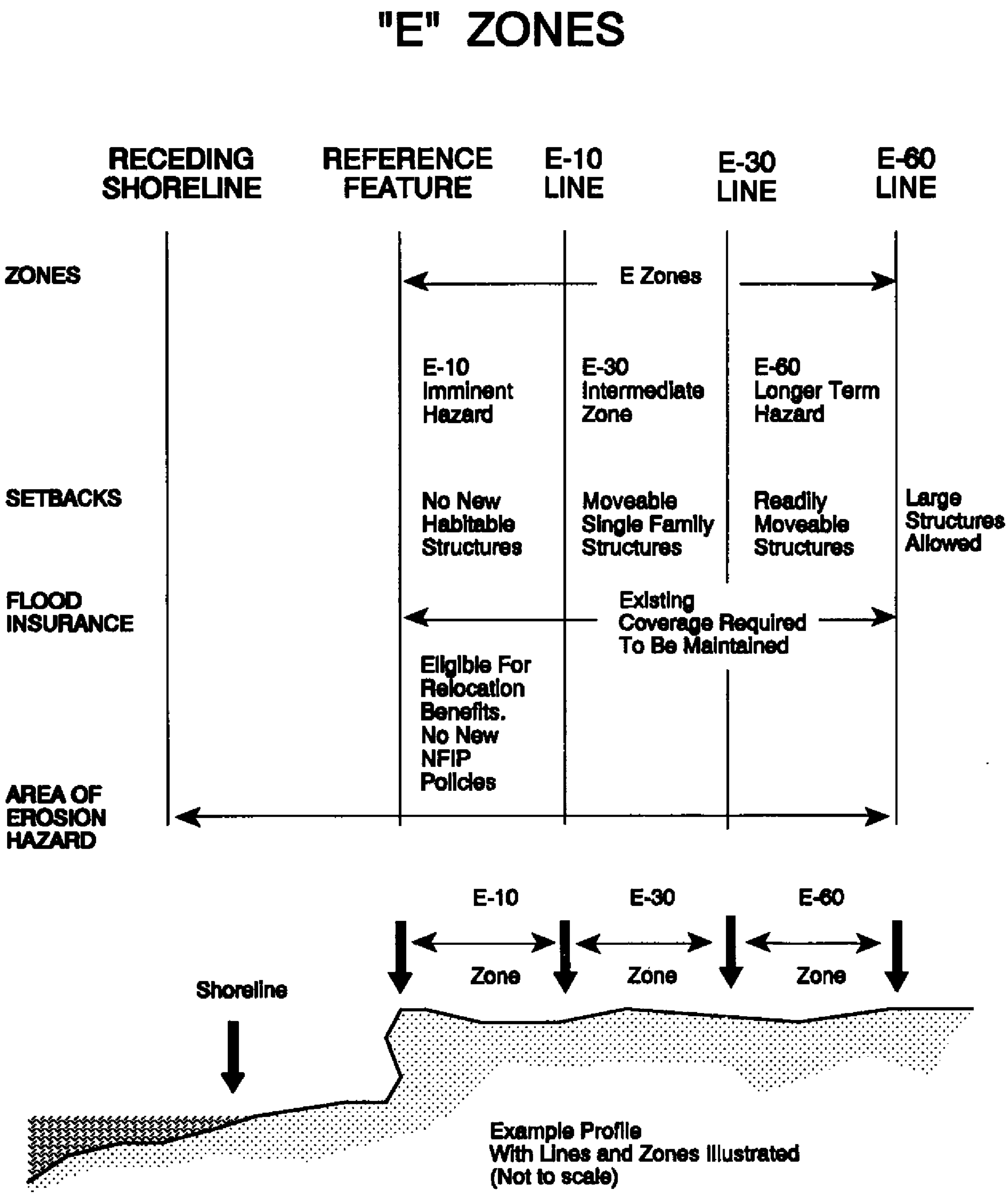

Figure 1. "E" zones (erosion zones) have been developed for coastal hazard regulation. Source: Adapted from "Managing Coastal Erosion," National Academy Press, 1990.

sunset deadline can be tied to the more critical hazard periods of projected sea rise.

3) A third proposal involves public acquisition or land banking of sensitive coastal areas. Albeit expensive, this technique gives local or state governments direct control over coastal areas through fee simple ownership. Ground leases could be issued for hazard-sensitive, interim developments, and then terminated when the more dangerous impacts of sea rise begin to be felt.

Each of these coastal land use policies has its advantages and disadvantages. Which will be implemented? It depends on how accurate our sea rise forecasts are, on how bad our coastal erosion and flooding problems become, on how well we do our advance planning. One thing is certain, though. There is no need to reinvent the wheel. We can draw on our experiences with traditional comprehensive planning, coastal zone management, flood protection and emergency preparedness to create reasonable and effective coastal protection policies. We need to especially learn from our mistakes.

Coastal Land Use Considerations

Before I close, I would like to identify some special considerations for certain types of coastal land uses. These locational and site requirements peculiar to water-dependent land uses must be factored into our overall planning for coastal sea rise.

The expansion and development of our ports, harbors and marinas must be provided for. Our ports and harbors will continue to provide the transportation infrastructure for many of our industrial processes. Commercial docks and loading facilities are the backbone of our fisheries. As leisure time and activities increase, so does recreational boating. As we safeguard our coastlines by reducing individual, fragmented dock space, we need to provide convenient, well-served, publicly accessible, marinas.

Similarly, we need to ensure improved public access and cost-effective development of such recreational facilities as boatramps, community piers, fishing areas, and waterfront parks. In many cases, these may be the highest and best uses for potential hazard areas. We also must develop a sensitivity to our potential sea rise dilemma as we develop new landside public facilities. New upland infrastructure must be located in floodproof areas, and should not create flood or erosion hazards downstream. We don't need submersible sewage treatment plants, floating expressways, or drainage systems that don't drain. Nor do we need water wells or supply systems contaminated by salt water intrusion, or water lines that collapse with periodic flooding. We don't need public buildings that go under water with each storm (and in some cases, lose their roofs), especially if they are designated as storm shelters. We must eventually realize that we live in coastal areas and that we have certain responsibilities and limitations. Sea rise may drive that point home.

By the same token, we may soon learn that not all land uses belong on the water. Here, our lifestyles may come in serious conflict with our obligations. Having the waterfront as the backdrop for most of our human activities may become a luxury sooner than we think. Although many industries and their support services require waterborne transportation, their actual processing or production facilities can be located almost anywhere. We need to determine which industries are truly water dependent, reserve adequate space for them, and design facilities that minimize flooding and shoreline retreat.

And when you really think about it, how many commercial establishments and residential developments **need** to be located on the water? It sure adds to the ambience! But here again, we may be in for some attitudinal adjustments. Perhaps we should encourage, at least on an interim basis, compact concentrations of mixed uses for the retail and service businesses and offices that benefit from a waterfront location. As sea level rise invades our coasts, the scarcity and cost of waterfront land may automatically control its use.

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Perceptions of Risk in Florida's Local Governments Resulting from Sea Level Rise

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Abstract

A survey was made of local, coastal governments in Florida to establish a 1990 benchmark for comprehensive plan attention to sea level rise (SLR); sources of SLR information in use; resource-specific opinions regarding the severity of previous and projected rates of SLR; and types of most-needed assistance. Most (71%) respondents of 76 total were municipalities. More than two-thirds of all respondents had comprehensive plans approved or in review. Forty percent of the plans referred to SLR. In planning stages, one-fourth of the respondents discussed SLR at workshops and staff meetings and level of local interest in SLR was reported as "some concern" (42%), a "important but a minority voice" (11%), or "very serious" (3%). SLR was not an issue for 43% of the respondents. Local officials get SLR information from journals, television, local scientists, newspapers, professional meetings, and citizen input, in descending order of importance. One-fourth get their information exclusively from popular sources. Respondents believe that impacts from historic SLR rates have been minor for most resources.

"Major" historical impacts were reported for islands, estuaries, beaches and dunes, wetlands, and shore protection structures. Impacts are expected to be more widespread and severe for 10- to 50-inch SLR by the year 2100. Most concern was reported for beaches and dunes, islands, wetlands, estuary/lagoons, and shore protection structures and drainage systems (tied). Fewest concerns were reported for farmlands, landfills, industry, and cultural resources. Assistance requests were numerous, mostly for general SLR data (19%), more certain projections (9%), and technical planning assistance (7%). Local governments already recognize SLR as a significant issue; rely on professional sources for guidance; and believe that historic impacts are manageable but recognize considerable risk if rates accelerate. Based on these findings, recommendations are made for subsequent state-level assistance to local governments.

Introduction

An upper limit to Florida's stake in sea level and the issue of sea level rise can be set as the combined value of its natural resources and cultural infrastructure situated along the coast. Most of the state's biology, geology, and chemistry are the result of past sea level stands, and human settlement patterns are filigrees of development on the edge of a comparatively stable sea that has persisted during the past century. Actually, sea level has been rising since 1900 at a rate of one to two millimeters per year, and this history is legible in the geology and biology of Florida's coastline. A hundred years ago, this process was unknown, but probably would have changed little in the way the coast was explored, settled, or developed. Now, with most of the state's population so close to the coast and every part of the shore valued highly as private or public property, the implications of rising sea level –even a gradually rising sea– must be reckoned. Increasing hurricane vulnerability is a good example of how small but chronic, vertical increases in water level can be translated into large and acute horizontal (inland) effects.

An accelerated rate of sea level rise is one outcome of global warming generally predicted to accompany the accumulation of carbon dioxide and other greenhouse gases. In 1990, it is fair to summarize insight to the issue of global change thusly: a doubling of greenhouse gases by 2100 is reasonably certain; a significant (ca. 3°C) increase of average, global temperature is probable in 100 - 150 years, and so are regional cases of higher and lower warming; and some acceleration in the rate of sea level rise is possible. The apparent level of the sea around Florida may change even if the state's temperature or rainfall patterns do not, because of averaging processes in the world atmosphere and ocean. The apparent level of the sea in particular reaches of the state's coast may also change if subsidence increases.

The policy issue facing Florida and other low coastal states is how to respond appropriately to the probability that sea level will continue to rise at least as rapidly as it has during the past century, and to the possibility that the rate will accelerate. In the former case, the practical problem is separating the impacts of a slowly rising sea from those associated with the catastrophic impacts of hurricanes. Uncertainty is the critical problem in the latter case. Elected officials and agency staff are reluctant to embrace an issue that remains unsettled at expert scientific levels, which is precisely the situation of accelerated sea level rise resulting from global warming. Better projections are urgently needed (and are under pursuit) for future energy use, energy mixtures, and generation rates of CO_2 and other greenhouse gases. Major improvements must be made in the fields of satellite monitoring, atmospheric chemistry, and modeling of the coupled atmosphere-hydrosphere-lithosphere. And the proxy record for past climates must be broadened and deepened.

The next decade will see much improvement in our understanding of Earth's climate and its responsiveness to human forcing. An analogy with the dramatic improvements made in 10 years of AIDS research is not a misleading expectation, but even if theoretical advancements are arrested for reasons yet unknown, we can still evaluate the prospects of rising sea level with 20 to 30 years more of direct measurement. By 2025, the signal of future rates of sea level should be apparent through the use of straight-forward statistical analysis. By the same time, we could also know which natural and cultural resources are at greatest risk, and how best to respond. The economic advantage of early preparation for sea level rise has already been demonstrated: in Florida's case, the policy issue reduces to the appropriateness of advance planning before the 21st century.

This paper speaks directly to the impact of accelerated rates of sea level rise and indirectly to the continuation of existing rates. The basis for the paper was a survey conducted at the levels of county and municipal government in Florida. The survey was sponsored by the Governor's Coastal Resource Management Citizen Advisory Committee (CRMCAC) and was performed by the Mote Marine Laboratory, with the assistance of the Coastal Management Office of the Florida Department of Environmental Regulation. The CRMCAC was created by Executive Order 88-63, in 1988, to assist the state with implementing the Florida Coastal Management Act of 1978 by (1) reviewing and recommending coastal issue priorities, (2) guiding allocation of coastal management funds, (3) providing coastal program oversight, and (4) facilitating the exchange of coastal information. The present survey was developed by a CRMCAC Subcommittee on Sea Level Rise.

The goal of this project was to establish a 1990 baseline description of local government awareness and concern for the issue of sea level rise. Objectives of the survey were to:

- Determine the extent to which local government comprehensive plans addressed sea level rise;
- Characterize local government interest in, knowledge of, and sources of information on the issue of sea level rise;
- Assess local government perceptions of risk associated with existing and projected rates of sea level rise; and
- Identify types of information about sea level rise

that would best assist local governments monitor the issue.

Acknowledgments

The author appreciates the assistance of Tina Bernd-Cohen in survey design, and Peggy Mathews and the Office of Coastal Management in distributing surveys. Cooperation of each respondent is gratefully acknowledged. Opinions and interpretations of data are the sole responsibility of the author and do not necessarily reflect the position of the Florida Department of Environmental Regulation or the Citizen Advisory Committee.

Methods and Rationale

A short, open survey was constructed (Appendix I). It began by identifying the respondent, classifying the level of government and establishing the status of the government's comprehensive plan. Florida has 35 coastal counties and 160 coastal cities and towns (Florida Administrative Code, Chapter 17-24). Collectively, these govern about 90 percent of Florida's population, illustrating the attractiveness of the coast. Beginning in 1985 with the Florida Local Government Comprehensive Planning and Land Development Regulation Act, counties and municipalities have been required to develop comprehensive plans, which must contain elements on housing, water and sewer, transportation, coastal management, recreation and open space, conservation, and future land use. Each element must establish goals and adopt objectives, in some cases tied to predetermined level of service standards. The plan must lead to a future land use map, capital improvements plan, development codes, ordinances, and other implementation measures consistent with the local plan. Once adopted, the plan can only be revised under a formal and public process under local control. Because coastal governments were required to prepare their plans in advance of inland governments, the form and content of each plan was well known to coastal governments by the time of this survey, at least with respect to plan references to sea level. Therefore, the survey asked local governments to identify plan elements addressing sea level and indicate the extent of plan coverage, ranging from narrative/background to land development codes or ordinances. Copies of pertinent plan sections were solicited if respondents indicated any plan references to sea level or sea level rise.

Four questions were asked in order to learn how local governments regarded the issue of sea level rise, apart from the content of their respective comprehensive plans. In related planning contexts, we desired to know whether sea level rise has been discussed at public workshops, by department or agency staff, or by elected officials. This set of questions meant to reveal the penetration of sea level rise as an issue from the citizen to policy-maker levels. The survey then asked respondents to choose one of four statements describing their government's general perception of sea level rise as an issue of importance, with options ranging from "not an issue of interest" to "very serious consideration." Respondents then were asked to identify their primary sources of information on sea level rise, and were given eight technical and popular sources to rank, plus an open "other" category. Finally, we asked whether respondents knew of any employee in their respective governments who monitored the issue of sea level rise, or of other persons to whom staff turned for information on the subject. A place was provided to identify these people.

The next section of the survey sought to describe respondents' perceptions of the type and severity of impacts associated with a relatively small historic rise of sea level, and also an accelerated rate of future sea level rise. In each case, 16 coastal resource categories were presented (4 "natural" and 12 "cultural") and respondents were asked to state whether known, suspected, or expected impacts of sea level rise are none, minor, major, or unknown. This method intentionally created latitude in interpreting the resource and meaning of each level of impact because we were aware of the considerable variability that exists in both sets of terms, among local governments situated along the Florida coast. In other words, "wetland," "historic structure," or "port" have different contextual meanings in each government. Likewise, the loss of a small wetland may be "minor" to one local government but "major" to another. The future case was presented as a scenario in which sea level rises 10 to 50 inches during the next century, and respondents were expected to evaluate resource impacts according to their own use of that range. In fact, the lower limit of 10 inches simply extends the actual, past rate into the future.

The upper limit for sea level rise was set at 50 inches (1.27 meters) to correspond to the well-publicized "Middle-Low" estimate of 55 inches used by the Environmental Protection Agency. New estimates by other sources were made, after the survey was prepared, which set the upper limit of predicted sea level rise in the range of 29 to 49 inches (0.73 to 1.25 meters) per century.

Finally, respondents were asked to identify the types of policy or technical support that would be most helpful in planning or other local government functions, with respect to sea level rise, and whether they wanted a copy of the report.

A mailing list provided by the DER Office of Coastal Management was used to send the survey and a cover letter to the chairmen of all coastal county commissions, and to the mayors of coastal cities and towns. A total of 174 surveys were distributed. After a 6-month response period, a preliminary tabulation of returns indicated that replies from county governments and large city governments were underrepresented. Consequently, a second set of surveys was mailed to the directors of planning departments in counties and large cities for which replies had not been received. Twenty-one surveys were distributed in the second mailing.

Results and Discussion

Eighty replies (total) were received from the two requests. Of these, four were discounted as inadequate or nonresponsive, leaving 76 useful replies, or 44 percent. All data used in this report accompany the survey form in Appendix I and respondents are listed in Appendix II. County governments accounted for 22 replies (29% of total response) and city governments accounted for 54 replies (71% of total response). As there are 35 coastal counties in Florida, this survey's completeness for that level of local government was 63%. Based on 160 recog,nized coastal cities, 54 replies represents a completeness of 34%. Response to the second mailing was high (86%) and probably reflects the effectiveness of targeting the requests to planning directors.

The southern half of the peninsula produced more county responses than other coastal reaches (Figure 1). The northeast seacoast was only represented by Volusia County, but geophysical conditions in the northeast are similar to the southeast coast, represented by five counties. County-wise, coverage of Pensacola and Choctawhatchee Bays and Charlotte Harbor was spotty, but other large bays and lagoons were represented well. City-wise, coverage was slightly better along the Atlantic coast than along the Gulf coast (Figure 2). Panhandle response was low and no cities were represented in the survey from the long but sparsely populated coast from Panama City south to Dun,edin. Gulf coast cities situated along barrier island reaches responded better than did cities on open shorelines.

Plan Coverage

Most (91%) respondents had submitted their local plans by the time of their reply to the survey. Over the 6-month response period, the number of approved plans was the same as those still in review and 15 (22% of submitted plans) were under appeal or being negotiated. Sixteen responses failed to indicate whether sea level rise was addressed, leaving 60 useful replies, of which 36 (60%) reported no plan coverage of the issue.

A total of 24 local governments reported that sea level/rise was addressed. This response means that 40% of usefully responding governments considered the issue to some extent. For the sample population as a whole, at least 14% –or one in seven– of the coastal local governments elected to address sea level rise in some manner, within the text of their official comprehensive plans. It should be noted that the issue of sea level rise was not a mandatory or even a recom-

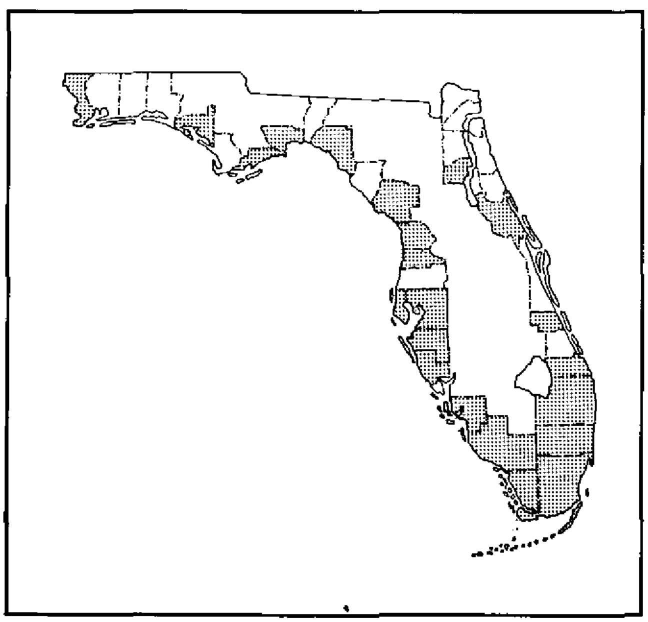

Figure 1. County governments in Florida responding to the survey.

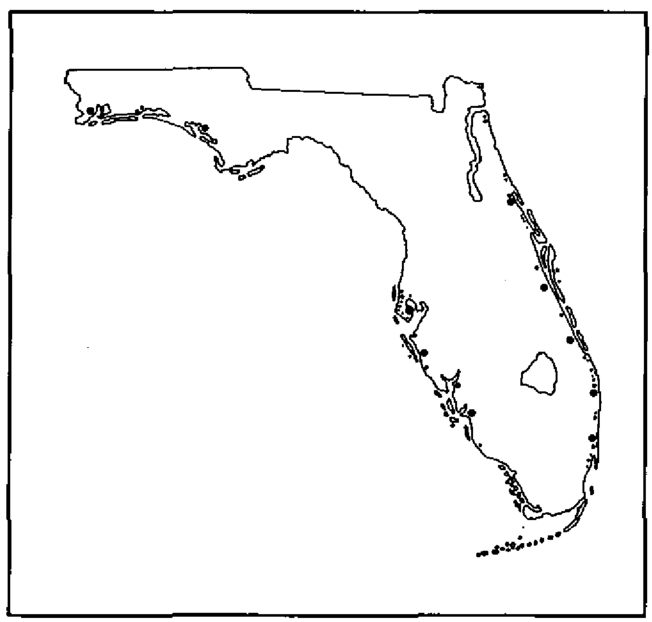

Figure 2. City governments in Florida responding to the survey.

mended element of local government comprehensive plans, so the degree to which it has been recognized represents a useful measure of voluntary concern.

Not all respondents included copies of pertinent plan language so the accuracy of respondents' reports could not be verified. In fact, inspection of plan excerpts submitted with the surveys indicated that some reports of pertinent language were not actually so, but dealt instead with issues of beach protection, coastal construction, hurricane preparedness, or post-disaster planning. In most cases (15), the issue of sea level rise was reported as having been addressed as background to the Coastal Management Element of local plans. An example of how sea level rise was treated is cited from pages 41-42 of the Hernando County plan:

Sea Level Rise

There is increasing concern that sea levels are rising. Various scenarios have been developed to predict the future magnitude of the documented steady increases in sea level.[1] The number of feet of rise is predicted as follows for the year 2100:

Type of Projection	Feet of Rise
1. Minimum	1.8
2. Maximum	11.3
3. Average	5.9

Along the Hernando County coastline, the average predicted sea level rise could move the shoreline landward from its present location a distance of about 2.5 miles. This new shoreline is shown on Map 5.3 [Figure 3 of this report] for the entire coastal zone. The new shoreline would be located near to what is currently the "V-zone" boundary as previously described.

It is noteworthy that Hernando County has a large expanse of low marsh, a sediment-starved coastline, and the benefit of a recent site-specific study that made explicit reference to the potential impact of sea level rise, including a map of the affected area (Figure 3).

As the local government plans moved into goals and objectives, and then to implementation via development codes, ordinances, etc., references to sea level rise dropped rapidly. The most definite reference to sea level rise in the substantive parts of local plans we read (Collier County) was only advisory: the county's coastal management policy 11.6.4 stated "The program shall consider the implications of a potential rise in sea level." Similar language appeared in the same plan for development and redevelopment proposals.

To recapitulate, in 1990 some 40% of responding local governments reported plan language that addressed sea level rise. Several of these reports were indirect rather than direct references and direct references were made almost entirely as background to coastal elements. Few references to sea level rise penetrated to more important planning levels and those that did were advisory in nature. From this situation, we conclude that sea level rise was an issue that voluntari-

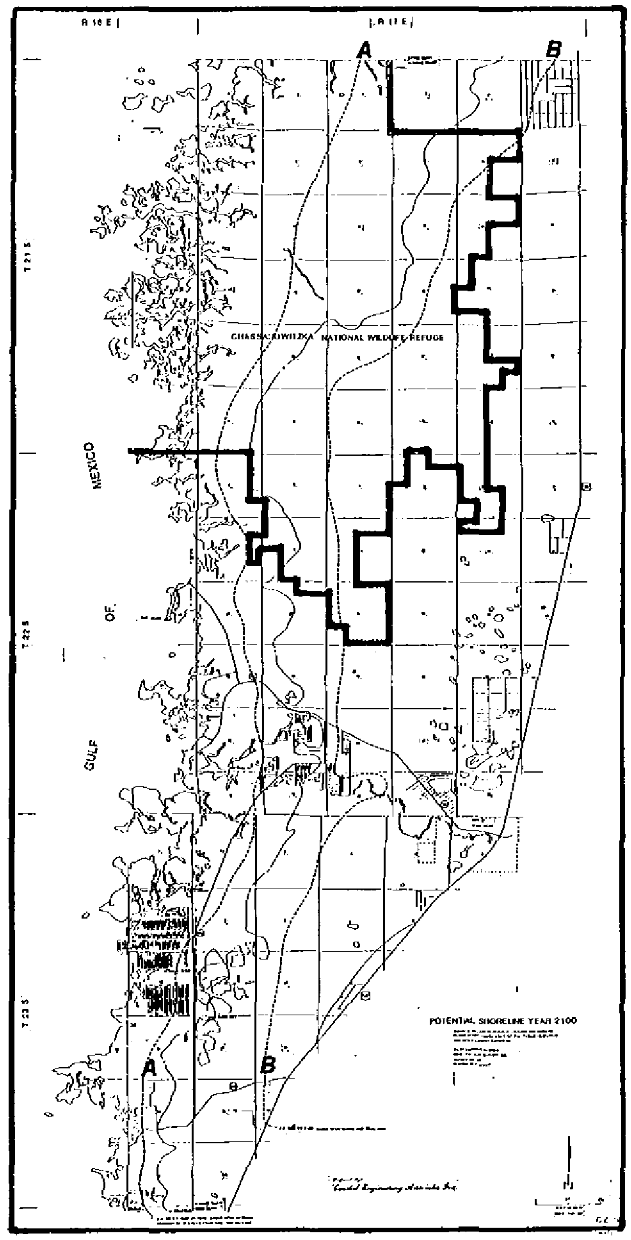

Figure 3. Potential shorelines of Hernando County in the year 2100. Line A corresponds to a rise in sea level of 3.3 feet; Line B, 5.9 feet. Borders of the Chassahowitzka National Wildlife Refuge are also shown. (Source: Hernando County Comprehensive Plan, p. 110).

[1]Albert C. Hine and Daniel Belknap. Recent geological history and modern sedimentary processes of the Pasco, Hernando and Citrus County coastline, west central Florida. Florida Sea Grant Report No. 79.

ly arose often, but not certainly, as plans were developed but it was not regarded important enough to warrant action, at least for the immediate planning horizon.

Interest and Knowledge

When asked whether the issue of sea level arose during public workshops on the local plan, or as a staff initiative, respondents replied yes in one-fourth of all replies (N = 74). It is interesting to note that elected officials raised the subject of sea level rise only half as often (13.6%) as the general public or planning agency staff. Disinterest on the part of elected policy-deciding officials parallels the penetration of sea level rise as an issue in plan implementation, and may be the cause although reasons for this are not apparent.

When asked to summarize their government's overall attitude toward sea level rise, more respondents replied that it mattered to some degree (57%) than not at all (43%). Two replied that "sea level is a very serious consideration in our government and it affects several policies and programs, budgets, and practices" and eight replied that "one or a few staff or officials mention it as an important issue, or they may have actually undertaken some task or effort addressing sea level rise, but these are minority voices." Among replies expressing any concern for the issue, the majority (32) held that there is "some knowledge or concern on the part of staff or elected officials, but other issues are far more pressing and there just isn't time to give it more attention." In light of these results, it may be correct to view local government staff concerned for sea level rise as a minority, both within and between their governments. There was a definite counter-position expressed in some replies, for which one thoughtful example is quoted:

"The effect of sea level rise on Volusia County is not expected to be significant. Our data indicate that relative sea levels have been essentially stable since 1874, the earliest, accurate, available record. The county's beaches and estuarine shorelines appear to be in the same configuration during this period. Moreover, recent studies by Dr. Dean and others suggest that rises in sea level have not been responsible for beach erosion in Florida. In fact, tide gauge stations in Florida show a decrease in the rate of sea level rise since the 1960's, and even a slight decline in some places. Relative subsidence of land appears to be the major factor of upland inundation as a result of changes in water level. In this part of Florida, local subsidence is negligible."

In addition to its content, this is an interesting reply because of its reference to an external [to local government] authority, in this case Dr. Robert Dean of the University of Florida. Such use of technical information was seen also in the case of Hernando County's plan reference to the Hine and Belknap report on coastlines of west-central Florida, although in the latter case the external authority was cited in support of concern **for** sea level rise. Here we see the importance of technical information sources available to local government, and also the "sampling effect" that can result when staff access to resident or outside expertise is incomplete. We shall take each in turn, beginning with the general sources of information about sea level rise on which local governments depend.

Most respondents (72 of 76) indicated a first choice of information sources, but subsequent choices were made in progressively fewer replies (51, 33, 15, and 9 replies for second, third, fourth and fifth preferences, respectively). Table 1 summarizes the rank order of information sources in terms of importance.

Table 1. Sources of sea level rise information used by local governments.

Sources, Ordered by Number of	
First Choices	**All Choices**
Journals	Newspaper
Television	Journals
Newspaper/Local Scientists	Professional Meetings
Professional Meetings	Television
Citizen Input	Local Scientists
Popular Magazines	Popular Magazines
–	Citizen Input

Local governments drew from a diversity of information sources on sea level rise. Except for staff meetings, which were almost never cited as a source of information, the two least-used sources were citizen input and popular magazines. Popular sources were important as first or any choices and appear to balance the use of technical sources by local governments. Professional meetings, local scientists, and especially journals were relied upon as much or as more as popular sources. However, the blending of multiple sources was not as striking as their segregation into popular and technical subsets (Table 2).

We noticed in tabulating replies that many (47%)

Table 2. Distribution of information sources by type. Citizen input was counted as "popular" and staff meetings were counted as "technical" sources.

Type	No.	%
Only Popular Sources	16	24%
Only Technical Sources	20	29%
Mixed Sources	32	47%
N	68	100%

reported mixed sources, some (24%) reported only popular sources, while others (29%) reported only technical sources. We conclude that three-fourths of the local government respondents used technical sources to advantage all or part of the time, whereas one-fourth made exclusive use of popular sources of information. Given the negligible reliance of these respondents upon other staff it must be further concluded that many coastal governments in the state could be operating with highly limited knowledge on the subject of sea level rise.

As mentioned, local governments reported a low (19%) use of resident or outside expertise. Twelve local governments identified an employee in planning or another agency who monitored the issue of sea level rise, and three replies identified local scientists who were used for guidance on the issue. Only one of these 15 replies made exclusive use of popular sources of information. This sample was small but suggested that local governments monitoring sea level rise relied upon technical sources more than popular sources.

Risk Assessment

Responses to the two scenarios revealed patterns in the perception of risks associated with sea level rise, as held by local governments. The first scenario was more accurately the record of sea level as measured in Florida during the past several decades. For all resources combined, respondents indicated "no effect" an average of 40% of the time, compared to 32% "unknown," 22% "minor effect," and only 6% "major effect." The three most cited instances of major effects were beach/dune, islands, and wetlands, in descending order[2] followed by estuary/lagoon, and shore structures and drainage systems (tied). Whereas most of these have sensible vulnerabilities to sea level rise, especially in terms of hurricane impacts, it is curious that six local governments cited major historical impacts to wetlands. Unfortunately, explanations were not requested or offered for their impact assessments, so reasons for these listings are unknown. Studies relating sea level changes to modern wetlands in Florida are few and we know of none that documents specific wetland loss –or change in general– to sea level rise, but the survey results offer an opportunity to pursue this question with affirmative respondents.

On average, one-fifth of the replies reported minor effects to local resources resulting from sea level rise. In descending order, the resources most frequently reported as having had minor effects were islands, wetlands and beach/dune (tied), shore structures, estuary/lagoon, and roads, followed by drainage systems and ground water (tied). The less-affected resources were similar to most-affected ones with the additions of roads and ground water. For reasons that can only be evaluated on a case-specific basis, some 10% of respondents believed that sea level rise was responsible for some measure of impact to roads and ground water.

Again on average, 40% of the replies stated definitely that the historic rate of sea level rise has had no effect on their resource base. The majority of "no-effect" replies were made for cultural resources and infrastructure (in contrast to replies of "unknown," which were made most often for natural resources). In descending order, resources for which no effects were reported were landfills, farmland, ports, industry, historic structures, archaeological sites, and utilities.

One-third of the replies stated that effects of historic rates of sea level rise were unknown. This choice was made most often for ground water, surface water, archaeological sites, shore structures, estuary/lagoon, and wetlands.

Responses to the future scenario were of interest because of the changes in perception of risk they reported, compared to historic impacts. For all resources combined, respondents indicated "no effect" an average of 19% of the time, down from 40% for historic conditions. "Minor effect" and "unknown" each contracted from 22 to 19% and 32 to 27%, respectively. These downward changes were mirrored by an increase from only 6% (historical) to 35% (future) impact ratings of "major effect." Overall, respondents gave more definite and more extreme assessments of possible effects resulting from an increased rate of sea level rise, than for historical rates. This pattern indicates a sense of greater risk to coastal resources in the future than in the past. However, some respondents could have interpreted the range (10-50 inches per century) at the lower end while others used the upper end. Thus, the results mask the possibility that even historic rates were interpreted to have greater future consequences now that the coast is intensively developed.

In descending order, resources for which major, future effects are expected included beach/dune, islands, wetlands and shore structures (tied), drainage systems, estuary/lagoon, roads, and utilities. Resources with the most "minor effect" replies were utilities, roads, historic structures, archaeological sites, estuary/lagoon and shore structures (tied), and surface waters and drainage systems (tied). These lists show small overlap with resources listed most often as "no effect" or "unknown." For example, the most common cases for which no effect was projected were landfills, farmland, industry, archaeological sites and historic structures (tied), and surface water. Likewise,

[2]Effects were expressed as percentages of all responses given for each resource, and ranks were based upon within-resource scores.

unknown effects were cited most often for ground water, industry, archaeological sites, farmland, historic structures, and surface waters.

Information and Assistance

Thirteen of the seventy-six responses did not reply to this question. A total of 89 separate requests and suggestions were made by the others, with requests for general information on sea level made most often. Insight to the types of information that would be responsive to local government requests is available from the replies. The single most-wanted piece of information was more certain rate forecasting of sea level rise. Many local governments seemed expertly familiar with uncertainties concerning sea level and rate projections, whereas others seemed aware that the subject is generally indefinite or disputed, as illustrated by these two remarks:

"The scientific community [needs] to reach a consensus on rate of sea level rise and graph past and projected rates that are smoothed so that small-scale variations do not confuse the overall picture."

"The biggest problem is conflicting reports from the scientific community on the severity of the problem, including some who think it is not a problem."

One strategy in assisting local governments to monitor the subject of sea level rise could be a primer covering background topics for which broad agreement already exists, topics that are presently under study and the general direction of opinion for each, and open issues. Such a primer could also address types of physical data and their limitations, such as proxy records, and the constraints of existing computer support. The point of such a review ought to be describing the scientific certainty and uncertainty involved not only with sea level rise, but also the more fundamental processes of modeling and forecasting at global scales. It would be helpful if the primer could be updated by periodic revisions.

In a similar vein, an effort to inform local governments of past and ongoing technical and policy studies and options for sea level rise would be received well in Florida and other coastal plain states. Respondents wanted to know what other local governments were doing. Information on how regional and local assessments of risk are made would enable local governments to evaluate their own situations. Access to existing inventory data would assist in self-evaluations, and applications of the inventory data would be improved with explanations of how specific resources are known or thought to be affected by sea level and changes of sea level. Given the extensive amount of farm land situated near the coast and at low elevation in southernmost Florida, for example, agriculture may be affected by inundation, increased storm flooding, changes to surface or ground water quality, pests, or conflicting land-use objectives. It will not be possible to meet one respondent's request for "Information... on impact **per inch** of rise on beaches, drainages, and saltwater intrusion into aquifers," [emphasis added], but these impacts can be characterized and compared for low and high rates over short to long periods of time.

Summary and Conclusions

Florida's tremendous population growth has strained state and local government budgets and their ability to manage coastal resources. More than ever, local governments will be active participants in statewide coastal issues such as beach nourishment, water quality improvement, and habitat protection, but the next 10 years will see their priorities given first to implementation of requirements accompanying their respective growth management plans. In 1990, relatively little reference was made to the issue of sea level, at least of the kind requiring local commitments for policies or programs. The priorities reflected in these plans must be addressed first, leaving the matter of sea level rise as a subject to be monitored. Many local governments are monitoring the issue expertly although a significant number have not yet made extensive use of technical sources of information.

The State of Florida's coastal management program relies heavily upon coordination between and cooperation among all levels of government. At this point in time, the state's coastal program could facilitate this process by fostering communication of technical and policy information responsive to the requests reported here. One economical method that deserves to be implemented is a network of resource managers, scientists and engineers, and local governments within which basic information on global change and sea level can be exchanged. The first products of such a network could be modeled after recommendations made above, to **(a)** report and interpret recent advancements in measurement, modeling and forecasting; **(b)** convey realistic descriptions of certainty and uncertainty; **(c)** inform participants of relevant, existing data and ongoing projects in the state; and **(d)** encourage the development of sea level expertise resident to each local government so that local, self-evaluations of community risk can be made within the comprehensive planning process.

APPENDIX I: CRMCAC SURVEY ON SEA LEVEL RISE

Name of Respondent: ____________________

Title: ____________________

Agency: ____________________

Address: ____________________

Telephone: ____________________ FAX: ____________________

NAME OF GOVERNMENT: ____________________

(Response: 54 cities and towns and 22 counties – see Appendix 2.)

LOCAL GOVERNMENT PLAN STATUS (check one)

28 1. Submitted and approved

26 2. Submitted and in review

15 3. Submitted, reviewed, and under appeal by DCA

7 4. Not submitted

PLANNING FOR SEA LEVEL RISE (check the boxes to describe plan elements addressing sea level rise and extent of plan coverage).

ELEMENT	TYPE OF COVERAGE				
	Narrative or Background	Goals or Objectives	Land Dev. Codes	Ordinances	Other
Coastal Mgt.					
Conservation					
Recreation & Open Space					
Future Land Use					
Other:					

(**NOTE:** please attach photocopies of plan language related to each type of coverage)

(**Response:** 16 not reporting; 36 reporting no coverage; 15 coastal management background; 3 background for Conservation; 1 each for (a) background for Drainage, (b) goal for Conservation, (c) future land use codes, (d) goals and codes for Coastal Zone Management and Conservation. Also extensive references from 7 local governments in several plan elements. Overall, 24 governments reported plan coverage, in a total of 34 ways, and 19 of the responses were background and 15 were references to goals, objectives, codes, and/or ordinances.)

Has the issue of sea level rise been discussed in related planning contexts, such as:

- **Public workshops on the local plan?** 18 Yes 55 No
- **Statements by other department staff?** 18 Yes 54 No
- **Comments/actions by elected officials?** 10 Yes 63 No
- **Other (describe):** One discussion on shoreline preservation , bulkhead/seawall permits and beach nourishment; one mention at a public workshop by the local NOAA meteorologist was dismissed as unimportant.

Generally, how would you describe your local government's interest in the issue of sea level rise?

33 1. Not an issue of interest; never discussed or discussed but rejected as an issue of importance.

32 2. Some knowledge or concern on the part of staff or elected officials but other issues are far more pressing and there just isn't time to give it more attention.

8 3. One or a few staff or officials mention it as an important issue, or they may have actually undertaken some task or effort addressing sea level rise, but these are minority voices.

2 4. Sea level is a very serious consideration in our government and it affects several policies and programs, budgets, and practices.

1 5. No report

What have been your primary sources of information on sea level rise? Please rank, using 1 as your most important source:

____ Television ____ Professional Meetings ____ Popular Magazines

____ Newspaper ____ Citizen Input ____ Staff Meetings

____ Journals ____ Local Scientists ____ Other: ________

Results

	RANK				
SOURCES	**First**	**Second**	**Third**	**Fourth**	**Fifth**
Television	13	5	4	1	
Newspaper	10	17	9	1	
Journals	16	10	4	4	2
Meetings	9	7	6	3	1
Citizens	5	0	2	1	2
Scientists	10	3	3	3	1
Magazines	4	3	4	2	3
Colleagues	0	1			
Other	5	5	1		

Is there an employee in planning or another agency of your government who monitors the issue of sea level rise, or is turned to by other staff for information on the subject?

57 No **13** Yes Name: ______________________

Sea level has risen about 10 inches in the past century. Which resources in your area have been affected by this rate (or do you think may have been), and to what degree?

RESOURCE	**EFFECT** (none, minor, major, unknown)
Sand beaches and dunes	________
Barrier islands	________
Wetlands	________
Estuaries and lagoons	________
Shore protection structures	________
Surface water supplies	________
Ground water supplies	________
Farm lands	________
Archaeological sites	________
Historic structures	________
Transportation (roads)	________
Utilities	________
Drainage systems	________
Ports	________
Industry	________
Landfills	________

Results, Raw Scores

	SEVERITY			
RESOURCE	**None**	**Minor**	**Major**	**Unknown**
Beach/dune	13	24	12	18
Island	12	28	7	17
Wetland	12	25	6	25
Estuary/lagoon	16	22	5	27
Shore structures	21	22	4	21
Surface water	26	10	1	28
Ground water	16	16	3	35
Farmland	35	3		17
Archaeological sites	29	6	2	25
Historic structures	33	9		20
Roads	27	19	1	19
Utilities	28	12	1	23
Drainage systems	26	16	4	22
Ports	34	6		15
Industry	35	6		18
Landfills	40	3		13

Sea level is projected to rise 10 to 50 inc hes during the next century because of global warming caused by the greenhouse effect. Which resources in your area would be affected most by this process, and to what degree?

RESOURCE	**EFFECT** (none, minor, major, unknown)
Sand beaches and dunes	________
Barrier islands	________
Wetlands	________
Estuaries and lagoons	________
Shore protection structures	________
Surface water supplies	________
Ground water supplies	________
Farm lands	________
Archaeological sites	________
Historic structures	________
Transportation (roads)	________
Utilities	________
Drainage systems	________
Ports	________
Industry	________
Land fills	________

Results, Raw Scores

	SEVERITY			
RESOURCE	**None**	**Minor**	**Major**	**Unknown**
Beach/dune	4	10	43	8
Island	5	9	35	6
Wetland	5	11	35	13
Estuary/lagoon	4	13	31	16
Shore structures	3	13	36	14
Surface water	11	11	18	18
Ground water	4	10	22	27
Farmland	24	6	1	16
Archaeological sites	12	12	11	20
Historic structures	12	13	12	18
Roads	6	19	28	13
Utilities	4	19	22	16
Drainage systems	2	12	34	15
Ports	16	7	8	14
Industry	20	6	5	21
Landfills	25	7	3	13

What type of policy or technical support would help you the most, in planning or other local government functions, with respect to sea level rise?

Results

17 General information on sea level rise
13 No requests
8 More reliability on when and how fast sea level will rise
6 Technical assistance and funding
6 Maps of affected coastal areas for long range planning
5 Extent of sea level rise
5 Study to estimate specific effects of different rates in developed coastal areas
3 Design and mitigation guidelines
3 Seminar on sea level rise for local government officials, especially new issues such as legal problems of ownership, etc.
3 Information on what other cities are doing
2 Coastal acquisition program
1 Documented damage
1 State laws governing control and status of sea level rise
1 Specific recommendations relevant to residential single family communities
1 Remove barriers to innovative shoreline protection such as beach nourishment for inland beaches
1 Identify importance of wetland buffers in terms of future inundation
1 Identify areas where CCCL and V-zone protection does not adequately protect areas from effects of sea level rise
1 Elevations for streets and floors that are meaningful for their useful life, given most reasonable forecasts
1 Level of service standards set by legislature
1 9J5 rule requirement for a specific response element in comprehensive plans
1 Strong national policy
1 Summary of recent modeling scenarios and assumptions
1 Model plan policies and local ordinances
1 State approved 30 year erosion setback line
1 Criteria for review of coastal development
1 Detailed information on nearshore, coastal and marine habitats
1 Strong coastal setbacks in excess of state's
1 Beach nourishment and effective inlet management
1 consistent coastal monitoring

Would you like a copy of our report of findings from this survey?

70 Yes 5 No 1 No Response.

use less than 25 percent of the energy of older appliances. States can facilitate the adoption of stricter appliance standards.

2. Implement Strategies to Reduce Greenhouse Gas Emissions From Forestry and Agricultural Practices.

Most actively growing forests represent a net sink for CO_2. Policies that encourage tree planting to increase carbon sequestering rates should be encouraged.

2.1 Enlarge Tree Planting Programs. Trees increase the rate of CO_2 sequestering, reduce soil erosion, provide habitat for wildlife, and improve water and air quality. Many lands are suitable for tree planting, including degraded forest lands, lands recovering from strip mine operations (such as phosphate mining in Florida or coal mining in Kentucky), along highway corridors, and in shelterbelt or windrows in agricultural areas. Many additional landscapes hold potential for tree planting.

2.2 Encourage Urban Tree Planting. The strategic (the planting trees to shade houses and central air conditioners) planting of trees in urban areas yields significant energy saving in the south (Akbari et al., 1988). Each tree strategically planted in urban areas may be as much as 15 times more effective in combating climate change than the planting of rural trees (Parker, 1987).

2.3 Increase Forest Productivity. Promote best management practices to increase yields and reduce "wasted" timber products.

2.4 Promote Best Agricultural Management Practices. Promote efficient use of fertilizer to reduce nitrous oxide emissions. Encourage the plowing under of crop residues, rather than burning, to reduce CO_2 and to replenish the soil. Attempt to reduce CH_4 (methane) emissions from livestock through best management (feedstock) techniques. In addition, biogas can be produced and utilized, depending on the type of livestock operation.

3. Implement Strategies to Reduce Greenhouse Gas Emissions BY POLLUTION PREVENTION.

3.1. Recycling. States should reduce municipal and industrial soil waste by promoting recycling efforts and by mandating the acquisition of recycled products. In addition, states can promote the procurement of recycled products by county and local government agencies. The recycling of aluminum, steel, paper, glass, and other products generally saves between 35 and 95 percent of the energy that is necessary to produce a product from virgin material.

3.2 Collection of Methane from Landfills. Approximately 130 million tons of municipal solid waste are disposed of annually in more than 5,000 landfills in the United States (Franklin, 1988). In many areas of the country, CH_4 can be economically recovered and used from landfills.

3.3. Collection of Methane from Coal Seams. In many areas, CH_4 can be economically recovered from coal seams. The recovery of CH_4 not only reduces the emission of a greenhouse gas, it can be used as an energy source (Gibbs and Hogan, 1990).

3.4 Water Conservation. Energy is consumed to produce water suitable for human consumption and also for waste water treatment. Water conservation can reduce energy use.

Conclusions

The recent United Nations Working Group 1 concluded that global climate change is real, and that without a reduction in the rate of greenhouse gas emissions, mean global temperatures will substantially increase in the near future. In addition to global warming, it is anticipated that global climate patterns will be significantly altered. The continued excessive use of fossil fuels will unalterably change the fabric of Earth's biosphere. Because of the magnitude of potential changes, it is prudent to include an assessment of climate change into federal and state planning assessments. It is usually much more cost effective to construct something properly than it is to retrofit later.

The views expressed in this article are solely those of the author and do not necessarily reflect the policy of the U.S. Environmental Protection Agency.

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APPENDIX II: LIST OF PARTICIPATING GOVERNMENTS

Atlantic Beach

Bay County
Belleair Bluffs
Beverly Beach
Boca Raton
Bradenton Beach
Broward County

Citrus County
Clearwater Cocoa Beach
Cocoa
Collier County

Dade County
Daytona Beach
Dunedin

Edgewater
Escambia County

Fernandina Beach
Flagler Beach
Fort Lauderdale
Fort Pierce
Fort Myers
Fort Walton Beach
Franklin County

Golden Beach
Gulf Breeze
Gulfport

Hernando County
Highland Beach
Hillsborough County
Hollywood

Indian River Shores
Indian River County

Jacksonville Beach
Juno Beach

Lee County
Levy County
Longboat Key

Madeira Beach
Manatee County
Martin County
Melbourne
Miami Beach
Miami Shores Village
Monroe County

Naples
North Palm Beach
North Redington Beach
North Miami

Ormond Beach

Palm Beach County
Panama City
Pensacola
Pinellas County
Ponce Inlet
Port Orange
Punta Gorda
Putnam County

Redington Beach
Riviera Beach

Safety Harbor
Sanibel
Sarasota
Sarasota County
Satellite Beach
Sewall's Point
Shalimar
South Daytona
St. Petersburg
Stuart

Taylor County
Tequesta

Venice
Volusia County

Wakulla County
West Palm Beach

Global Climate Change and the Need for Planning

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Abstract

Human activities, such as energy production and land use conversions, are changing the composition of the earth's atmosphere. There is a general consensus among scientists that the projected increases in atmospheric concentrations of greenhouse gases will substantially alter the global climate. Concentrations of greenhouse gases, primarily carbon dioxide, but also methane, chlorofluorocarbons, and nitrous oxides, retain radiant energy as heat, warming the globe. The National Research Council (1987) and other groups, such as the Department of Energy and the United Nations, concluded that doubling the concentration of CO_2 relative to the preindustrial atmosphere would result in an eventual global warming of approximately 2° to 5°C.

Many reports indicate potential impacts of climate change on natural resources. Predicted impacts include changes in ambient air temperature and precipitation patterns, simplification of forest ecosystems, the loss of many coastal wetlands, and the unprecedented reduction of global biodiversity.

Sea level is currently rising at about 0.1 inch/yr^{-1} in many southern locations, but the rate of rise is predicted to dramatically increase in the near future. Many estimates put sea level at approximately 1 m above present levels by the year 2100 resulting in the loss of about 7,000 m^2 or almost 17% of vegetated wetlands in the Southeast. Wetlands would be lost due to inundation and erosion, and their natural resource value would decrease. Many unprotected barrier islands would be lost through beach erosion, much of Florida Everglades and Keys would be inundated, and low-lying cities, such as Charleston, SC, could be submerged if extensive measures were not taken.

Many coastal freshwater supplies may be substantially reduced. In many tidal rivers, salt fronts are projected to migrate substantially upstream, forcing water supply managers to protect or relocate freshwater intakes. To date, few agencies are incorporating sea level rise predictions into their planning activities. Planners need methods of incorporating uncertain environmental "risks" into long-range planning activities. Because of the almost certain continuation of the present trends in the emissions of greenhouse gases and predicted climate change impacts, which include eustatic sea level rise, shoreline erosion and wetland loss, it is prudent at this time to include an assessment of climate change into Federal, state, and regional planning assessments.

Introduction

The composition of the earth's atmosphere is changing due to emissions from energy and material production and population development patterns. Concentrations of greenhouse gases, carbon dioxide (CO_2), methane (CH_4), chlorofluorocarbons (CFCs), nitrous oxide (N_2O), and a variety of low-volume gases, are increasing in the atmosphere. These gases (Figure 1) collectively function to retain heat that has historically radiated to space. Although the rate and magnitude of global temperature increase are difficult to predict, there is a general consensus among scientists that global climate change and associated impacts will significantly impact the global environment (Graedel and Crutzen, 1989; Gushee, 1989; Hoffman, 1987; Houghton and Woodwell, 1989; Ramanathan et al. 1987). While there are still questions concerning this issue, the recent report (June 1990) of Working Group 1 of the United Nations Environment Program's Intergovernmental Panel on Climate Change (IPCC, 1990) is summarized below.

The group concluded that there is a natural greenhouse effect that keeps the earth warmer than it would otherwise be. Emissions resulting from human activities are substantially increasing the atmospheric concentrations of CO_2, CH_4, CFCs, and N_2O. Some of these gases are long-lived (Lashof and Ahuja, 1990) and will commit the earth to decades of future warming. If greenhouse gas emissions continue to grow at present levels, there will be a mean increase over current temperatures by 1°C by the year 2025, and 3°C by the end of the next century. It is predicted that land surfaces will warm more rapidly than the oceans, and that high northern latitudes will warm more than equatorial regions. Regional impacts of this effect will vary and estimates of regional impacts are less certain than are global projections.

The IPCC also concluded that mean global surface air temperature has increased by 0.3°C to 0.6°C over the last 100 years, with the 5 global-average warmest years being in the 1980's. Over the same time period global sea level has increased by 10-20 cm. These increases have varied with time and have not been uniform over the globe.

Atmospheric concentrations of long-lived gases (CO_2, N_2O, and CFCs) adjust only slowly to changes in emissions. Continued emissions of these gases at present rates would commit us to increased concentrations for up to decades or centuries. The longer emissions continue to increase at current rates, the greater the reductions would have to be for concentrations to stabilize at a given level. The long-lived gases would require immediate reductions in emissions from human activities of over 60% to stabilize their concentrations at today's levels. Gases that turn over faster, such as CH_4 would require smaller, approximately 15-20% reductions, to stabilize concentrations at current levels.

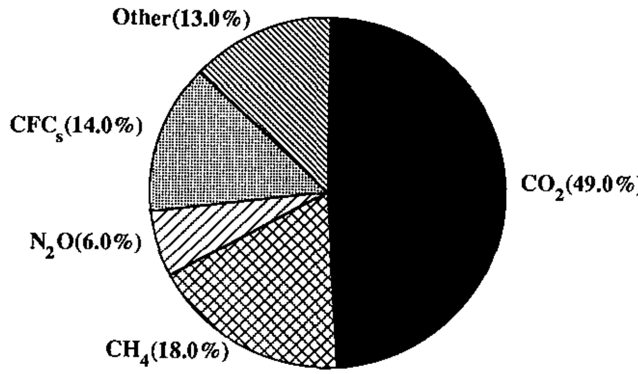

Figure 1. Greenhouse gas contributions to global climate change (EPA, 1989).

Many authorities speculate on the potential impacts of climate change on natural resources and they conclude that projected impacts will be more severe in the South than in other parts of the country (EPA, 1989). Predicted impacts include changes in temperature and precipitation patterns, changes of stream and river flow rates, simplification of forest ecosystems (Pastor and Post, 1988), the loss of many coastal wetlands, and the unprecedented reduction of global biodiversity (EPA, 1989; Peters, 1989).

Sea level is currently rising at approximately 0.1 inch/yr^{-1} in many southern locations, but the rate of rise is predicted to dramatically rise in the near-term future (Wanless, 1990). Sea level may increase about 1 m by the year 2100 and about 7,000 m^2 or almost 17% of vegetated coastal wetlands in the Southeast would be lost. Wetlands would be lost due to inundation and erosion, and their natural resource value would decrease. Near-shore temperature and salinity changes associated with climate change may lead to decreased populations of various commercial marine fisheries by interfering with reproduction cycles during critical development periods.

Many unprotected barrier islands would be lost through beach erosion, much of Florida Everglades and Keys would be inundated, and low-lying cities such as Charleston, SC, could be submerged if not protected by dikes. Volonte and London (1990) estimated that without protective structures, up to $1.8 billion dollars in property losses could result from sea level rise in the Myrtle Beach, SC area alone. As the rate of sea level rise increases, additional beach nourishment projects may have to be contemplated, because outer coast sandy beaches exposed to ocean waves may erode 1 m or more for each 1-cm rise in sea level (Bruun's rule).

Many authors (CEICRMSL, 1987) point out that the protection of fresh water may dramatically increase in cost because of sea level rise. For example, the wedge of saline water through estuaries and tidal rivers may advance as much as 1 km for a 10-cm rise in mean sea level. This will be of special concern for drinking water supplies and coastal ecosystems during droughts (CEICRMSL, 1987). In many tidal rivers, salt fronts are projected to migrate substantially upstream, forcing water supply managers to relocate freshwater intakes. In addition, salinity intrusion may pose large problems in coastal aquifers where the landward displacement of the saltwater and freshwater interface (zone of mixing) is a large multiplier of the sea level rise. Current problems of salinity intrusion into groundwater supplies will be increased with only a relatively small rise in sea level. (CEICRMSL, 1987).

Because of the almost certain continuation of the present trends in the emissions of greenhouse gases and predicted climate change impacts, such as sea level rise, shoreline erosion and wetland loss, it is prudent at this time to include an assessment of climate change into Federal, state and regional planning assessments.

Global Climate Change and NEPA Assessments

The National Environmental Policy Act of 1969 (NEPA) requires U.S. government agencies to carry out reviews of proposed Federal actions, which may significantly affect the quality of the human environment. Since 1969, NEPA procedures have been developed through regulatory actions of the Council on Environmental Quality (CEQ), action of Federal agencies and by court decisions.

Beginning in 1987, CEQ held a series of public meetings concerning stratospheric ozone depletion and global climate change. Additional input was solicited from Federal agencies that had appropriate ongoing research programs. The council concluded that although questions regarding climate change remain, the best available scientific evidence furnishes ample cause for serious concern. CEQ concluded that global climate change is "reasonably foreseeable" within the context of NEPA and CEQ regulations: potential impacts should be considered in future NEPA documents. CEQ is currently promulgating guidance for all Federal agencies regarding global climate change.

NEPA is a very appropriate mechanism to examine global climate impacts (Cushman et al., in press; Montgomery et al., in press). NEPA is entirely a procedural statute, requiring a complete evaluation process, not a specific outcome (40CFR pt6). NEPA does not require control measures, but rather mandates that a Federal agency: (1) give consideration to the environmental effects of a major Federal action; (2) give consideration to alternatives if an Environmental Impact Statement is prepared; and (3) hold public review and receive comments. Evaluating alternatives and receiving public comment presents opportunities for developing creative approaches for solving environmental problems.

Montgomery et al. (in press) thoroughly discusses NEPA and climate change and considers three important questions relevant to resource planning. (1) Since NEPA requires that agencies consider the effects of their action on the environment, must these agencies consider the impacts of global climate change on their actions? (2) Is it meaningful to consider global climate change contributions at the project level and can thresholds be developed? (3) How can uncertainties be handled in the NEPA reviews, particularily predicting warming impacts due to emissions and differential regional responses to climate change?

The primary reasons for assessing the impacts of proposed Federal projects on global climate and the effects of climate change on proposed actions are to inform the policy architects of the potential climate change consequences associated with the action. The decision maker may then take actions to minimize adverse climate change impacts. As with Federal policy-makers, state and regional policy-makers would clearly benefit from including an assessment of climate change in appropriate environmental assessments. It is usually much more cost effective to construct or locate something properly the first time, than it is to retrofit at a later time period.

State Environmental Assessments

Many regulatory functions now reside at state and county levels. States have the primary regulatory authority for gas and electric utilities, which are responsible for much of the CO_2 emissions from the United States. In general, states have statutory authority for building codes, land use decisions, transportation guidelines, industrial energy use, and solid waste management–all of which are responsible for substantial quantities of greenhouse gases.

Informed state policy-makers can develop cost-effective response options that have a wide range of common sense environmental and economic benefits. In addition, policy-makers have the option of educating the public on potential future consequences and soliciting public input into the planning process. Recently, the National Governors' Association recommended seven global climate change policy goals for the United States (Task Force, 1990).

1. Develop an international agreement to protect the atmosphere.
2. Utilize cost-effective energy conservation and efficiency measures to stabilize and reduce CO_2.
3. Stop the production of and recycle CFCs and use cost-effective measures to stabilize and reduce other greenhouse gases.
4. Develop and commercialize alternative energy systems, including clean fossil fuel, renewable energy resources, and safe nuclear power.
5. Implement forestry programs to reduce the effects of global climate change.
6. Plan and act now to adapt to a changing climate.
7. Pursue an aggressive research program to reduce key uncertainties about global climate change.

Many of the policy goals can be translated into strategies to reduce greenhouse gas emissions, and hence, probably slow the rate of predicted changes, such as sea level rise.

Options for Limiting Climate Change Impacts

Atmospheric CO_2 is the primary radiant gas responsible for global warming. Because CO_2 is derived primarily from fossil fuel combustion, any process that reduces fossil fuel use can reduce CO_2 emissions. In general, states can reduce fossil fuel-based greenhouse gas emissions by promoting energy efficiency and conservation strategies and by promoting pollution prevention. In the following sections, a few specific strategies designed to reduce greenhouse gas emissions are presented. Additional information is provided by (Benioff, 1990; Lashof and Washburn, 1990; and Marchado and Piltz, 1988). Many of the planning strategies could be implemented at state, regional or local levels.

1. Implement Strategies to Improve Energy Efficiency and Conservation

Strategies that increase energy efficiency and conservation are probably the most cost effective approaches to reduce the emissions of greenhouse gases. Lashoff and Washburn (1990) point out that energy efficiency is the most economical and environmentally benign energy resource.

1.1 Least Cost Utility Planning. States should realize this goal by instituting and requiring electric and gas utilities to undertake least-cost energy planning and investment.

1.2 Utility Financial Incentive Reform. States can galvanize utilities to undertake energy efficiency and conservation programs by allowing utilities to profit from reducing the demand for energy. Utilities could charge for the power saved as the result of conservation efforts. Consumers would save on their total energy bill.

1.3 Alternative Sources and Fuels. States can implement plans that allow for electricity generated from nontraditional sources of energy to enter utility grid systems. The production of electrical energy from cogeneration sources could reduce fossil fuel use in the south, and the cogeneration of electricity from the phosphate industry is especially promising. In addition, the use of renewable energy sources can dramatically reduce CO_2 emissions. In appropriate localities, the use of wind and photovoltaics should be encouraged. States can encourage the development of fuels from woody and herbaceous biomass and cogeneration facilities.

1.4 State Energy Use. States consume energy by operating buildings and vehicles. States have the potential to reduce energy use by requiring that all state buildings, including associated county public education and state university systems, retrofit older buildings with highly efficient lighting, heating and cooling systems, and by increasing building insulation. States can mandate the use of alternative fuels in government, university, and other related fleets. Examples of appropriate fuels include liquefied natural gas and biomass-based alcohol. The use of biomass-based alcohol is especially appropriate in the Southeast, given the extensive agricultural potential of the region.

1.5 Mass Transit. States can provide increased funding for mass transit, encourage carpooling and mandate the designation of multiple passenger car lanes.

1.6 Building Codes. States can mandate energy-efficient uniform building codes for residential, commercial and industrial buildings. The codes can be for buildings shells, heating and ventilation, and air conditioning equipment. In addition, states could facilitate the retrofitting of older, inefficient buildings with more efficient equipment and insulation. However, constructing something right the first time is better and more cost and energy efficient.

1.7 Appliance Standards. Many new appliances use less than 25 percent of the energy of older appliances. States can facilitate the adoption of stricter appliance standards.

2. Implement Strategies to Reduce Greenhouse Gas Emissions From Forestry and Agricultural Practices.

Most actively growing forests represent a net sink for CO_2. Policies that encourage tree planting to increase carbon sequestering rates should be encouraged.

2.1 Enlarge Tree Planting Programs. Trees increase the rate of CO_2 sequestering, reduce soil erosion, provide habitat for wildlife, and improve water and air quality. Many lands are suitable for tree planting, including degraded forest lands, lands recovering from strip mine operations (such as phosphate mining in Florida or coal mining in Kentucky), along highway corridors, and in shelterbelt or windrows in agricultural areas. Many additional landscapes hold potential for tree planting.

2.2 Encourage Urban Tree Planting. The strategic (the planting trees to shade houses and central air conditioners) planting of trees in urban areas yields significant energy saving in the south (Akbari et al., 1988). Each tree strategically planted in urban areas may be as much as 15 times more effective in combating climate change than the planting of rural trees (Parker, 1987).

2.3 Increase Forest Productivity. Promote best management practices to increase yields and reduce "wasted" timber products.

2.4 Promote Best Agricultural Management Practices. Promote efficient use of fertilizer to reduce nitrous oxide emissions. Encourage the plowing under of crop residues, rather than burning, to reduce CO_2 and to replenish the soil. Attempt to reduce CH_4 (methane) emissions from livestock through best management (feedstock) techniques. In addition, biogas can be produced and utilized, depending on the type of livestock operation.

3. Implement Strategies to Reduce Greenhouse Gas Emissions BY POLLUTION PREVENTION.

3.1. Recycling. States should reduce municipal and industrial soil waste by promoting recycling efforts and by mandating the acquisition of recycled products. In addition, states can promote the procurement of recycled products by county and local government agencies. The recycling of aluminum, steel, paper, glass, and other products generally saves between 35 and 95 percent of the energy that is necessary to produce a product from virgin material.

3.2 Collection of Methane from Landfills. Approximately 130 million tons of municipal solid waste are disposed of annually in more than 5,000 landfills in the United States (Franklin, 1988). In many areas of the country, CH_4 can be economically recovered and used from landfills.

3.3. Collection of Methane from Coal Seams. In many areas, CH_4 can be economically recovered from coal seams. The recovery of CH_4 not only reduces the emission of a greenhouse gas, it can be used as an energy source (Gibbs and Hogan, 1990).

3.4 Water Conservation. Energy is consumed to produce water suitable for human consumption and also for waste water treatment. Water conservation can reduce energy use.

Conclusions

The recent United Nations Working Group 1 concluded that global climate change is real, and that without a reduction in the rate of greenhouse gas emissions, mean global temperatures will substantially increase in the near future. In addition to global warming, it is anticipated that global climate patterns will be significantly altered. The continued excessive use of fossil fuels will unalterably change the fabric of Earth's biosphere. Because of the magnitude of potential changes, it is prudent to include an assessment of climate change into federal and state planning assessments. It is usually much more cost effective to construct something properly than it is to retrofit later.

The views expressed in this article are solely those of the author and do not necessarily reflect the policy of the U.S. Environmental Protection Agency.

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